Economics of Adaptation to Climate Change

SYNTHESIS REPORT

EACC Publication and Reports

1. Economics of Adaptation to Climate Change: Synthesis Report
2. Economics of Adaptation to Climate Change: Social Synthesis Report
3. The Cost to Developing Countries of Adapting to Climate Change: New Methods and Estimates

Country Case Studies:

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5. Mozambique: Economics of Adaptation to Climate Change
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14. Social Dimensions of Adaptation to Climate Change in Ethiopia
15. Social Dimensions of Adaptation to Climate Change in Ghana
16. Social Dimensions of Adaptation to Climate Change in Mozambique
17. Social Dimensions of Adaptation to Climate Change in Vietnam
18. Participatory Scenario Development Approaches for Identifying Pro-Poor Adaptation Options
19. Participatory Scenario Development Approaches for Pro-Poor Adaptation: Capacity Development Manual

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Abbreviations and Acronyms

AR4	Fourth Assessment Report of the Intergovernmental Panel on Climate Control
BAP	Bali Action Plan
CGE	Computable general equilibrium (model)
CLIRUN	Climate and runoff (model)
CMIP3	Coupled Model Intercomparison Project phase 3
CSIRO	Commonwealth Scientific and Industrial Research Organization (climate model)
DALY	Disability-adjusted life years
DIVA	Dynamic and interactive vulnerability assessment (model)
EACC	Economics of Adaptation to Climate Change
EAP	East Asia and Pacific (World Bank region)
ECA	Europe and Central Asia (World Bank region)
ENSO	El Niño Southern Oscillation
GCM	General circulation model
GDP	Gross domestic product
IMPACT	International model for policy analysis of agricultural commodities and trade
IPCC	Intergovernmental Panel on Climate Change
LAC	Latin America and Caribbean (World Bank Region)
MIP	Mixed integer programming (model)
MIROC	Model for interdisciplinary research on climate
MNA	Middle East and North Africa (World Bank Region)
NAPA	National Adaptation Plans of Action
NCAR	National Centre for Atmospheric Research (climate model)
NGO	Nongovernmental organization
ODA	Official development assistance
OECD	Organisation for Economic Co-operation and Development
PNC	National Watershed Program (by its Spanish acronym)
PPM	Parts per million
PSD	Participatory scenario development
SAR	South Asia (World Bank region)
SRES	Special Report on Emissions Scenarios (of the IPCC)
SSA	Sub-Saharan Africa (World Bank region)
UN	United Nations
UNDP	United Nation Development Program
UNFCCC	United Nations Framework Convention on Climate Change
WCRP	World Climate Research Programme
WHO	World Health Organization

Note: Unless otherwise noted, all dollars are U.S. dollars; all tons are metric tons.

Acknowledgments

The Economics of Adaptation to Climate Change (EACC) study has been a large, multiyear undertaking managed by a core team of the World Bank's Environment Department led by Sergio Margulis (Task Team Leader) and comprising Urvashi Narain, Kiran Pandey, Laurent Cretegny, Ana Bucher, Robert Schneider, Gordon Hughes, and Timothy Essam. Robin Mearns, Anne Kuriakose, and Carina Bachofen coordinated the social dimensions of the study. The study would not have been possible without the exceptional administrative support from Hawanty Page, Jasna Vukoje, Grace Aguilar, Hugo Mansilla, Arathi Sundaravadanan, and Patricia Noel.

Since the beginning, the EACC team has had intense interaction with the Environment Department's management, particularly Warren Evans and Michele de Nevers, who are an integral part of the EACC team. The team is also immensely grateful to Ravi Kanbur, Sam Fankhauser, and Joel Smith for serving on the advisory committee, providing overall guidance to the team, and resolving critical technical and strategic issues.

A very large number of people have directly worked on the various reports and background studies, and an even larger number of people have provided direct and indirect support and advice to the teams. It will be hard to do justice individually to all people, so we simply list the main teams of the EACC study and acknowledge indirect contributions in the end.

Synthesis Report. Sergio Margulis, Gordon Hughes, Robert Schneider, Kiran Pandey, and Urvashi Narain with editorial services from Bruce Ross-Larson, Laura Wallace, and Robert Livernash and administrative support from Hugo Mansilla. Contributions to the country case studies were provided by the respective country teams listed below.

Global Track Report. Sergio Margulis and Urvashi Narain (coordinators), Laurent Cretegny, Anne Kuriakose, Glenn Marie Lange, and Kiran Pandey (World Bank), as well as Paul Chinowsky, Gordon Hughes, David Johnson, Paul Kirshen, Gerald Nelson, James Neumann, Robert Nicholls, Jason Price, Adam Schlosser, Robert Schneider, Roger Sedjo, Kenneth Strzepek, Rashid Sumaila, Philip Ward, and David Wheeler (consultants). Major contributions were made by Carina Bachofen, Brian Blankespoor, Ana Bucher, David Corderi, Susmita Dasgupta, Timothy Essam, Robin Mearns, Siobhan Murray, Hawanty Page, and Jasna Vukoje (World Bank), and Jeroen Aerts, Steve Commins, William Farmer, Eihab Fathelrahman, Prodipto Ghosh, Dave Johnson, James Juana, Tom Kemeny, Benoit Laplante, Larissa Leony, Linh Phu, Mark Rosegrant, Klas Sanders, Arathi Sundaravadanan, Timothy Thomas, and Tingju Zhu (consultants). Sally Brown and Susan Hanson made important contributions to the coastal sector report; Miroslac Batka, Jawoo Koo, David Lee, Marilia Magalhaes, Siwa Msangi, Amanda Palazzo, Claudia Ringler, Richard Robertson, and Timothy Sulser to the agriculture sector report; William Cheung to the fishery sector report; and Pieter Pauw and Luke M. Brander to the water sector report (consultants).

Africa Country Case Studies. Overall coordination by Raffaello Cervigni and Aziz Bouzaher (former coordinator), with contributions by Stephen Mink and Stephen Ling (World Bank).

Ethiopia. Raffaello Cervigni (coordinator), Aziz Bouzaher (former coordinator); Principal authors were Kenneth Strzepek, Sherman Robinson, Len Wright and Raffaello Cervigni; additional experts on the team were Paul Block, Brent Boehlert, Paul Chinowsky, Chas Fant, William Farmer, Alyssa McCluskey, Michelle Minihane, Niko Strzepek, and Gete Zeleke. The World Bank team comprised Marie Bernadette Darang, Susmita Dasgupta, Edward Dwumfour, Achim Fock, Francesca Fusaro, Anne Kuriakose, Stephen Ling, Sergio Margulis (team leader of the overall EACC study), Stephen Mink, Kiran Pandey, Dawit Tadesse, and Fang Xu.

Mozambique. Jean-Christophe Carret (coordinator), Kenneth Strzepek, Channing Arndt, Paul

Chinowsky, Anne Kuriakose (World Bank), James Neumann, Robert Nicholls, James Thurlow, and Len Wright with support from Carina Bachofen (World Bank), Sally Brown, Charles Fant, Adèle Faure, Susan Hanson, Abiy Kebede, Jean-Marc Mayotte, Michelle Minihane, Isilda Nhantumbo, and Raphael Uaiene (all Consultants except as noted) authored the report. Inputs were also provided by Aziz Bouzaher, Raffaello Cervigni, Sergio Margulis(team leader of the overall EACC study), Stephen Mink, and Antonio Nucifora (all World Bank).

Ghana. Peter Kristensen (coordinator) and Robin Mearns (World Bank); Channing Arndt, Dirk Willenbockel, Kenneth Strzepek, Eihab Fathelrahman, Robert Nicholls, Len Wright, Chas Fant, Paul Chinowsky, Alyssa McCluskey, Sherman Robinson, Michelle Minihane, William Farmer, Brent Boehlert, Jean-Marc Mayotte, Tony Dogbe, Joseph Yaro, David Pessey, Emilia Arthur, George Ahiable, Tia Yahaya, Kamil Abdul Salam, Samantha Boardley, Simon Mead, and Livia Bizikova (consultants). Other contributors include Aziz Bouzaher, Raffaello Cervigni, Anne Kuriakose, Sergio Margulis, Stephen Mink, Urvashi Narain, Kiran Pandey, and John Fraser Stewart (World Bank) as well as Saadia Bobtoya, John Asafu-Adjaye, Dyson Jumpah, Daniel Bruce Sarpong, Philip Acquah, Robert Schneider,and Victoria Bruce-Goga (consultants).

Bangladesh. Kiran Pandey (coordinator), Nilufar Ahmad, Susmita Dasgupta, Shakil Ferdausi, Anne Kuriakose, Khawaja M. Minnatullah, Winston Yu (World Bank), Mainul Huq, Zahirul Huq Khan, Manjur Murshed Zahid Ahmed, Ainun Nishat, Nandan Mukherjee, Malik Fida Khan, and Zulfiqar Iqbal (consultants).

The Plurinational State of Bolivia (hereafter referred to as Bolivia). Ana Bucher (coordinator), Carina Bachofen, Robert Schneider, Laurent Cretegny, David Corderi, Morten Blomqvist, Anne Kuriakose, and Ruth Llanos (World Bank);Magali García Cárdenas, Jorge Cusicanqui, Bruno Condori Alí, Victoria Parra Goitia, Gladys Tesoro Michel, Carmen Rosa Del Castillo Gutierrez, Consuelo Luna, Claudia Canedo, Carlos Cabrera, Alvaro Lambert, Victor Vazquez, Erwin Kalvelagen, Miguel Morales, Fernando Cossio, and Valeria Sanchez (consultants).

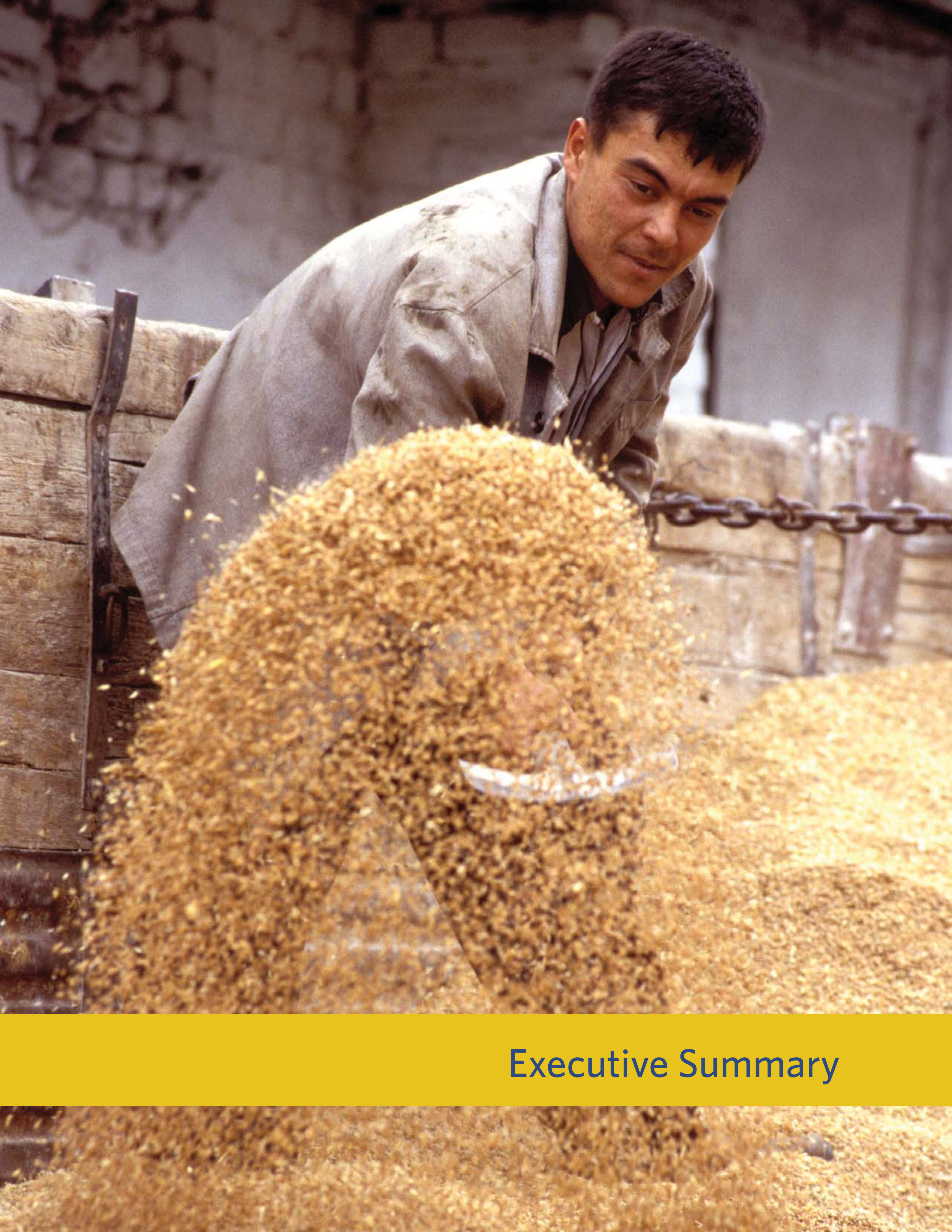
Samoa. Laurent Cretegny and Sergio Margulis (coordinators), Gordon Hughes (consultant) with contributions from Timothy Essam (World Bank); Simon Bannock, Michele Daly, Erwin Kalvelagen, Peter King, Thakoor Persaud, Isikuki Punivalu, Graeme Roberts, and Fernanda Zermoglio (consultants).

Vietnam. Benoit Laplante (coordinator), David Corderi, Laurent Cretegny, Douglas Graham, Steve Jaffee, Robin Mearns, and Anne Kuriakose (World Bank), Gordon Hughes (consultant) with contributions from Huynh Thuy (consultants); Tingju Zhu and Zhe Guo (IFPRI); Le Heng Nam, Nguyen Thuy Hang, Ha Le Thanh, and Thuy Dung (Institute of Water Resources Planning); Do Duc Dung (Southern Institute of Water Resources planning); Philip Adams, James Giesecke, Michael Jerie, and Nhi Hoang Tran (Centre of Policy Studies, Monash University); To Trung Nghia, Le Hung Nam, Le Hong Tuan, Truong Trong Luat, and Vu Dinh Huu (Institute of Water Resources and Planning); Pham Quang Ha, Mai Van Trinh, Tran Van The, and Vu Duong Quynh (Institute for Agricultural Environment); Bao Thanh, Luong Van Viet, Nguyen Thi Phuong, and Bui Chi Nam (Sub-Institute of Hydrometeorology and Environment of South Viet Nam); Tuyen Nghiem, Hue Le, and Huoung Vu Dieu (Center for Natural Resources and Environmental Studies); Pamela McElwee (Arizona State University); Dang Thu Phuong (Challenge to Change); Nguyen Van Be, Le Canh Dung, Nyuyen Hieu Trung and Sinh Le Xuan(Can Tho University); Suan Pheng Kam, Marie Caroline Badjeck, Michael Phillips, and Robert Pomeroy(World Fish Center); Louise Teh and Lydia The (University of British Columbia); Be Nam Vo Thi (Sub-National Institute for Agricultural Planning and Projection); and Hien

Than Thi and Hue Nguyen Thu (Centre for Marine-life Conservation and Community Development).

The team is also grateful for both general and specific comments received from the following colleagues: Julia Bucknall, Shanta Devarajan, Marianne Fay, Gherson Feder, Armin Fidler, Kirk Hamilton, Tamer Rabie, Peter Rogers, Jim Shortle, Michael Toman, Gary Yohe, Vahid Alavian, Jan Bojö, Henrike Brecht, Kenneth Chomitz, Vivian Foster, Alexander Lotsch, Kseniya Lvovsky, Chopp Margulis, Dominique van Der Mensbrughe, John Nash, Ian Noble, Giovanni Ruta, Apurva Sanghi, Robert Townsend, Walter Vergara, and Winston Yu. From outside the Bank, they include Marten van al Aast, Shailaja Annamraju, Roy Brouwer, Maureen Cropper, Anton Hilbert, Christine Pirenne, Tamsin Vernon, Peter Wooders, and Vincent-van Zeijst. None of these colleagues and reviewers are in any way responsible for the contents and eventual errors of this report, which remain the sole responsibility of the study team.

The EACC study was conducted by a partnership consisting of the World Bank (leading its technical aspects); the governments of the Netherlands, the United Kingdom, and Switzerland (funding the study); and the participating case study countries. The team would like to thank the partnership that initiated, funded, and actively engaged with the study team through its multiyear journey.



Executive Summary

As developing countries weigh how best to revitalize their economies and craft a sustainable development path to boost living standards, they will have to factor in the reality that the global annual average temperature is expected to be 2° C above pre-industrial levels by 2050. A 2° warmer world will experience more intense rainfall and more frequent and more intense droughts, floods, heat waves, and other extreme weather events. As a result, it will have dramatic implications for how countries manage their economies, care for their people and design their development paths. Countries will need to adopt measures to adapt to climate change. These measures offer a way to make the effects of climate change less disruptive and spare the poor and the vulnerable from shouldering an unduly high burden.

Against this backdrop, the global community adopted the Bali Action Plan at the 2007 United Nations Climate Change Conference. The plan calls for developed countries to allocate "adequate, predictable, and sustainable financial resources and new and additional resources, including official and concessional funding for developing country parties"[1] to help them adapt to climate change. It also underscores that international cooperation is essential for building capacity to integrate adaptation measures into sectoral and national development plans.

How high will the price tag be? Studies to date have provided only a wide range of estimates, from $4 billion to $109 billion a year. That is why the Economics of Adaptation to Climate Change (EACC) study was initiated in early 2008 by the World Bank in partnership with the governments of Bangladesh, Plurinational State of Bolivia, Ethiopia, Ghana, Mozambique, Samoa, and Vietnam, and funded by the governments of The Netherlands, Switzerland, and The United Kingdom. Its objectives are twofold: to develop a global estimate of adaptation costs for informing the international community's efforts in the climate negotiations, and to help decision-makers in developing countries assess the risks posed by climate change and design national strategies for adaptation.

To address these objectives, the study was conducted on two parallel tracks: (1) a *global track*—a top-down approach, in which national databases were used to generate aggregate estimates at a global scale, drawing on a wide variety of sector studies; and (2) a *country level track*—a bottom-up approach, in which sub-national data were aggregated to generate estimates at economywide, sectoral, and local levels. This Synthesis Report integrates and summarizes the key findings of a *global study* report and seven *country case study* reports—covering Bangladesh, Bolivia, Ethiopia, Ghana, Mozambique, Samoa, and Vietnam (Figure ES-1). By providing information on lessons learned and insights gained on adaptation to climate change from global, country, and sector-level analyses, the hope is to help policymakers worldwide prioritize actions, along with developing a robust, integrated approach for greater resilience to climate risks. The Report begins with the concepts and methodology used for analyses in both the global and the country case studies, including a discussion of study limitations. This is followed by a synthesis of key results from the global and country tracks and a conclusion with lessons learned.

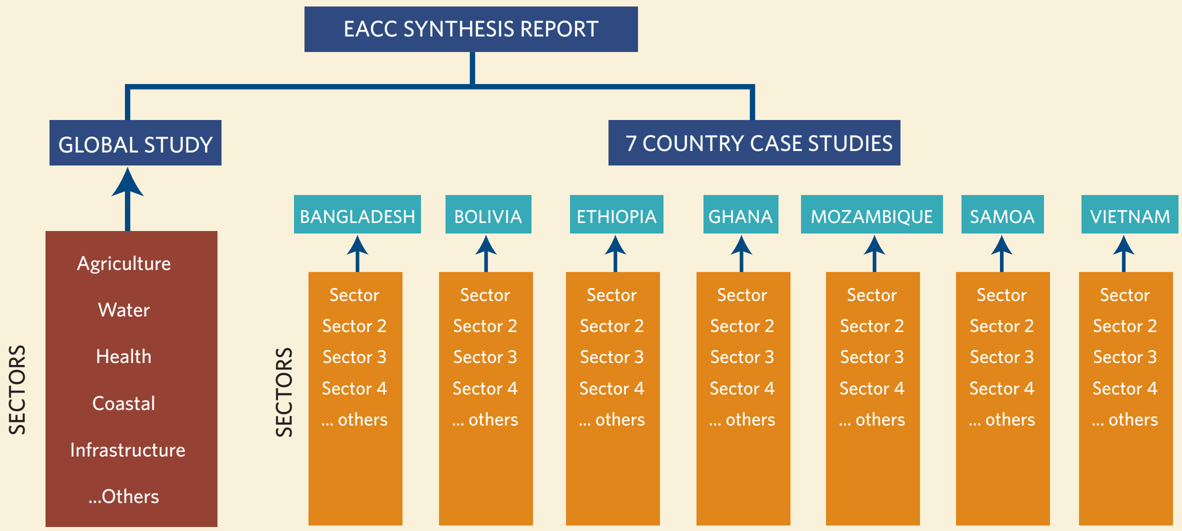
A Call to Change Course

What are the key findings of the Report? To begin with, ***economic development is perhaps the best hope for adaptation to climate change***. Development enables an economy to diversify and become less reliant on sectors such as agriculture that are more vulnerable to climate change effects. It also makes more resources available for minimizing risk, and similar measures often promote development and adaptation.

That said, ***it cannot be development as usual***. Adaptation will require a different kind of development—such as breeding crops that are drought and flood tolerant, climate-proofing infrastructure to make it resilient to climate risks and accounting for the inherent uncertainty in future climate projections in development planning. And it will cost to adapt. Our global study estimates that ***the price tag between 2010 and 2050 for***

FIGURE ES-1

PULLING TOGETHER THE KEY FINDINGS



Source: Revised estimates (World Bank 2010a)

adapting to an approximately 2°C warmer world by 2050 will be in the range of $70 billion² to $100 billion a year (World Bank 2010a).Our country studies suggest that costs could be even higher, once cross-sectoral impacts are taken into account.

However, ***there are numerous "low-regret" actions***—typically policies that would be priorities for development even without climate change—especially in water supply and flood protection. Economists regularly urge policymakers to adopt mechanisms for managing water resources that recognize the scarcity value of raw water, advice that is almost invariably ignored because of deeply embedded political interests. The reality is that the costs of misallocation of water resources will escalate even without climate change and could be overwhelming with it. At the same time, ***steps must be taken to identify and help the poor and most vulnerable***—including soliciting their views on adaptation priorities and ensuring an enabling environment (for example, providing farmers with the tools and resources to respond to climate change) (World Bank 2010a).

Finally, given the uncertainty surrounding both climate outcomes and longer-term projections of social and economic development, ***countries should try to delay adaptation decisions as much as possible*** and focus on low-regret actions. They should also ***build the resilience of vulnerable sectors***. In agriculture, for example, this would mean better management of water resources and access to extension services to give policymakers greater flexibility in handling either droughts or waterlogging caused by floods.

How the Studies were Done

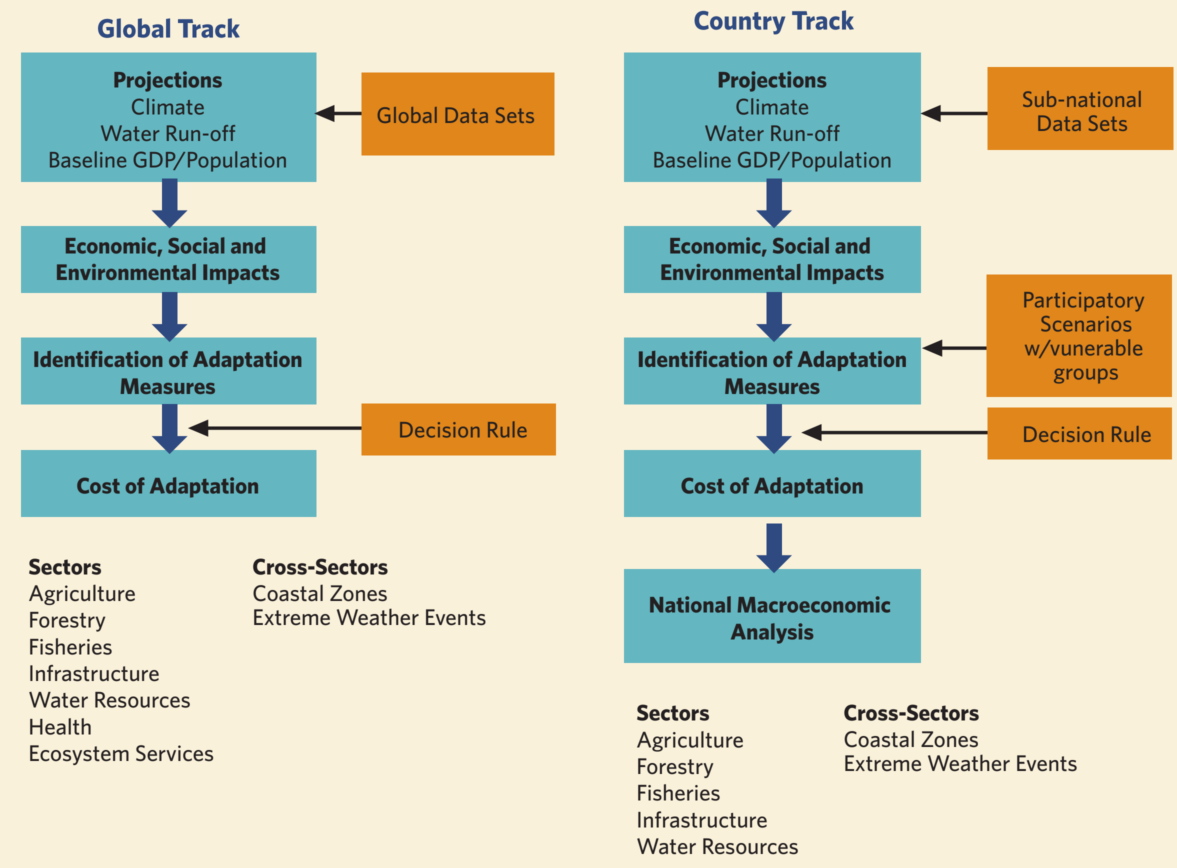
The intuitive approach to costing adaptation involves comparing a future world without climate change with a future world with climate change. The difference between the two worlds entails a series of actions to adapt to the new world conditions. And the costs of these additional actions are the costs of adapting to climate. Figure ES-2 summarizes the methodological approaches of the two tracks.

For the *global* study, the following four steps were taken:

- ***Picking a baseline.*** For the timeframe, the world in 2050 was chosen, not beyond (forecasting climate change and its economic impacts becomes even more uncertain beyond this period). *Development baselines* were crafted for each sector, essentially establishing a growth path in the absence of climate change that determines sector-level performance (such as stock of infrastructure assets, level of nutrition, and water supply availability). The baselines used a consistent set of GDP and population forecasts for 2010–2050.
- ***Choosing climate projections.*** While there is considerable consensus among climate scientists that climate change is unequivocal, accelerating and human-induced (IPCC 2007), there is much less agreement on how climate change will affect natural and social systems. For that reason, two climate scenarios were chosen to capture as large as possible a range of model predictions—from extreme wet to extreme dry.
- ***Predicting impacts.*** An analysis was done to predict what the world would look like under

FIGURE ES-2

A TWO-TRACK APPROACH



Source: Revised estimates (World Bank 2010a) the new climate conditions. This meant translating the impacts of changes in climate on the various economic activities (agriculture, fisheries), on people's behavior (consumptions, health), on environmental conditions (water availability, forests), and on physical capital (infrastructure).

- ***Identifying and costing adaptation alternatives.*** Adaptation actions were selected to offset the predicted impacts and to restore welfare in each of the major economic sectors analyzed—infrastructure, coastal zones, water supply and flood protection, agriculture, fisheries, human health, and forestry and ecosystem services. The costs of these actions together with the cost implications of changes in the frequency of extreme weather events were also estimated. But a cross-sectoral analysis of costs was not feasible.

For the *country* studies, two additional steps were taken:

- ***Evaluating economywide impacts.*** A macroeconomic modeling framework—known as a Computable General Equilibrium (CGE) model—was used to facilitate the analysis of macroeconomic and cross-sectoral effects of the impacts and adaptation to climate change.
- ***Evaluating social impacts.*** A social component was used to gather information on preferred adaptation strategies and sequence strategies from a bottom-up, local–level perspective. It also provided new evidence on how vulnerability is socially differentiated, and on the importance of social accountability and good governance for achieving pro-poor, climate-resilient development. It went beyond planned adaptation, weighing the potential of adaptation taken by households, collective action, nongovernmental organizations, and the private sector.

For all of the studies, a number of concepts had to be agreed upon:

- ***How much to adapt.*** The studies assumed that countries would fully adapt—that is, adapt up to the level at which they enjoy the same level of welfare in the (future) world as they would have without climate change. This in principle overstates the costs of adaptation. Of course, governments can choose to not adapt at all, incurring all damage from climate change, or adapt to the point where benefits from adaptation equal their costs, at the margin ("optimal" adaptation).
- ***What exactly is "adaptation"?*** Countries face not only a deficit in adapting to current climate variation, let alone future climate change, but also deficits in providing education, housing, health, and other services. Thus, many countries face a more general "development deficit," of which the part related to climate events is termed the "adaptation deficit." This study makes the adaptation deficit a part of the development baseline, so that adaptation costs cover only the additional costs to cope with *future* climate change.
- ***Soft versus hard measures.*** "Hard" options (capital intensive) were favored over "soft" options (institutions and policies)—because they are easier to quantify.
- ***Public versus private adaptation.*** The focus was on planned adaptation (deliberate public decision) rather than autonomous or spontaneous adaptation (households or communities acting on their own without public interventions but within an existing public policy framework).
- ***How to include benefits.*** Some countries and some sectors may benefit from changes in climate. The question is how to account for these gains. A number of different approaches were used to account for these gains.
- ***How to handle uncertainty.*** Total adaptation costs for a specific climate projection assume that policymakers know with certainty that a particular climate projection will materialize. Thus, the use of two extreme scenarios, wettest and driest, provides a range of estimates for a world in which decision-makers have perfect foresight. If decision-makers end up having to hedge their bets and consider both scenarios at the same time, costs will be higher.

The Global Picture

Overall, the global study estimates that the cost between 2010 and 2050 of adapting to an approximately 2°C warmer world by 2050 is in the range of $70 billion[3] to $100 billion a year. This sum is the same order of magnitude as the foreign aid that developed countries now give developing countries each year. But it is still a very low percentage (0.17 percent) of the income of countries (measured by their GDP, which was roughly $60 trillion in 2009). The costs vary by climate scenario and whether benefits from climate change are used to offset adaptation costs (see Table ES-1).

The driest scenario (Commonwealth Scientific and Industrial Research Organization, CSIRO) requires lower total adaptation costs than does the wettest scenario (National Centre for Atmospheric Research, NCAR), largely because of the sharply lower costs for infrastructure, which outweigh the higher costs for water and flood management. In both scenarios, infrastructure, coastal zones, and water supply and flood protection account for the bulk of the costs.

On a regional basis, for both climate scenarios, the East Asia and Pacific Region bears the highest adaptation cost, and the Middle East and North Africa the lowest. Latin America and the Caribbean and Sub-Saharan Africa follow East Asia and Pacific in both scenarios. On a sector breakdown, the highest costs for East Asia and the Pacific are in infrastructure and coastal zones; for Sub-Saharan Africa, water supply and flood protection and agriculture; for Latin America and the Caribbean, water supply and flood protection and coastal zones; and for South Asia, infrastructure and agriculture.

Not surprisingly, both climate scenarios show costs increasing over time, although falling as a percentage of GDP—suggesting that countries become less vulnerable to climate change as their economies grow. There are considerable regional variations, however. Adaptation costs as a percentage of GDP are considerably higher in Sub-Saharan Africa than in any other region, in large part because of the lower GDPs but also owing to higher costs of adaptation for water resources, driven by changes in precipitation patterns.

On the sectoral level, the EACC findings offer insights for policymakers who must make tough choices in the face of great uncertainty (see Table ES-2).

TABLE ES-1

EAST ASIA AND PACIFIC WILL SHOULDER THE BIGGEST BURDEN

(Global costs of adaptation by region)

Aggregation type/ Scenario	East Asia & Pacific	Europe & Centr.Asia	Latin America & Caribbean	Middle East/ North Africa	South Asia	Sub-Saharan Africa	Total
Gross-sum/ Wet Scenario	25.7	12.6	21.3	3.6	17.1	17.1	97.5
X-sum/ Dry Scenario	17.9	6.9	14.8	2.5	15	14.1	71.2

Note: Gross-sum is the sum of the positive costs of adaptation in all sectors and all countries, excluding gains (negative costs) from climate change. X-sum deducts these eventual gains in countries with overall positive costs of adaptation.
Source: Revised estimates (World Bank 2010a).

TABLE ES-2

INFRASTRUCTURE, COASTAL ZONES, AND WATER CAPTURE THE BULK OF ADAPTATION COSTS
(Global costs of adaptation by sector, X-Sum)

Sector	Wet	Dry
Infrastructure	27.5	13.0
Coastal zones	28.5	27.6
Water supply and flood protection	14.4	19.7
Agriculture, forestry, fisheries	2.5	3.0
Human health	2.0	1.5
Extreme weather events	6.7	6.4
Total	81.5	71.2

Source: Revised estimates (World Bank 2010a).

Infrastructure.[4] This sector has accounted for the largest share of adaptation costs in past studies and takes up a major share in the EACC study—in fact, the biggest share for the NCAR (wettest) scenario because the adaptation costs for infrastructure are especially sensitive to levels of annual and maximum monthly precipitation. Urban infrastructure—drainage, public buildings, and similar assets—accounts for about 54 percent of the infrastructure adaptation costs, followed by railways at 18 percent, and roads (mainly paved) at 16 percent. East Asia and the Pacific and South Asia face the highest costs, reflecting their larger populations. Sub-Saharan Africa experiences the greatest increase over time.

Coastal zones.[5] These zones are home to an ever-growing concentration of people and economic activity, yet they are also subject to a number of climate risks, including sea-level rise and storm surges, and possible increased intensity of tropical storms and cyclones. The study shows that adaptation costs are significant and vary with the magnitude of sea-level rise, making it essential for policymakers to plan while accounting for the uncertainty. One of the most striking results is that Latin America and the Caribbean and East Asia and the Pacific account for about two-thirds of the total adaptation costs.

Water supply.[6] In some parts of the world, water availability has risen and will continue to do so, but in others, it has fallen and will continue to do so—and the frequency and magnitude of floods are expected to rise. The EACC study shows that water supply and flood management ranks as one of the top three adaptation costs in both the wetter and drier scenarios, with Sub-Saharan Africa footing by far the highest costs. Latin America and the Caribbean also sustain high costs under both models, and South Asia sustains high costs under CSIRO.

Agriculture.[7] Climate change affects production by altering yields and areas where crops can be grown. The EACC study shows that temperature and precipitation changes in both climate scenarios will significantly lower crop yields and production—with irrigated and rainfed wheat and irrigated rice affected the most. Developing countries fare worse for almost all crops compared to developed countries, with South Asia shouldering the biggest production declines. Moreover, the changes in trade flow patterns are dramatic—with exports for developed countries rising and South Asia becoming a much larger food importer under both scenarios. That said, the total costs for the agricultural sector relative to other sectors is lower than would have been expected, in part because welfare is restored through trade rather than by restoring yields within countries. Yet, it is important to note that larger population shares, and among them, the poorer of the poor, are highly vulnerable because of their dependence on agriculture.

Human health.[8] Climate change can trigger increases in the incidence of vector-born diseases, water-borne diseases, heat- and cold-related deaths, injuries and deaths from flooding, and the prevalence of malnutrition. The EACC study, which focuses on malaria and diarrhea, finds adaptation costs falling in absolute terms over time to less than half the 2010 estimates of adaptation costs—thanks to improvements in basic health conditions that accompany higher incomes and development. While the declines are consistent across regions, the rates of decline in South Asia and East Asia and Pacific are faster than in Sub-Saharan Africa—a continent that will shoulder more than 80 percent of the health sector adaptation costs by 2050.

Extreme weather events.[23] Without reliable data on emergency management costs, the EACC study tries to shed light on the role of socioeconomic development in increasing climate resilience. It asks: As climate change increases potential vulnerability to extreme weather events, how many additional young women would have to be educated to neutralize this increased vulnerability? And how much would it cost? The findings show that by 2050, neutralizing the impact of extreme weather events requires educating an additional 18 million to 23 million young women at a cost of $12 billion to $15 billion a year. For 2000–50, the tab reaches about $300 billion in new outlays. This means that in the developing world, neutralizing the impact of worsening weather over the coming decades will require educating a large new cohort of young women at a cost that will steadily escalate to several billion dollars a year. But it will be enormously worthwhile on other margins to invest in education for millions of young women who might otherwise be denied its many benefits.

Putting Global Findings in Context

How does this study compare with earlier studies? The EACC estimates are in the upper end of estimates by the UNFCCC (2007), the study closest in approach to this study, though not as high as suggested by a recent critique of the UNFCCC study by Parry and others (2009). A comparison of the studies is limited by methodological differences—in particular, the use of a consistent set of climate models to link impacts to adaptation costs and an explicit separation of costs of development from those of adaptation in the EACC study. But the major difference between them is the nearly six-fold increase in the cost of coastal zone management and defense under the EACC study. This difference reflects several improvements to the earlier UNFCCC estimates under the EACC study: better unit cost estimates, including maintenance costs, and the inclusion of costs of port upgrading and risks from both sea-level rise and storm surges.[9]

The bottom line: calculating the global cost of adaptation remains a complex problem, requiring projections of economic growth, structural change, climate change, human behavior, and government investments 40 years in the future. The EACC study tried to establish a new benchmark for research of this nature, as it adopted a consistent approach across countries and sectors and over time. But in the process, it had to make important assumptions and simplifications, to some degree biasing the estimates.

Important shortcomings of this study relate to three broad categories: uncertainty, institutions, and modeling limitations (Table ES-3). They are natural entry points for thinking about future work and knowledge needs. The highest priority in the immediate future must be to reduce the range of uncertainty about future climate impacts and to identify forms of adaptation that are robust across the range of uncertainty that will remain.

TABLE ES-3

GETTING A BETTER PICTURE

STUDY LIMITATION	RECOMMENDATION
Use of mathematical models and no efficiency criterion	Include institutional, social, cultural and political perspectives to identify good policies. Find simpler rules for policymaking
Climate uncertainty	Consider more scenarios, Monte Carlo simulations and other probabilistic approaches
Growth uncertainty	Hard to improve other than through sensitivity analyses
Technological uncertainty	Incorporate better information from sector specialists and simulate the impact of potential advances.
Non-consideration to institutional issues	Context specific institutional capacity has to be assessed and considered to make recommendations realistic and feasible
Limited focus on migration and urbanization	Work with outside projections; limited current knowledge on cities and climate change
Limited range of adaptation	Include a broader range of strategies, including more local level
No environmental services	Pull better information and introduce more consistent estimates

The Country Picture

As for the EACC country studies, seven countries were selected based on overall vulnerability to major climate change impacts; differing environmental, social, and economic conditions and adequate data at the national level. Government interest at the highest level was also important. Mozambique, Ghana, and Ethiopia represent nearly the full range of agricultural systems in Africa. Vietnam and Bangladesh—Asian countries with most of their economic activity and population concentrated along the coast and in low-lying deltas—are among the world's most vulnerable to climate change, especially from extreme weather events and flooding. Bolivia is a poor Latin American country traditionally dependent on the Andean glaciers to supply good portions of water demand, and it consists of a wide range of agro-ecosystems. Samoa represents a low-lying Pacific island at increased risk to sea level rise and storm surge.

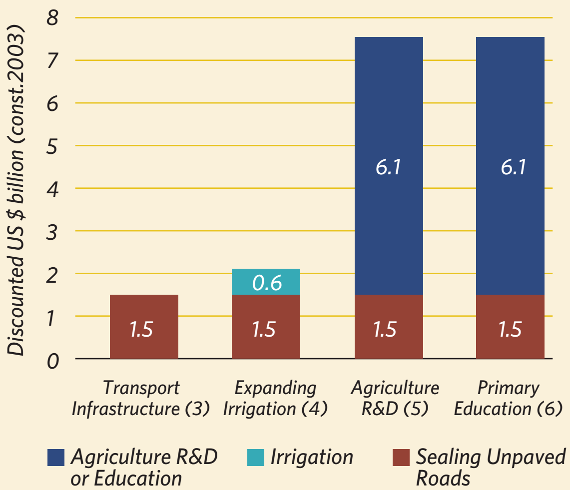
Mozambique is subject to frequent droughts, floods, and tropical cyclones—events that threaten the country's economic performance, which is already highly affected by high rainfall variability. The most vulnerable sectors from climate change are agriculture, which employs over 70 percent of the Mozambique population; energy, particularly hydropower generation, which is dependent on water runoff; transport infrastructure, notably roads; and coastal areas. Findings from the social component suggest that livelihood activities most sensitive to climate change continue to take place in areas most exposed to climate change.

On adaptation, the EACC Mozambique country study shows that with small additional costs, sealing unpaved roads—a low-regret option—would restore about one-fifth of the welfare loss owing to climate change (see Figure ES-3). Remaining welfare losses could be regained with better agricultural productivity or human capital accumulation (education). Irrigation investments appear to be a poor alternative. Investment costs are likely to be about US$400 million per year over 40 years. As part of the social component, participants in scenario development workshops were asked to draft preferred adaption options for the government (planned) and non-government entities (autonomous) (see Table ES-4). For

FIGURE ES-3

ADAPTATION IN MOZAMBIQUE ENTAILS GREATER CLIMATE RESILIENCE

(Reduction in climate change damages, 2003-2050; 5 percent discount rate, constant 2003 US$)



Note: In the worst scenario: NPV of damages without adaptation is $7.6 billion discounted at 5%)
Source: World Bank 2010g.

the hard options, more resources will be needed, and for the soft options, an enabling economic and political environment.

Ethiopia is heavily dependent on rain-fed agriculture, and its geographical location and topography in combination with low adaptive capacity entail a high vulnerability to the impacts of climate change. Historically the country has been prone to extreme weather variability, resulting in seven major droughts since the early 1980s—five of which led to famines. The primary losses owing to climate change in Ethiopia arise from the effect of extreme weather events, both droughts and flooding, on agricultural production and infrastructure.

Adaptation strategies considered in Ethiopia build on current government programs—such as increasing the irrigated cropland area and investing in

TABLE ES-4

KEY ADAPTATION OPTIONS IN MOZAMBIQUE

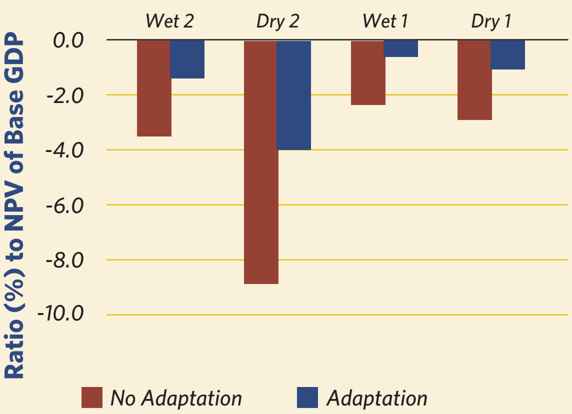
	Planned Adaptation	Autonomous Adaptation
Hard	■ Flood control dikes and levies ■ Coastal flood control gates ■ Dams and irrigation channels ■ *Improved roadways* ■ *Improved communication infrastructure* ■ Improved hospitals and schools	■ More robust buildings ■ Farm-scale water storage facilities ■ Deep wells to provide drinking water for people and animals ■ *Grain storage facilities* ■ Improved food processing equipment
Soft	■ Improved early warning of climatic hazards, and of dam releases ■ Better planning and management of forest, fish, and other natural resources ■ Resettlement of populations to lower risk zones ■ *More credit and financial services for small businesses and rural development* ■ *Better education and information for the rural areas* ■ Improved health care, social services, and social support for all people	■ Better utilization of short season, drought resistant crops to prepare for drought, floods, and cyclones ■ Diversification of flood and drought risk by maintaining fields in both highland and lowland areas ■ Better household and community management and use of natural resources, including wild fruits ■ Practice of soil conservation agriculture ■ Migration to lower risk areas ■ *Diversification of livelihoods away from agriculture* ■ Better planning of how much grain to save for personal consumption, and how much to sell for income generation

Note: The options in plain text respond directly to climate hazards, while those in *italics* represent measures to increase the population's adaptive capacity, or make them more resilient to shocks to their livelihoods.
Source: World Bank 2010g.

FIGURE ES-4

ADAPTATION SIGNIFICANTLY LOWERS WELFARE LOSSES IN ETHIOPIA

(Net present value (NPV) of absorption differences)



Note: NPV of absorption, difference from base (percent of NPV of GDP). Absorption is defined as GDP, plus imports minus exports. Wet 1 and Dry 1 are the two secnarios used in the global analysis, and Wet 2 and Dry 2 are the wettest and driest scenarios in Ethiopia.
Source: World Bank 2010e.

agricultural research and development; boosting the share of paved and hardened roads; and altering the scale and timing of planned hydropower projects. The EACC Ethiopia country study shows that without adaptation Ethiopia's GDP would be lower by 2 to 8 percent for the four different climate scenarios analyzed. Adaptation reduces welfare losses by about 50 percent (see Figure ES-4) and also lowers income variability. It also highlights the potential benefits of accelerating the diversification of the economy away from climate sensitive sectors, such as agriculture; upgrading road design; strengthening hydropower development; and accelerating absorption of the rural labor force into non-agriculture activities—including through skills-upgrading programs and encouragement of growth poles around medium-size municipalities. Total adaptation costs range from US$1.22 billion (wet) to $5.84 billion (dry) per year over 40 years, though it may be possible to reduce these costs through a labor-upgrading program.

Ghana is highly vulnerable to climate change and variability because it is heavily dependent on climate-sensitive sectors such as agriculture—largely rain-fed with a low-level of irrigation development—forestry, and hydropower. The country has a 565 kilometer long coastline that is inhabited by about a quarter of the population and is the location of significant physical infrastructure. The EACC Ghana country study estimates that climate change causes a reduction in real household consumption of 5-10 percent in 2050, with rural households suffering greater reductions, primarily through its impact on agricultural production.

The study evaluated adaptation options focused on roads, agriculture, hydropower, and coastal protection. It found that changes in road design standards alone provide significant reductions in welfare losses in most scenarios. The combination of better road design and investments in agriculture or agriculture and hydropower or education would minimize or even reverse the losses caused by climate change under the four climate scenarios analyzed (see Table ES-5).

TABLE ES-5

BETTER ROAD DESIGN STANDARDS ARE A HIGH PRIORITY FOR GHANA

(NPV of deviations of real welfare from baseline under alternative adaptation strategies, US$ billions)

No Adaptation scenario		Road Design	Adaptation Investment in		
			Agriculture	Hydro /Agric.	Education
Global Dry	-13.118	-10.308	-0.121	-0.941	-2.090
Global Wet	-10.095	-5.854	-2.973	2.116	0.584
Ghana Dry	-2.709	-3.009	-1.193	-1.782	-1.308
Ghana Wet	-4.050	-0.766	1.936	1.358	1.795

Note: The options in plain text respond directly to climate hazards, while those in *italics* represent measures to increase the population's adaptive capacity, or make them more resilient to shocks to their livelihoods.
Source: World Bank 2010f.

Bangladesh is one of the most vulnerable countries to climate risks. About two-thirds of the nation is less than 5 meters above sea level and is susceptible to river and rainwater flooding. Once every three to five years, up to two-thirds of Bangladesh is inundated by floods. Cyclone-induced storm surges owing to climate change are expected to inundate an additional 15 percent of the coastal area and increase the inundation depth in these areas. The damages from a single typical severe cyclone with a return period of 10 years is expected to rise nearly fivefold to over $9 billion by 2050, accounting for 0.6 percent of GDP. The burden is likely to fall disproportionately on the rural poor in low-lying coastal areas who are also affected by other climate-related hazards such as saline water intrusion into aquifers and groundwater and land submergence.

For storm surges induced by tropical cyclones, the EACC Bangladesh country study evaluated adaptation measures such as embankments, afforestation, cyclone shelters, and early warning systems. It found that the total estimated cost would be $2.4 billion in initial investment and $50 million in annual recurrent costs (see Table ES-6). As for inland flooding, the focus was on infrastructure measures to avoid further damage from additional inundation—road network and railways, river embankments and embankments to protect highly productive agricultural lands, drainage systems, and erosion control measures. The study found that the total estimated cost would be $2.7 billion in initial investment and $54 million in annual recurrent cost—with 80 percent of these costs stemming from road height enhancement. Given the large existing variability, a prudent near–term strategy for Bangladesh is to address the large adaptation deficit while investing to reduce uncertainties about future climate change which will define where additional investments are required. By 2050, the number of people living in cities will triple while the rural population will fall by 30 percent. The long-term challenge is to move people and economic activity into less climate-sensitive areas.

Bolivia is exposed to hydro-meteorological extremes and climate variability, particularly because of the influence of the El Niño oscillation (ENSO), which, regardless of climate change, occurs periodically in different parts of the country. Floods, landslides, and droughts—which seriously affect food security and the water supply—are also common. Given that Bolivia's economic mainstays are minerals and gas, it is relatively insensitive to climate change. Yet most people are engaged in small-scale agriculture, a sector that is quite vulnerable to climate changes.

TABLE ES-6

POLDERS AND CYCLONE SHELTERS ARE KEY FOR BANGLADESH'S CYCLONE-INDUCED STORM SURGES

(Total adaption cost for inland flooding by 2050, US$ Million)

	Baseline Scenario (existing risks) (1)		(additional risk due to CC) (2)		CC Scenario (total risk = (1) + (2))	
Adaptation Option	IC	AMC	IC	AMC	IC	AMC
Polders	2,462	49	893	18	3,355	67
Afforestation			75		75	
Cyclone shelters	628	13	1,219	24	1,847	37
Resistant housing			200		200	
Early warning system			39	8	39	8
Total	3,090	62	2,426	50	5,516	112

CC = climate change; IC = investment cost; AMC = annual maintenance cost
Source: World Bank 2010c.

The EACC Bolivia country study focused on agriculture and water resources. Even in the more optimistic scenario of wetter conditions, agricultural productivity can only increase if the capacity to store and use the needed additional water is available for farmers and poor peasants. Thus, "no-regrets" measures would include better water resources management and building water storage and irrigation infrastructure. These types of measure are already envisaged by Bolivia in its development agenda, but the study shows that the development agenda must now be accelerated.

Vietnam's exposure to weather-related events and disasters ranks among the highest among all developing countries. Storms and floods occasionally resulting from tropical cyclones have caused extensive and repeated damages to buildings and infrastructure, agriculture and fisheries sectors, and resulted in a large number of fatalities. Climate change may well bring an increase in the frequency, intensity, and duration of floods, and greater drought problems in the dry season.

The EACC Vietnam country study focused on agriculture, aquaculture, forestry, and coastal ports. In agriculture, adaptation measures ranged from autonomous actions by farmers (such as sowing dates, switching to drought-tolerant crops, and adoption of salinity-tolerant varieties of rice) to planned public actions (such as greater spending on research, development, and extension; and extending the areas of irrigated land). The study shows that the impacts of climate change on agriculture and related sectors, even with no adaptation, appear to be relatively modest—given that farmers are expected to change, without government interventions, the crops and crop varieties that they grow and their methods of farming. The CGE macroeconomic analysis suggests that the drop in real GDP and real consumption is much less severe with adaptation—and adaptation offsets most of the disproportionate impact of climate change on the poor (see Table ES-7). In fact, GDP would not only fall less but possibly also even increase. That said, a major concern is how much poorer households will suffer from lower agricultural incomes and higher food prices relative to the general cost of living.

Samoa is a country at extreme risk from a variety of natural disasters including tropical cyclones and

TABLE ES-7

AGRICULTURAL ADAPTATION IN VIETNAM REDUCES INEQUALITIES AND HELPS GDP

(Percentage deviations in 2050 from baseline with no climate change)

	No adaptation			With adaptation			Adaptation benefits		
	Dry	Wet	MoNRE	Dry	Wet	MoNRE	Dry	Wet	MoNRE
GDP	-2.4%	-2.3%	-0.7%	-1.1%	-0.7%	0.7%	1.3%	1.6%	1.3%
Aggregate consumption	-2.5%	-2.5%	-0.7%	-1.4%	-0.8%	0.6%	1.1%	1.7%	1.3%
Agricultural value-added	-13.9%	-13.5%	-5.8%	-3.8%	-3.4%	5.4%	10.0%	10.1%	11.2%
Regional GDP									
North Central Coast	-6.6%	-6.1%	-2.6%	0.5%	-0.3%	4.8%	7.1%	5.8%	7.4%
South East	1.1%	0.8%	1.0%	0.0%	1.1%	0.2%	-1.1%	0.3%	-0.9%
Rural household consumption									
Bottom quintile	-6.5%	-6.3%	-2.6%	-1.9%	-1.4%	2.4%	4.7%	4.9%	5.0%
Top quintile	-1.6%	-1.7%	-0.4%	-1.5%	-1.0%	0.0%	0.1%	0.7%	0.4%

Note: MoNRE is Vietnam's Ministry of Environment, which has established an "official" climate change scenario that is roughly similar to the Hadley Center (UK) projections.

Source: World Bank 2010i.

TABLE ES-8

BETTER DESIGN STANDARDS WOULD ENHANCE SAMOA'S RESILIENCE
(Impact of climate change with and without adaptation)

	No adaptation		With adaptation		Benefit of adaptation	
	NCAR	CSIRO	NCAR	CSIRO	NCAR	CSIRO
Design standards for 10-year return period						
Present value @ 5%, $ million	103.9	212.4	34.8	24.5	69.1	187.9
Annualized equivalent, $ million per year	5.9	12.1	2.0	1.4	3.9	10.7
Loss/benefit as % of baseline GDP	0.6	1.3	0.2	0.2	0.4	1.2
Loss/benefit as % of baseline consumption	0.9	1.9	0.3	0.2	0.6	1.7
Design standards for 50-year return period						
Present value @ 5 %, $ million	19.9	37.0	4.5	5.4	15.4	31.6
Annualized equivalent, $ million per year	1.1	2.1	0.3	0.3	0.9	1.8
Loss/benefit as % of baseline GDP	0.1	0.2	0.0	0.0	0.1	0.2
Loss/benefit as % of baseline consumption	0.2	0.3	0.0	0.0	0.1	0.3

Note: NCAR is wettest scenario; CSIRO is driest scenario.
Source: World Bank 2010h.

tsunamis caused by earthquakes. It is also subject to inter-annual climate fluctuations associated with El Nino (ENSO), which affect precipitations as well as air and sea temperatures. Many scientists believe that climate change will lead to some increase in the intensity of tropical cyclones accompanied by greater variability of rainfall with more frequent episodes of heavy rainfall and drought. A major concern is that about 70 percent of the population lives in low-lying areas that would be vulnerable to inundation as a result of the combined effects of sea level rise, more severe storm surges, and flooding caused by heavier rainfall.

The EACC Samoa country study focuses on the implementation of design standards to ensure that buildings and other assets can cope with higher winds and more intense precipitation without damage. It found that the adoption of more stringent design standards today would reduce the impact of the climate change in future and the residual damage after adaptation (see Table ES-8). It also found that extreme weather variability in the coastal zone will involve significant costs for either investments in coastal protection or the relocation of assets. In the longer term, the relocation of assets—or even whole villages—may be the best option as it would shift economy activity such as tourism, crops, and other businesses away from the coast.

Lessons and Recommendations

Lesson 1: The cost of developing countries to adapt to climate change between 2010 and 2050 is estimated at US$70 billion to US$100 billion a year at 2005 prices. This amounts to about "only" 0.2 percent of the projected GDP of all developing countries in the current decade and at the same time to as much as 80 percent of total disbursement of ODA.

The averages across all developing countries hide a very uneven distribution of the burden of adaptation across regions as well as decades. Our estimates of the overall cost of adaptation are 0.6-0.7 percent of GDP for the Sub-Saharan Africa region in 2010-19 falling to about 0.5 percent of GDP in 2040-49. In contrast, the equivalent figures for the East Asia and Pacific region are 0.13-0.19 percent in 2010-19 and about 0.07 percent in 2040-49. Apart from Sub-Saharan Africa, the regions facing high relative costs of adaptation are the Latin America and Caribbean region and (under the dry climate scenario) the South Asia region. In addition, the absolute costs of adaptation increase over time and will certainly continue to increase after 2050. Our projections suggest that real GDP will increase more rapidly than the costs of adaptation over the next four decades, even on quite conservative assumptions about growth in GDP per person. However, it would be unsafe to assume that this trend will continue into the second half of the current century.

Lesson 2: Economic development is a central element of adaptation to climate change, but it should not be business as usual.

Economic development is the most basic and cost effective method of adaptation, provided that it is properly managed. It generates the resources and opportunities to adapt to climate change at a relatively low cost by ensuring that the design and location of new infrastructure, buildings, and other assets take account of the effects of climate change on their performance. Our country studies show that a failure to adapt to climate change may lead to very large weather-related losses—both in terms of the destruction of infrastructure and foregone opportunities for future growth. In Ethiopia, robust growth based on infrastructure investment is the first line of defense against climate change impacts. In Bolivia, development measures are not only robust to changes in climate impacts but also help reduce them by increasing local resilience.

Lesson 3: Invest in human capital, develop competent and flexible institutions, focus on weather resilience and adaptive capacity, and tackle the root causes of poverty. Eliminating poverty is central to both development and adaptation, since poverty exacerbates vulnerability to weather variability as well as climate change.

Countries that reach the middle of the 21st century with large shares of their populations engaged in subsistence agriculture—with substantial illiteracy and lethargic or inept institutions—will be particularly vulnerable to the effects of climate change. Rapid development leads to a more flexible and resilient society, so that building human and social capital—including education, social protection and health, and skills training—are crucial to adaptation.

In all of our country studies, the burden of existing climate variability is especially heavy in areas that have high concentrations of poor and socially vulnerable populations. Climate change exacerbates this pattern. In the Southern region of Bangladesh, for example, the rural poor are expected to face the largest declines in per capita consumption, declining productivity of the subsistence crops, and land losses owing to greater salinity brought forth by sea level rise.

Lesson 4: Do not rush into making long-lived investments in adaptation unless these are robust to a wide range of climate outcomes or until the range of uncertainty about future weather variability and climate has narrowed. Start with low-regret options.

For public policymakers, the fundamental problem is one of *uncertainty* regarding both climate outcomes and longer–term projections of social and economic development (such as anticipated migration of people from rural areas to the cities). This uncertainty is particularly large for patterns of precipitation. Some country studies highlight crucial differences between alternative wet and dry scenarios and their effects on agricultural production, water resources, and transport infrastructure. Other countries show large variation in the magnitude of increased precipitation. As a result, countries should try to delay adaptation decisions as much as possible and focus on low-regret actions—those actions that are robust under most climate scenarios. These are typically policies or investments that can be identified as priorities for development even without climate change. For Africa, our studies show that expanding the road system and increasing the share of paved roads would yield high returns by lowering transport costs and expanding markets. They would also lessen flood impacts and enhance farmers' ability to respond to changes in agricultural comparative advantage.

Lesson 5: Adaptation to climate change should start with the adoption of measures that tackle the weather risks that countries already face, for example, more investment in water storage in drought-prone basins or protection against storms and flooding in coastal zones and/or urban areas. Climate change will exacerbate these risks.

Climate change will always hide beneath climate variability. Systems that effectively cope with existing climate variability will be more successful in adapting to future climate change than those that cannot. The short–term priority is to better prepare for the weather risks that countries are already facing. One clear example concerns the impact of storms, especially in coastal areas. Despite the uncertainty over future rainfall, there is relative certainty that warmer climate will lead to rising sea levels and increased intensity of storms. With the inevitable increase in urban populations, the costs of failing to protect coastal cities against major storms will rise rapidly. At the same time, the deficiencies of storm water drainage in coastal or inland cities already lead to avoidable—and sometimes large—losses caused by urban flooding that have disproportionate effects on the health and welfare of the poor. The Vietnam study suggests that it is important to enhance the capacities of agricultural and water systems to cope with current climate variability and build resilience into such systems from now on. Samoa similarly shows that improving building codes to cope with current variability makes infrastructure more climate-resilient.

Lesson 6: Beware of creating incentives that encourage development in locations exposed to severe weather risks. Where possible build future cities out of harm's way—flood plains or coastal zones that are exposed to sea level rise and storm surges.

Economic development has been accompanied by a tendency for more rapid urban growth in coastal areas than in inland cities. This may reflect relative differences in transport costs as well as government policies or individual preferences. There will be many opportunities to reduce weather risks and associated costs by intelligent urban and land-use planning. Whether in rural or urban areas, the rule of thumb is simple: whenever possible, ensure that growth and infrastructure take place in locations that are less exposed to weather risks. The right incentives must also be adopted to discourage accumulating physical capital in the shadow of dykes considered to be "safe." As the New Orleans tragedy illustrated, a sufficiently extreme event will breach a dyke.

Lesson 7: Hard and soft approaches to adaptation are two sides of the same coin. Good policies, planning, and institutions are essential to ensure that more capital-intensive measures are used in the right circumstances and yield the expected benefits.

The distinction between "hard" (capital-intensive) and "soft" (institutions and policies) adaptation is easily exaggerated. There is no point in building the best type of road in the wrong place, while the best institutions will provide no protection against a storm that destroys buildings or power lines. The challenge is to get the balance between hard and soft adaptation right. In some field sites in Vietnam, afforestation of mangroves ranks above the infrastructure options such as sea dike repair, given the lower costs of mangrove planting and the potential for this activity to be more pro-poor. In Ghana, a number of soft measures are given priority over hard measures—including an upgrade of peri-urban slums and controlled development of new ones, and the protection, management, and sustainable use of coastal wetlands.

One

Introduction

Context

Under the Bali Action Plan adopted at the 2007 United Nations Climate Change Conference, developed countries agreed to allocate "adequate, predictable, and sustainable financial resources and new and additional resources, including official and concessional funding for developing country parties" to help them adapt to climate change (UNFCCC 2007) . The plan views international cooperation as essential for building capacity to integrate adaptation measures into sectoral and national development plans. Yet studies on the costs of adaptation offer a wide range of estimates, from $4 billion to $109 billion a year. A recent critique of estimates suggests that these may be substantial underestimates (Parry et al. 2009). Similarly, National Adaptation Programmes of Action, developed by the least-developed countries under Article 4.9 of the United Nations Framework Convention on Climate Change (UNFCCC), identify and estimate costs for only urgent and immediate adaptation measures. They do not incorporate the measures into long-term development plans.

The Economics of Adaptation to Climate Change (EACC) study is intended to fill this knowledge gap. Soon after the Bali Conference of Parties, a partnership—comprising the World Bank and the governments of Bangladesh, Plurinational State of Bolivia, Ethiopia, Ghana, Mozambique, Samoa, and Vietnam—initiated the EACC study to estimate the cost of adapting to climate change. The study, funded by the governments of the Netherlands, Switzerland, and the United Kingdom, also aims to help countries develop plans that incorporate measures to adapt to climate change.

Objectives

The EACC study has two broad objectives: to develop a global estimate of adaptation costs for informing the international community's efforts in the climate negotiations, and to help decision makers in developing countries assess the risks posed by climate change and design national strategies for adapting to climate change.

These two objectives complement each other. To some extent, however, they are also at odds with each other, and cannot be fully consistent: supporting developing country efforts to design adaptation strategies requires incorporating country-specific characteristics and sociocultural and economic conditions into the analyses. Identifying the global costs of adaptation to climate change to support international negotiations requires analysis at a more aggregate level. Reconciling the two involves a tradeoff between the specifics of individual countries and a global picture.

Approaches: the two parallel tracks

To address the two objectives, the EACC was conducted on two parallel tracks: a global track, where national databases were used to generate aggregate estimates at a global scale; and a series of country-level studies, where national data were disaggregated to more local and sector levels, helping to understand adaptation from the bottom-up perspective. The top-down and bottom-up approaches were compared and to the extent possible integrated. Some elements had to be analyzed separately, or solely, under each perspective.

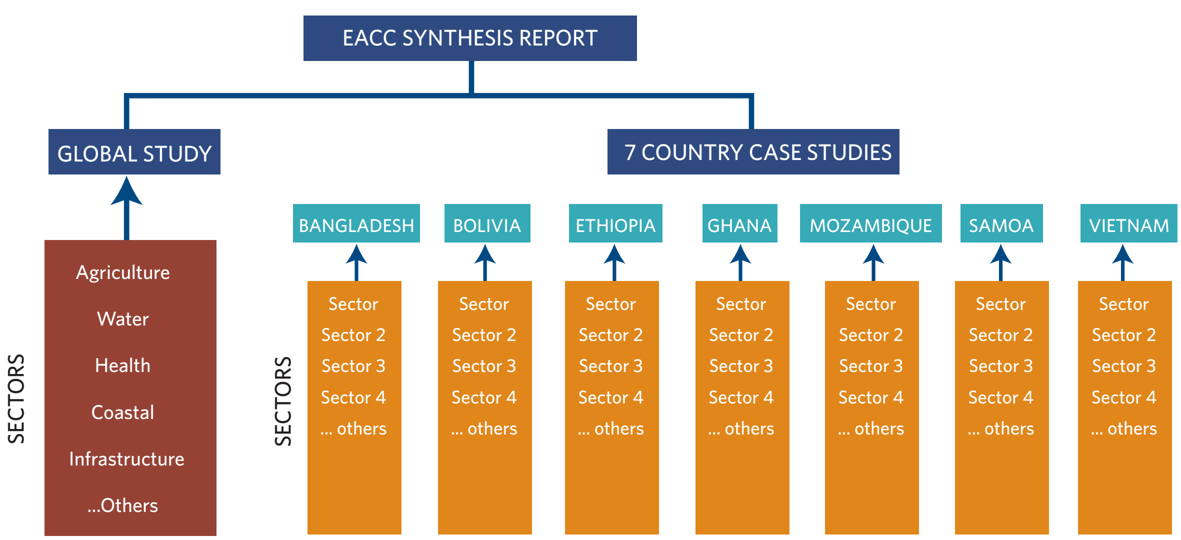
The Synthesis Report

This report is a synthesis of the global study report and seven country case study reports. The global study consists of a number of sector studies, which were commissioned by the EACC project. Country case study reports present findings from sector analyses conducted at the national level, and include analysis of three to five sectors, depending on the country. Figure 1 below depicts the various EACC study components and their links.

Given that climate change is a relatively new subject, the numerous reports produced as part of the EACC global and country tracks, including this report, cover many technical areas—from climate science to social and economic areas, as well as a number of sectors, including agriculture, energy, water resources, infrastructure, and coastal zone management. Given the political importance of climate change, the findings of this and similar studies are highly relevant for policy making in both developed and developing countries. While aimed at a very broad audience, it is primarily written for policy makers in developing countries. Given their different objectives, related EACC reports may be of interest to a diverse audience. These reports and background papers are available at www.worldbank.org/eacc.

FIGURE 1

STUDY STRUCTURE: GLOBAL AND COUNTRY TRACKS



This report presents a synthesis of the methodology and results derived from research conducted for the EACC global and country study tracks in Bolivia, Bangladesh, Ethiopia, Ghana, Mozambique, Vietnam, and Samoa. It provides information on lessons learned and insights gained on adaptation to climate change from global, country, and sector-level analyses. It develops a robust, integrated approach for increasing resilience to climate risks, and presents recommendations to help policy makers set priorities.

The remainder of the report comprises of four chapters. The next chapter presents the concepts and methodology used for analyses in both the global and the country case studies. This chapter also describes some of the study's limitations. Chapter III introduces the results from the global analysis, while chapter IV focuses on results from the country analyses. Chapter V presents lessons learned and recommendations for policy makers.

Two

CONCEPTS, METHODOLOGY, AND LIMITATIONS

Concepts

This multiyear study is based on a number of crucial concepts, including the definition of adaptation costs; understanding the links between adaptation and development; and dealing with the inherent uncertainty in climate projections and climate impacts.

Adaptation costs

One of the biggest challenges of the study has been to develop a usable definition of adaptation costs. The concept is intuitively understood as the costs societies incur to adapt to changes in climate. The IPCC defines adaptation costs as the costs of planning, preparing for, facilitating, and implementing adaptation measures, including transaction costs.

This definition is difficult to implement in practice, however. For one, "development as usual" needs to be conceptually separated from adaptation. That requires deciding whether the costs of development initiatives that enhance climate resilience ought to be counted as part of adaptation costs. It also requires deciding how to incorporate in those costs the adaptation deficit, defined as countries' inability to deal with current and future climate variability. It requires defining how to deal with uncertainty about climate projections and impacts. And it requires specifying how potential benefits from climate change in some sectors and countries offset, if at all, adaptation costs in another sector or country.

How much to adapt

Adaptation is clearly not a rigid set of actions, and governments can choose the amount of, or level of, adaptation. One possibility is to adapt completely, so that society is at least as well off as it was before climate change. At the other extreme, countries could choose to do nothing, experiencing the full impact of climate change. In the intermediate cases, countries invest in adaptation using the same criteria as for other development projects—until the marginal benefits of the adaptation measure just exceed the costs. This leads to a portfolio of adaptation actions that either restores social welfare relative to a baseline without climate change, or leaves some amount of residual damage from climate change.

How much to adapt is consequently an economic problem—how to allocate resources to adapt to climate change while also meeting other needs. And therein lies the challenge. Poor urban workers who live in a fragile slum dwelling might find it difficult to decide whether to spend money to make their living quarters less vulnerable to more intense rainfall, or to buy school books or first-aid equipment for their family—or how to allocate between the two. Poor rural peasants might find it difficult to choose between meeting these basic education and health needs and some simple form of irrigation to compensate for increased temperatures and their impact on agricultural productivity. These examples suggest that desirable and feasible levels of adaptation depend on both available income and other resources.

The definition in practice

Corresponding to a chosen level of adaptation is an operational definition of adaptation costs. If the policy objective is to adapt fully, the cost of adaptation can be defined as the minimum cost of adaptation initiatives to restore welfare to levels prevailing before climate change. Restoring welfare may be prohibitively costly, however, and policy makers may opt for an efficient level of adaptation instead. Adaptation costs would then be defined as the cost of actions that satisfy the criterion that their marginal benefits exceed their marginal costs. Because welfare would not be fully restored, there would be residual damage from climate change after allowing for adaptation. This study mostly uses the definition of adaptation costs where the objective is to restore welfare.

Links between adaptation and development

Economic development is perhaps the best hope for adaptation to climate change: development enables an economy to diversify and become less reliant on sectors such as agriculture that are more vulnerable to the effects of climate change. Development also makes more resources available for abating risk. And often the same measures promote development and adaptation. For example, progress in eradicating malaria helps countries develop and also helps societies adapt to the rising incidence of malaria that may accompany climate change.

At the same time, adaptation to climate change is essential for development: unless agricultural societies adapt to changes in temperature and precipitation (through changes in cropping patterns, for example),

development will be delayed. Finally, adaptation requires a new type of climate-smart development that makes countries more resilient to the effects of climate change. Urban development without attention to drainage, for example, will exacerbate the flooding caused by heavy rains.

These links suggest that adaptation measures range from discrete adaptations, or interventions for which adaptation to climate change is the primary objective (WRI 2007); to climate-smart development, or interventions to achieve development objectives that also enhance climate resilience; to development that is not business-as-usual, as compared to interventions that can exacerbate the impacts of climate change and that therefore should not be undertaken. The Bali Action Plan calls for "new and additional" resources to meet adaptation costs. This study therefore defines adaptation costs as additional to the costs of development. So, the costs of measures that would have been undertaken even in the absence of climate change are not included in adaptation costs, while the costs of doing more, doing different things, and doing things differently are included.

The adaptation deficit

The separation of adaptation from development costs is linked to the concept of the adaptation deficit, which captures the notion that countries are under-prepared for current climate conditions, much less for future climate change. Presumably, these shortfalls occur because people are under-informed about climate uncertainty and therefore do not rationally allocate resources to adapt to current climate events. The shortfall is not the result of low levels of development but of less than optimal allocations of limited resources resulting in, say, insufficient urban drainage infrastructure. The cost of closing this shortfall and bringing countries up to an "acceptable" standard for dealing with current climate conditions given their level of development is one definition of the adaptation deficit. The second use of the term, perhaps more common, captures the notion that poor countries have less capacity to adapt to change, whether induced by climate change or other factors, because of their lower stage of development. A country's adaptive capacity is thus expected to increase with development. This meaning is perhaps better captured by the term *development deficit*.

The adaptation deficit is important in this study for establishing the development baseline from which to measure the independent additional effects of climate change. Because the adaptation deficit deals with current climate variability, the cost of closing the deficit is part of the baseline and not of the adaptation costs. In practice, the distinction is difficult to apply because the costs of addressing current climate variability and future climate change are often intermingled. Hence, most parts of this study do not attempt to estimate the costs of adaptation by reference to a baseline under which the adaptation deficit has been closed. Two exceptions are adaptation to sea level rise in Bangladesh and to changes in extreme weather events in Samoa.

It is not simple to assess how the use of alternative baselines in which the adaptation deficit has or has not been closed will affect estimates of the costs of adaptation. For infrastructure, for example, closing the adaptation deficit will usually mean that a larger stock of infrastructure assets has to be climate-proofed, thus implying an increase in adaptation costs. In contrast, closing the adaptation deficit in agriculture might imply a higher reliance on irrigated agriculture, which may reduce the extent of adaptation required as a consequence of changes in rainfall patterns due to climate change. Adaptation costs are likely to be reduced in the agricultural sector as a result. The practical difficulty of separating the costs of closing the adaptation deficit from the costs of adaptation for carefully defined baseline means that the estimates reported in this study tend to over-state the "true" costs of adaptation costs, though by different degrees for different sectors and countries. As an illustration, adaptation measures in some of the country studies actually generate benefits for some climate scenarios that increase total welfare rather than just restoring it. This is because they combine adaptation with development measures that would be justified even without climate change.

A typology of adaptation measures

- **Proactive and reactive measures:** Reactive measures will be the dominant response until threats become better understood. But countries can become more proactive in disaster preparedness. The frequent cyclones and extreme coastal events in Bangladesh, for example, have led the country to greatly improve its early warning systems, and the number of deaths from such events has significantly decreased.

- **Soft and hard measures:** Many soft measures—such as water and energy pricing, strengthening property rights, and flood plain and landslide area zoning—have robust adaptation and development results. But they take time and require strong institutions to put in place. The timing may be consistent with the time frame of global warming, however, if concerted action begins now.

- **Public and private adaptation:** Adaptation measures can be classified by the types of economic agent initiating the measure—public or private. The literature distinguishes between autonomous or spontaneous adaptation (by households and communities acting on their own without public interventions but within an existing public policy framework) and planned adaptation (from a deliberate public policy decision).

Dealing with uncertainty

Uncertainty complicates the analysis of adaptation to climate change in three different ways. First, for most countries there is no consensus whether future climate will be wetter or drier, or how the frequency and severity of major storms will change. Changes in regional climate phenomena such as the Asian monsoon or the El Niño Southern Oscillation are even more uncertain. Consequently, decisions about investments in assets having a useful life of 20, 30, or even 40 years—such as dams, dikes, urban drainage, bridges, and other infrastructure—have to be based on incomplete information with a large variance in projections of future climate conditions. The second major uncertainty concerns economic growth. Faster economic growth puts more assets at risk in absolute terms, but higher levels of investment and technical change mean that countries have greater flexibility to absorb and respond to climate-induced changes in productivity and other climate shocks. Recent experience shows that predicting economic growth is a fragile science, while projecting how technological change may affect adaptation over the next 40 years is nearly impossible.

Uncertainty about climate outcomes

The EACC study—both the country and the global tracks—calculates adaptation costs as if decision makers know with certainty what the future climate will be. This must be complemented by considering how to maximize the flexibility of investment programs to take advantage of new climate knowledge as it becomes available. For most countries and sectors, the study was able to identify policies and investments that generate good outcomes over the range of the wettest and driest climate scenarios considered. But these scenarios could not encompass the full range of possible outcomes. Of the 26 climate projections available for the A2 SRES, an assessment of adaptation costs was feasible only for two projections for the global track and for two-to-four projections for the country studies. Further, climate models are evolving all the time, so it is inevitable that projections made in 2012 will differ from those made in 2008.

A good faith effort has been made to examine the wettest and driest scenarios available for each situation. This range is simply a snapshot of the state of climate science when this study was undertaken and does not reflect any view of the distribution of climate outcomes in future as scientific models and other information change. Because the range of both climate and economic uncertainty tends to grow exponentially over time, the study examines expenditures up to 2050 and limits the scope to adaptation to what may be broadly interpreted as the public sector. The major impacts of climate change, such as the melting of ice sheets, are likely to occur after 2050, but the degree of uncertainty after this date requires a quite different approach to quantifying the costs of adaptation.[10]

Hierarchy of uncertainty and timing

Rational resource allocation must take into account the degrees of uncertainty about the nature and timing of climate outcomes. When will it be optimal to start building sea walls in coastal areas and how high should they be? The uncertainties concern the rate of future sea level rise, the potential height of storm surges, the damage that may be caused to agricultural or urban assets in the coastal zone, and the future cost of upgrading sea walls. These must be balanced against the need to allocate resources that could be used to meet other social or economic goals instead. Further, there may be alternative measures which are less expensive than sea walls but which provide temporary or less effective protection. Developing a strategy involves choices about the selection, scale and timing of adaptation actions when both climate change and economic development are uncertain. A model is needed that allows governments to prioritize and sequence adaptation strategies in a financially constrained environment and which takes account of social, institutional, and cultural factors (Kellerer et al. 2004).[11] A pilot exercise was carried out at a sub-basin water level in Bolivia.

Economic forecasts

A key contribution of this study is to separate the costs of adaptation from those of development by defining an explicit development baseline. The study assumes just one future development path, based on growth in population, GDP per capita, and urbanization, which drive the demand for food, investment in infrastructure, the benefits of protecting coastal zones, and so on. How would the costs of adaptation change with a different trajectory? Alternative assumptions about population and economic growth have only a slight impact on estimates of the cost of adaptation in 2010–19, so the margins of error associated with the development baseline are not very important in the immediate future, although they will grow over time.

The United Nations publishes alternative population projections that rely on different assumptions about fertility decline in developing countries. The variation in population forecasts for developing countries in 2050 is approximately +/–14 percent for alternative fertility assumptions. The United Nation's central projection has consistently been revised downward over the last two decades as fertility rates have fallen faster than anticipated. Thus, the plausible range of uncertainty might be +/–10 percent. The range of uncertainty for growth in GDP per capita is larger, ranging from –26 percent to +40 percent in 2050. The variation for developing countries is even larger—from –40 percent to +50 percent – so the range of variation in total GDP might be –45 percent to +75 percent, a huge margin of uncertainty. These errors are compounded by the confidence intervals of projections of demand as functions of population and GDP per capita. On this basis, it is very difficult to calculate potential margins of error in the estimates of the costs of adaptation. Yet, there is nothing unique in the procedures adopted here. They are assumptions widely adopted in similar exercises. The very same uncertainties apply in the analyses of all economic sectors that have such extended time horizons.

Future technologies

With the exception of agriculture this study does not allow for the unknowable effects of innovation and technical change on adaptation costs. Hence, the reported costs are based on what is known today rather than what might be possible in 20–40 years. Sustained

growth in per capita GDP for the world economy rests on technical change, which is likely to reduce the real costs of adaptation over time. The exclusion of technical change is one factor that imparts an upward bias to the reported estimates of the costs of adaptation. In the case of agriculture, growth in agricultural productivity, based on historical trends and expert opinion, is built into the IMPACT model, and explicit account is taken of investment in agricultural research as an element of the cost of adaptation.

Methodology

Critical methodological issues include establishing a baseline, choosing climate projections, predicting impacts, simplifying assumptions, fine-tuning the methodological approaches of the global and country tracks, and introducing a social component into the country track.

The baseline

To estimate the impacts of climate change and then the costs of adaptation, it is necessary to compare, for each time period, the difference between the world with climate change and the world without climate change. To do this, we first have to project what the world will look like between now and 2050, our planning horizon. This projected world without climate change is the baseline. It is a reasonable trajectory for the growth and structural change of the economy over 40 years that can be used as a basis of comparison with the climate change scenario.

Using a time frame of 2050, development baselines are first developed for each sector using a common set of GDP and population forecasts for 2010–50.[12] The population trajectory is aligned with the United Nations Population Division's middle-fertility projections for 2006. To ensure consistency with emissions projections, the GDP trajectory is based on the average of the GDP growth projections of the three major integrated assessment models of global emissions growth—Climate Framework for Uncertainty, Negotiation, and Distribution (FUND; Anthoff and Tol 2008); PAGE2002 (Hope 2006); and Regional Dynamic Integrated Model of Climate and the Economy (RICE99; Nordhaus 2002)—and growth projections used by the International Energy Agency and the U.S. Energy Information Administration to forecast energy demand. All these sources provide growth estimates at a regionally disaggregated level.

The global average annual real GDP per capita growth rate constructed in this way is 2.1 percent, similar to global growth rates assumed in the United Nations Framework Convention on Climate Change (UNFCCC) A2 emissions scenario. From the baselines, sector-level performance indicators (such as stock of infrastructure assets, level of nutrition, and water supply availability) are determined.

Choosing climate projections

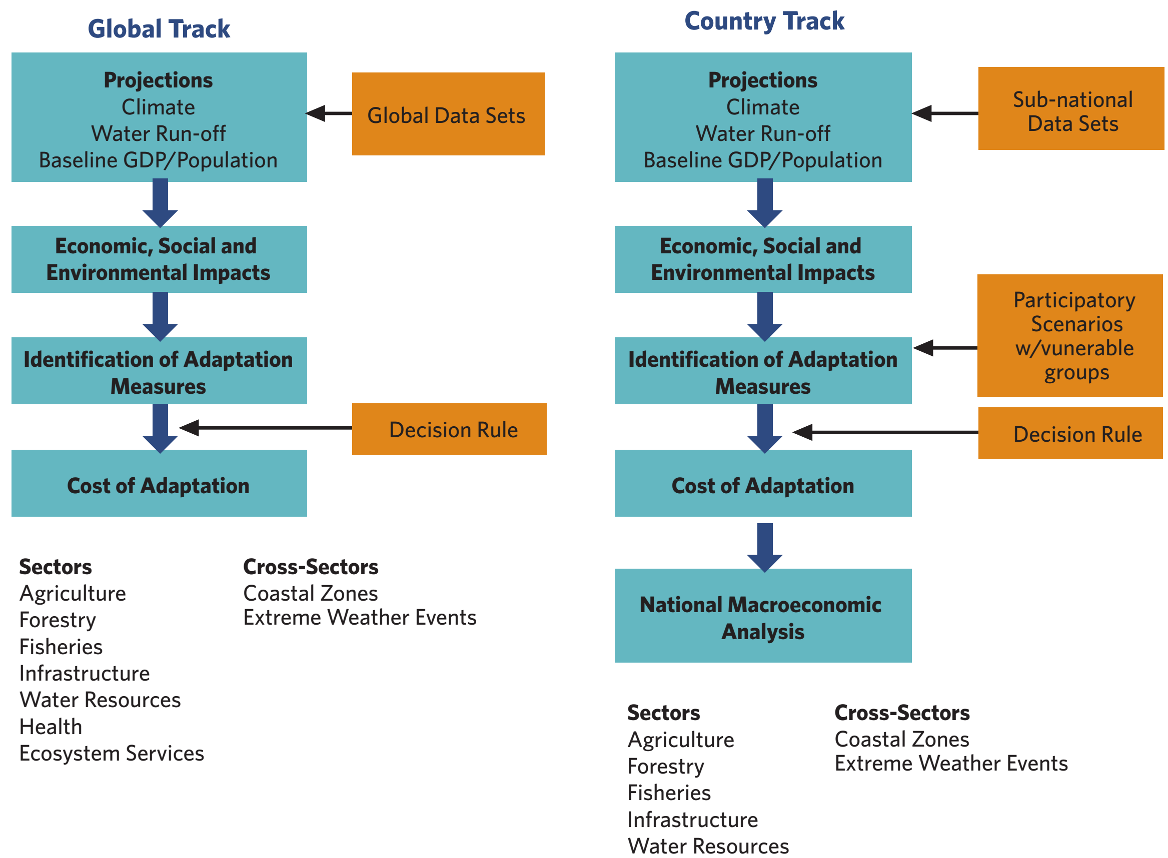
Climate scenarios were chosen to capture the largest possible range of model predictions. Although model predictions do not diverge much in projected temperature increases by 2050, precipitation changes vary substantially across models. For this reason, model extremes were captured by using the model scenarios that yielded extremes of dry and wet climate projections, although catastrophic events were not captured. Among the models reporting minimum and maximum temperature changes, NCAR was the wettest and CSIRO the driest scenario (globally, not necessarily the wettest and driest in every location) based on the climate moisture index.

Predicting impacts

The changes in climate are used to predict what the world would look like under the new climate conditions without and with adaptation. This meant translating the impacts of changes in climate on the various economic activities (agriculture, fisheries), on people's behavior (consumption, health), on environmental conditions (water availability, oceans, forests), and on physical capital (infrastructure).

FIGURE 2

STUDY METHODOLOGY: GLOBAL AND COUNTRY TRACKS



Simplifying assumptions

Analyses of complex decisions under uncertainty easily become intractable. The various dimensions of climate change combined with many countries, sectors and agents reinforce this danger. Hence, it is necessary to adopt a variety of assumptions whose purpose is to ensure that useful results can be generated from the models. First, it is assumed that policy makers know what the future climate will be and act to prevent its damages. Second, in costing the adaptation options, the study focuses on hard options (building dams, dykes) and not soft options (early warning systems, community preparedness programs, watershed management, urban and rural zoning). This approach was deliberately chosen because the former options can be assessed and their costs estimated, not because soft options are less important. In reality, soft options should be adopted whenever they are less expensive than hard options. Third, the adaptation costs are based on current knowledge. This implicitly assumes that there will be no future innovation and technical change beyond current trends, except in the agricultural sector. But we know that economic growth and thus development depend on technical change, which is likely to reduce the real costs of adaptation over time. All of these assumptions give an upward bias to the estimates of the adaptation costs. We return to these points in the limitations discussion.

Differences between the global and country tracks

The steps identified apply to both the global and country tracks. But given their different objectives, two steps of the methodologies differ. First, for most country studies a macroeconomic modeling framework was used allowing for the analysis of macroeconomic and cross-sectoral effects of the impacts and adaptation to climate change. This integrated approach has been less successful in generating lessons at the sector level, but provides important information for national level decision making. Second, the country track featured a social component in six of the seven country case studies. As a companion piece to the EACC Synthesis Report, an EACC-Social Synthesis Report has been produced that presents the findings of the social component, which was conducted in all case study countries except Samoa.

Social analysis

The social component in the country track focuses on preferred adaptation strategies from a bottom-up, local-level perspective. The methodology involved a combination of analytical methods, including participatory scenario development (PSD) workshops to reveal local stakeholders' assessments of adaptation pathways in the context of uncertainty. In the workshops, participants representing the interests of vulnerable groups identified preferred adaptation options and sequences of interventions based on local and national climate and economic projections. The findings on what forms of adaptation various groups consider to be most effective—including soft adaptation options such as land use planning, greater public access to information, and institutional capacity building—have implications for the costs of adaptation.

In addition, the social component generated new evidence on how vulnerability is socially differentiated; identified the risks and benefits of adaptation options for a range of actors in an integrated and cross-sectoral manner; and highlighted the importance of social accountability and good governance for achieving pro-poor, climate-resilient development. The focus of the EACC-social analysis went beyond planned adaptation and considered the potential of autonomous forms of adaptation undertaken by households, NGOs, and the private sector to inform future adaptation planning. This approach was not viable in the global track.

Limitations

The EACC study makes use of mathematical tools, which impose intellectual discipline. Examples of this discipline are the use of a well-defined baseline and the requirement under CGE models that the national income accounting identities balance at the end of each year. This approach is required to provide a quantitative evaluation of costs and benefits. The models can be used to assess the relative importance of different factors and the marginal impacts of changes in specific policy variables on outcomes. Such analysis provides an essential foundation for formulating policies and making decisions. Nonetheless, the usual limitations of relying upon econometric and other mathematical models apply.

Path dependency. Formal models can encourage a focus on questions that are amenable to analysis by the model at the expense of less tractable but perhaps more important issues. Adaptation to climate change involves responses that depend upon institutional or cultural factors or, more likely, a combination of these plus political factors: for example, how to influence the location of people away from high-risk or increasingly unproductive areas, how to improve the allocation of water and land, or how to improve the quality of education. The goal of this study was to focus on the economics of adaptation, but this approach presents only part of a much larger story.

Similarly, previous work in each country influenced both the direction of EACC research and what it has been possible to accomplish.[13] Where researchers, data, and models already existed, the EACC project naturally built upon prior work. The consequence is that the level and detail of the study's modeling and analysis varies across sectors and countries. In most cases, this reflects the relative importance that countries and analysts have attached to different kinds of adaptation.

Important limitations of this study fall under categories: (1) institutions, and (2) modeling limitations. The crucial issue of uncertainty and the limitations it poses has already been discussed above.

Institutions

Difficulty in addressing. From the outset the EACC study did not attempt to incorporate institutional, political, and cultural factors in the analysis of adaptation costs. Without question, these factors are crucial in understanding the process of adaptation and determining what is feasible as opposed to what might be desirable from an economic perspective. But there was a clear tradeoff between extending the scope of the study and ensuring that the economics of adaptation could be examined in sufficient detail.[14]

Some types of adaptation are best implemented through effective collective action at the community level. "Soft" adaptation measures—early warning systems, community preparedness programs, promoting education, and capacity building—require strong governance to be effective. If this can be achieved, they may go a long way in reducing vulnerability to climate change. However, estimating the costs of implementing such options is difficult for individual countries and impractical at a global level. The global study focused "hard" adaptation measures, while the country studies attempted to identify opportunities for soft adaptation without trying to cost them. There is an additional consideration: the country studies suggest that drawing a distinction between (a) what are good development policies, and (b) additional measures to adapt to climate changes is difficult under the best of circumstances. Hard adaptation measures can be identified and their costs estimated, whereas soft adaptation is generally a matter of doing things that would be desirable even in the absence of climate change. Sometimes, the focus has to be shifted or policies redesigned to take account of climate change, but it is rarely feasible to separate adaptation from development.

Migration. One concern that is often expressed is that climate change will lead to substantial amounts of intra- or inter-country migration, which will imply substantial public expenditures to meet the needs of migrants in their new places of residence. Recent work suggests that social processes linked to poverty and marginality as well as the treatment of migrants may be more important determinants of the amount and consequences of migration than environmental change (Barnett and Webber 2010). Good development policies to reduce poverty and enhance social inclusion are essential without any consideration of climate changes, so the additional element of adaptation is a small part of a larger picture. If such policies are not implemented, environmental change may be an important proximate factor in migration decisions leading to substantial costs of adaptation as a consequence of wider policy failures.

Modeling

The study has estimated the additional public sector (budgetary) costs that will be required for countries to adapt to climate change.[15] Governments achieve climate adaptation at lowest cost when (a) they use cost-benefit criteria to choose the most efficient projects to meet the overall goal, and (b) they sequence projects to maximize the net present value of their expected future investment streams. The models used for this study cannot meet these efficiency conditions and therefore do not ensure adaptation at least cost.

None of the sector models used in the global study is capable of choosing the best profile of government's investment through time (inter-temporal optimization). Some of the models in the country studies have such capability, but most do not. In any case, inter-temporal optimization is difficult assuming certainty and is nearly unmanageable in a stochastic framework. In addition, sectoral adaptation plans were identified independently in most cases for both the global and the country studies. Identifying whether the resources invested in one sector would have yielded higher adaptation benefits in another sector, or whether cash transfers would maintain welfare at lower cost, was beyond the capacity of this exercise.[16] Several of the country studies CGE models calculated the economywide effect of specific sectoral adaptation measures, but the adaptation strategies themselves were not optimized, either cross-sectorally or inter-temporally.

One method to overcome the temporal and cross-sectoral limitations of models is to construct a sufficiently large number of measures/strategies and compare their results. This has been the strategy of this study. However, collaboration with government has meant that for each country case study the first priority has been to simulate the government's preferred adaptation strategy. Because of time and resources constraints, and at times the reluctance on the part of government authorities to explore strategies outside the approved plan, few alternative strategies have been explored to date.

These qualifications do not mean that the study ignored efficient adaptation. For each of the sectoral and country studies, a serious attempt was made to apply rules of thumb or other criteria that identify low cost, though probably not least cost, strategies for adaptation. In any case, an optimal investment program for adaptation in a country or for a sector is difficult to define, let alone calculate, when there is so much uncertainty about future climate and economic development.

There is an important choice that has to be made when thinking about future work on adaptation. One approach would be to focus on efficient adaptation either by the use of optimization models across sectors and over time, or by comparing the results of a wide range of alternative investment programs, including those that implement projects at differing points in the future. An alternative approach would be to look for robust rules of thumb that yield reasonable or good adaptation strategies across a wide range of climate outcomes and economic conditions. In view of the uncertainties about climate and economic development as well as the limited information available to models, the second approach seems likely to be the better way forward in the immediate future.

There are two issues on which the economic framework used to examine adaptation requires additional work. The first issue concerns the treatment of ecosystem services. Some of the services of ecosystems that are used as indirect inputs to the production of market goods and services were included implicitly or explicitly in the sector. However, the role of ecosystems such as coastal and inland wetlands in providing both nonmarket services—including protection from droughts, floods, or storms—and cultural or recreational benefits was not addressed. Additional work is needed on flood protection services of wetlands other than mangroves and on the potential for using mangroves as an adaptation measure. With respect to biodiversity, it is difficult to separate the effects of climate change from those of more general economic development. Even if that can be done, little is known about what adaptation measures are effective for preserving biodiversity.

The second issue is how to combine social analyses with the economic models. The original intent of the EACC was to translate the very rich, mostly qualitative information from field work into economic terms, so that the adaptation measures indicated by the local populations could be included in the economic analysis as explicit adaptation alternatives. This approach proved to be unworkable. Among the difficulties were (a) the level of effort required to obtain the necessary economic information, (b) problems in scaling up very specific local and soft measures for incorporation in national models, and (c) the high degree of overlap between what local communities saw as immediate development priorities and adaptation measures. Nonetheless, the social component was invaluable as a complement to the quantitative analysis in assessing the consistency of adaptation measures viewed from national and local perspectives.

Future Work

As this section has emphasized, the EACC study has been a preliminary attempt to understand the economic issues that arise in identifying and implementing measures to adapt to climate change. The study has highlighted the wide range of uncertainty that hamper any attempt to draw immediate and specific conclusions about the best policies and investments for adaptation.

It is sometimes self-serving to emphasize the need for more detailed studies and further research. This is not the case when dealing with climate change. The highest priority in the immediate future must be to reduce the range of uncertainty about future climate impacts and to identify forms of adaptation that are robust across the range of uncertainty that will remain. Table 1 identifies areas in which future work can contribute to this process of reducing uncertainty. It is fundamentally based on the study's limitations.

TABLE 1

RECOMMENDATIONS FOR FUTURE WORK

STUDY LIMITATION	RECOMMENDATION
Use of mathematical models	Include institutional, social, cultural, and political perspectives to identify good policies
Climate uncertainty	Consider more scenarios, Monte Carlo simulations, and other probabilistic approaches
Growth uncertainty	Hard to improve other than through sensitivity analyses
Technological uncertainty	Incorporate better information from sector specialists and simulate the impact of potential advances
Non-consideration to institutional issues	Context-specific institutional capacity has to be assessed and considered to make recommendations realistic and feasible
Limited focus on migration and urbanization	Work with outside projections; limited current knowledge on cities and climate change
Models not worked on efficiency	Improve models to include inter-temporal, cross-sectoral, and cross-regional efficiency
Limited range of adaptation	Include a broader range of strategies
No environmental services	Pull better information and introduce more consistent estimates
Integration with local, bottom-up perspectives	Better understand economics of local actions

Three

Results From the Global Analyses

Putting a price tag on adaptation

Overall, the study estimates that the cost between 2010 and 2050 of adapting to an approximately 2°C warmer world by 2050 is in the range of $70 billion[17] to $100 billion a year (Table 2). This sum is the same order of magnitude as the foreign aid that developed countries now give developing countries each year. But it is still a very low percentage (0.17 percent) of the wealth of countries (measured by their GDP, which was roughly $60 trillion in 2009).

Total adaptation costs calculated by the gross sum method average roughly $10–$15 billion a year more than the other two methods (the insignificant difference between the X-sum and net sum figures is largely a coincidence). The difference is driven by

TABLE 2

TOTAL ANNUAL COSTS OF ADAPTATION FOR ALL SECTORS, BY REGION, 2010–50

(2005 $ billions, no discounting)

Cost aggregation type	East Asia & Pacific	Europe & Central Asia	Latin America & Caribbean	Middle East & North Africa	South Asia	Sub-Saharan Africa	Total
National Centre for Atmospheric Research (NCAR), wettest scenario							
Gross sum	25.7	12.6	21.3	3.6	17.1	17.1	97.5
X-sum	21.7	11.2	18.7	2.4	12.4	15.1	81.5
Net sum	21.7	11.1	18.7	2.3	12.3	14.9	81.1
Commonwealth Scientific and Industrial Research Organization (CSIRO), driest scenario							
Gross sum	20.1	8.1	17.9	3.5	18.7	16.4	84.8
X-sum	17.9	6.9	14.8	2.5	15.0	14.1	71.2
Net sum	17.7	6.5	14.5	2.4	14.6	13.8	69.6

Notes: (a) The gross aggregation method sets negative costs in any sector in a country to zero before costs are aggregated for the country and for all developing countries. The X-sums method nets positive and negative items within countries but not across countries and includes costs for a country in the aggregate, as long as the net cost across sectors is positive for the country. The net aggregate measure nets negative costs within and across countries. (b) NCAR is The National Center for Atmospheric Research, and CSIRO is the Commonwealth Scientific and Industrial Research Organisation.

Source: World Bank 2010a.

countries that appear to benefit from climate change in the water supply and flood protection sector, especially in East Asia and Pacific and in South Asia.

The drier scenario (CSIRO) requires lower total adaptation costs than does the wetter scenario (NCAR), largely because of the sharply lower costs for infrastructure, which outweigh the higher costs for water and flood management. In both scenarios, infrastructure, coastal zones, and water supply and flood protection account for the bulk of the costs. Infrastructure adaptation costs are highest for the wetter scenario.

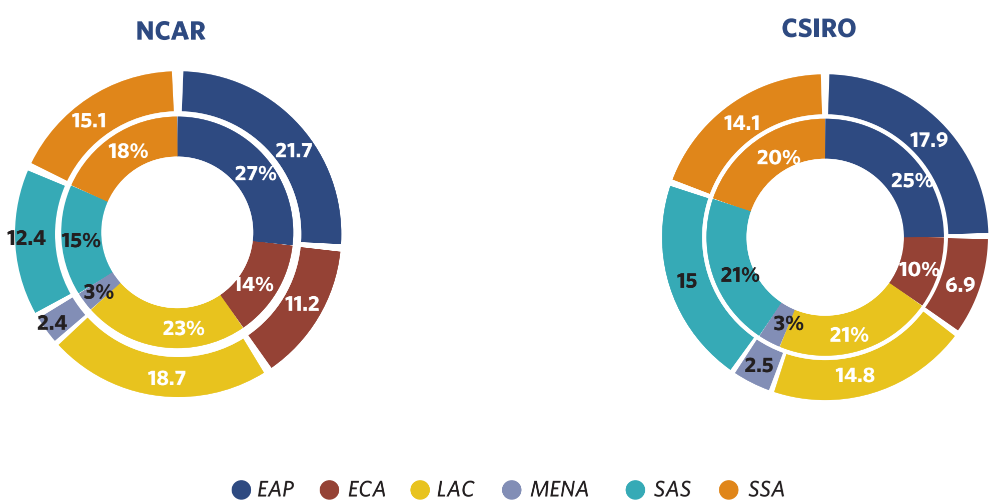
On a regional basis, for both climate scenarios, the East Asia and Pacific Region bears the highest adaptation cost, and the Middle East and North Africa the lowest. Latin America and the Caribbean and Sub-Saharan Africa follow East Asia and Pacific in both scenarios (Figure 3). On a sector breakdown, the highest costs for East Asia and the Pacific are in infrastructure and coastal zones; for Sub-Saharan Africa, water supply and flood protection and agriculture; for Latin America and the Caribbean, water supply and flood protection and coastal zones; and for South Asia, infrastructure and agriculture.

Not surprisingly, both climate scenarios show costs increasing over time, although falling as a percentage of GDP—suggesting that countries become less vulnerable to climate change as their economies grow (Figures 4 and 5). There are considerable regional variations, however. Adaptation costs as a percentage of GDP are considerably higher in Sub-Saharan Africa than in any other region, in large part because of the region's lower GDP, but also due to higher costs of adaptation for water resources (not shown) driven by changes in patterns of precipitation.

Turning to the EACC analyses of sectors and extreme events, the findings offer some insights for policy

FIGURE 3

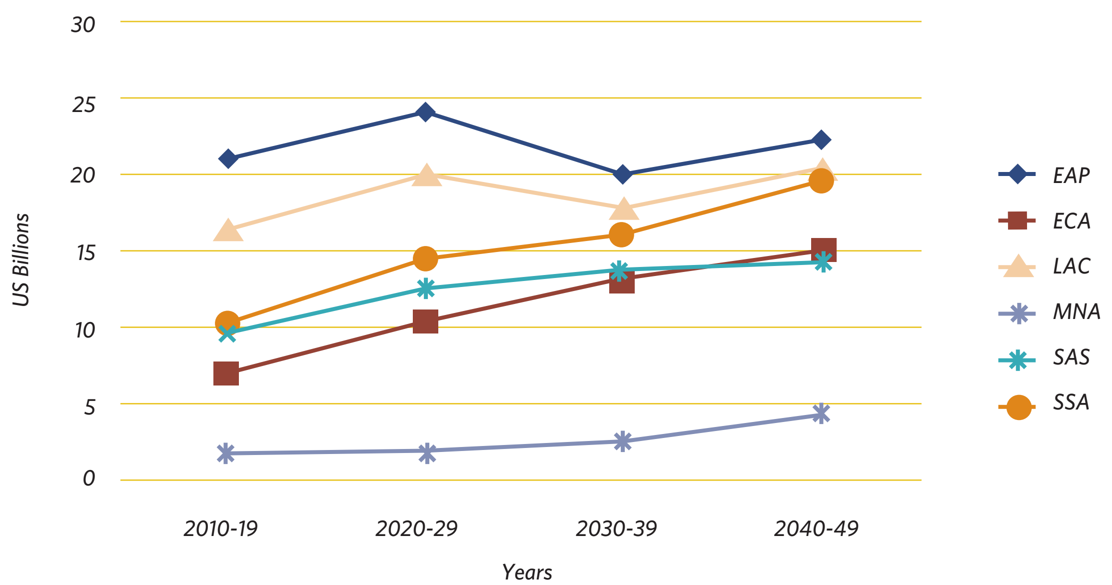
TOTAL ANNUAL COST OF ADAPTATION AND SHARE OF COSTS, NCAR AND CSIRO SCENARIOS, BY REGION
($ billions at 2005 prices, no discounting)



Note: EAP is East Asia and Pacific, ECA is Europe and Central Asia, LAC is Latin America and Caribbean, MNA is Middle East and North Africa, SAS is South Asia, and SSA is Sub-Saharan Africa.
Source: World Bank 2010a.

FIGURE 4

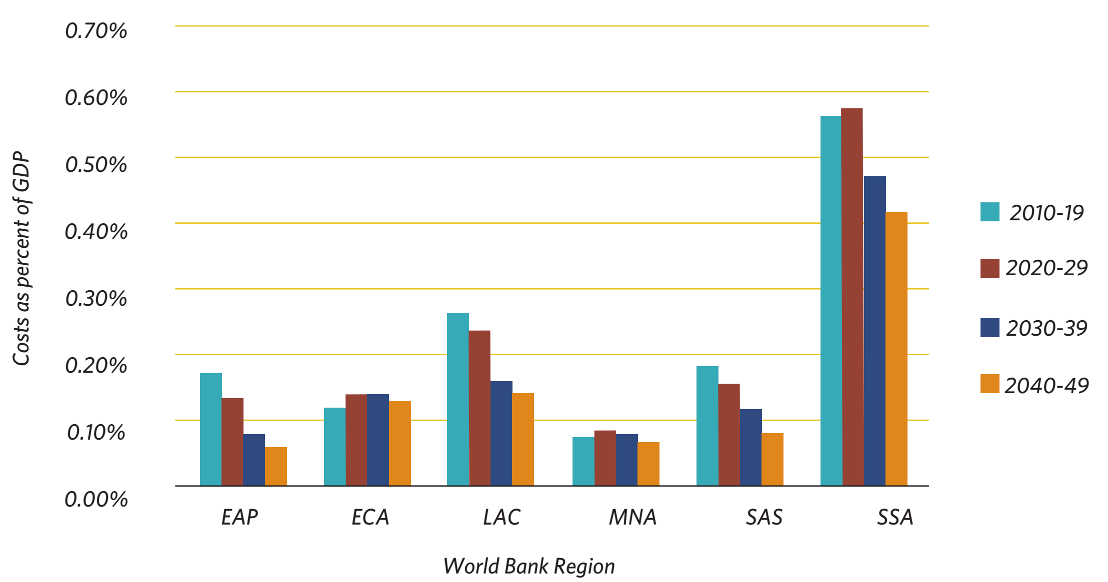
TOTAL ANNUAL COST OF ADAPTATION FOR THE NATIONAL CENTRE FOR ATMOSPHERIC RESEARCH (NCAR) SCENARIO, BY REGION AND DECADE *($ billions at 2005 prices, no discounting)*



Note: EAP is East Asia and Pacific, ECA is Europe and Central Asia, LAC is Latin America and Caribbean, MNA is Middle East and North Africa, SAS is South Asia, and SSA is Sub-Saharan Africa.
Source: World Bank 2010a.

FIGURE 5

TOTAL ANNUAL COST OF ADAPTATION FOR THE NATIONAL CENTRE FOR ATMOSPHERIC RESEARCH (NCAR) SCENARIO, BY REGION AND DECADE *($ billions at 2005 prices, no discounting)*



Note: EAP is East Asia and Pacific, ECA is Europe and Central Asia, LAC is Latin America and Caribbean, MNA is Middle East and North Africa, SAS is South Asia, and SSA is Sub-Saharan Africa.
Source: World Bank 2010a.

makers who must make tough choices in the face of great uncertainty.

Infrastructure.[18] This sector has accounted for the largest share of adaptation costs in past studies and takes up a major share in the EACC study—in fact, the biggest share for the NCAR (wettest) scenario because the adaptation costs for infrastructure are especially sensitive to levels of annual and maximum monthly precipitation. Urban infrastructure—drainage, public buildings, and similar assets—accounts for about 54 percent of the infrastructure adaptation costs, followed by railways at 18 percent, and roads (mainly paved) at 16 percent. East Asia and the Pacific and South Asia face the highest costs, reflecting their relative populations. Sub-Saharan Africa experiences the greatest increase over time, with its adaptation costs rising from $0.9 billion a year for 2010–19 to $5 billion a year for 2040–49.

Coastal zones.[19] Coastal zones are home to an ever-growing concentration of people and economic activity, yet they are also subject to a number of climate risks, including sea level rise and possible increased intensity of tropical storms and cyclones. These factors make adaptation to climate change critical. The EACC study shows that coastal adaptation costs are significant and vary with the magnitude of sea-level rise, making it essential for policymakers to plan while accounting for the uncertainty. One of the most striking results is that Latin America and the Caribbean and East Asia and the Pacific account for about two-thirds of the total adaptation costs.

Water supply.[20] Climate change has already affected the hydrological cycle, a process that is expected to intensify over the 21st century. In some parts of the world, water availability has increased and will continue to increase, but in other parts, it has decreased and will continue to do so. Moreover, the frequency and magnitude of floods are expected to rise, because of projected increases in the intensity of rainfall. Accounting for the climate impacts, the study shows

that water supply and flood management ranks as one of the top three adaptation costs in both the wetter and drier scenarios, with Sub-Saharan Africa footing by far the highest costs. Latin America and the Caribbean also sustain high costs under both models, and South Asia sustains high costs under CSIRO.

Agriculture.[21] Climate change affects agriculture by altering yields and changing areas where crops can be grown. The EACC study shows that changes in temperature and precipitation from both climate scenarios will significantly hurt crop yields and production—with irrigated and rainfed wheat and irrigated rice the hardest hit. South Asia shoulders the biggest declines in production, but developing countries fare worse for almost all crops compared to developed countries. Moreover, the changes in trade flow patterns are dramatic. Under the NCAR scenario, developed country exports increase by 28 percent, while under the CSIRO scenario they increase by 75 percent relative to 2000 levels. South Asia becomes a much larger importer of food under both scenarios, and East Asia and the Pacific becomes a net food exporter under the NCAR. In addition, the decline in calorie availability brought about by climate change raises the number of malnourished children.

Human health.[22] The key human health impacts of climate change include increases in the incidence of vectorborne diseases (malaria), waterborne diseases (diarrhea), heat- and cold-related deaths, injuries and deaths from flooding, and the prevalence of malnutrition. The EACC study, which focuses on malaria and diarrhea, finds adaptation costs falling in absolute terms over time to less than half the 2010 estimates of adaptation costs by 2050. Why do costs decline in the face of higher risks? The answer lies in the benefits expected from economic growth and development. While the declines are consistent across regions, the rate of decline in South Asia and East Asia and Pacific is faster than in Sub-Saharan Africa. As a result, by 2050 more than 80 percent of health sector adaptation costs will be shouldered by Sub-Saharan Africa.

Extreme weather events.[23] Without reliable data on emergency management costs, the EACC study tries to shed light on the role of socioeconomic development in increasing climate resilience. It asks: As climate change increases potential vulnerability to extreme weather events, how many additional young women would have to be educated to neutralize this increased vulnerability? And how much would it cost? The findings show that by 2050, neutralizing the impact of extreme weather events requires educating an additional 18 million to 23 million young women at a cost of $12 billion to $15 billion a year. For 2000–50, the tab reaches about $300 billion in new outlays. This means that in the developing world, neutralizing the impact of worsening weather over the coming decades will require educating a large new cohort of young women at a cost that will steadily escalate to several billion dollars a year. But it will be enormously worthwhile on other margins to invest in education for millions of young women who might otherwise be denied its many benefits.

Putting the findings in context

How does this study compare with earlier studies? The EACC estimates are near the upper end of estimates by the UNFCCC (2007), the study closest in approach to this study, though not as high as suggested by a recent critique of the UNFCCC study by Parry and others (2009). A comparison of the studies is limited by methodological differences—in particular, the use of a consistent set of climate models to link impacts to adaptation costs and an explicit separation of costs of development from those of adaptation in the EACC study. [24] But the major difference between them is the nearly six-fold increase in the cost of coastal zone management and defense under the EACC study. This difference reflects several improvements to the earlier UNFCCC estimates under the EACC study: better unit cost estimates, including maintenance costs, and the inclusion of costs of port upgrading and risks from both sea level rise and storm surges.

TABLE 3

COMPARISON OF ADAPTATION COST ESTIMATES BY THE UNFCCC AND THE EACC, $ BILLIONS

		EACC Study Scenario	
Sector	UNFCCC (2007)	NCAR (wettest)	CSIRO (driest)
Infrastructure	2–41	27.5	13.0
Coastal zones	5	28.5	27.6
Water supply and flood protection	9	14.4	19.7
Agriculture, forestry, fisheries	7	2.5*	3.0*
Human health	5	2.0	1.5
Extreme weather events	—	6.7	6.4
Total	28–67	81.5	71.2

Note: *In the agriculture, forestry, and fisheries sector, the cost of adaptation has changed as compared to the estimates presented in the EACC global report (World Bank 2010a), in which these costs stood at $7.6 billion for the NCAR and $7.3 billion for the CSIRO scenarios. The current costs are estimated as the difference in public spending in the scenario with climate change and adaptation as compared to the no-climate-change scenario, and use the same methodology as has been applied to the other sectors. In World Bank (2010), the costs were incorrectly reported as reflecting the difference in public spending in the scenario with climate change and adaptation as compared to the scenario with climate change but no adaptation. The difference lowers the EACC lower bound estimate of the global cost of adaptation from $75 billion reported in WB (2010) to $71.2 billion per year, rounded to $70 billion per year.
Source: UNFCCC (2007) and revised estimates World Bank 2010a.

Another reason for the higher estimates is the higher cost of adaptation for water supply and flood protection under the EACC study, particularly for the CSIRO drier climate scenario. This difference is explained in part by the inclusion of riverine flood protection costs under the EACC study. Also pushing up the EACC study estimate is the study's comprehensive sector coverage, especially inclusion of the cost of adaptation to extreme weather events.

The infrastructure costs of adaptation in the EACC study fall in the middle of the UNFCCC range because of two contrary forces. Pushing up the EACC estimate is the more detailed coverage of infrastructure. Previous studies estimated adaptation costs as the cost of climate-proofing new investment flows and did not differentiate risks or costs by type of infrastructure. The EACC study extended this work to estimate costs by types of infrastructure services—energy, transport, communications, water and sanitation, and urban and social infrastructure. Pushing down the EACC estimate are measurements of adaptation against a consistently projected development baseline and use of a smaller multiplier on baseline investments than in the previous literature, based on a detailed analysis of climate proofing, including adjustments to design standards and maintenance costs.

The one sector where the EACC estimates are actually lower than the UNFCCC's is human health. The reason for this divergence is in part because of the inclusion of the development baseline, which reduces the number of additional cases of malaria, and thereby adaptation costs, by some 50 percent by 2030 in the EACC study.

The bottom line: calculating the global cost of adaptation remains a complex problem, requiring projections of economic growth, structural change, climate change, human behavior, and government investments 40 years in the future. The EACC study tried to establish a new benchmark for research of this nature, as it adopted a consistent approach across countries and sectors and over time. But in the process, it had to make important assumptions and simplifications, to some degree biasing the estimates.

Lessons

The sector estimates of adaptation costs presented in the global track report point to a few important lessons.

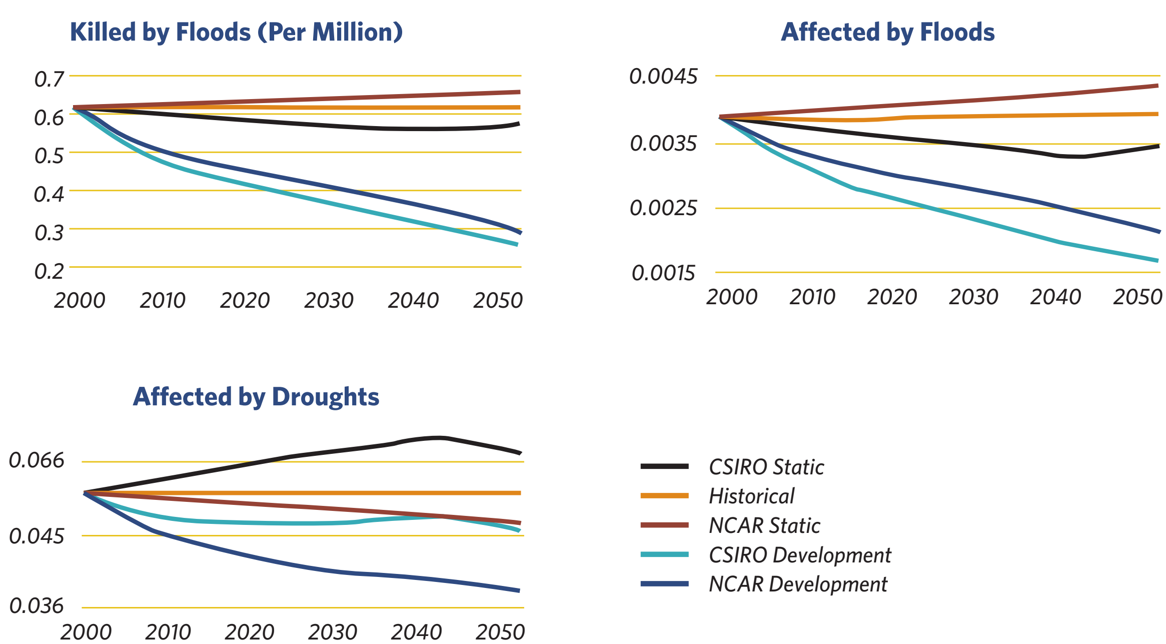
A. Development is imperative ... Development dramatically reduces the number of people killed by floods and affected by floods and droughts, quite apart from the impact of climate change (Figure 6). If development is held constant at 2000 levels, the number of people killed by floods increases over time under the NCAR (wettest) scenario and decreases under the CSIRO (driest) scenario. Allowing for development between 2000 and 2050 greatly reduces the numbers of people killed under both scenarios. The findings are similar for the number of people affected by floods and droughts.

In the health sector analysis, allowing for development reduces the number of additional cases of malaria, and thereby adaptation costs, by more than half by 2030 and more than three-quarters by 2050.

The greater the baseline level of development in each period, the smaller is the impact of climate change and the smaller are the costs of adaptation. Development must be inclusive, however, to have these effects. And development can also increase vulnerabilities: the more developed the country, the greater the value

FIGURE 6

DEVELOPMENT LOWERS THE NUMBER OF PEOPLE KILLED BY FLOODS AND AFFECTED BY FLOODS AND DROUGHTS, 2000–50



Source: World Bank 2010a.

of infrastructure and personal property at risk from climate change and therefore the greater the cost of climate-proofing such assets. However, these costs decrease with development as a percentage of GDP.

B. …but not simply development as usual. Adaptation will also require a different kind of development—breeding crops that are drought- and flood-tolerant, climate-proofing infrastructure to make it resilient to climate risks, reducing overcapacity in the fisheries industry, accounting for the inherent uncertainty in future climate projections in development planning, and others.

Consider water supply. Adapting to changing conditions in water availability and demand has always been at the core of water management. Traditionally, though, water managers and users have relied on historical experience when planning, such as consistency in flood recurrence periods. These assumptions no longer hold under climate change. Water management practices and procedures for designing water-related infrastructure need to be revised to account for future climate conditions. Similarly, dikes and other coastal protection measures will need to be built in anticipation of rising sea levels.

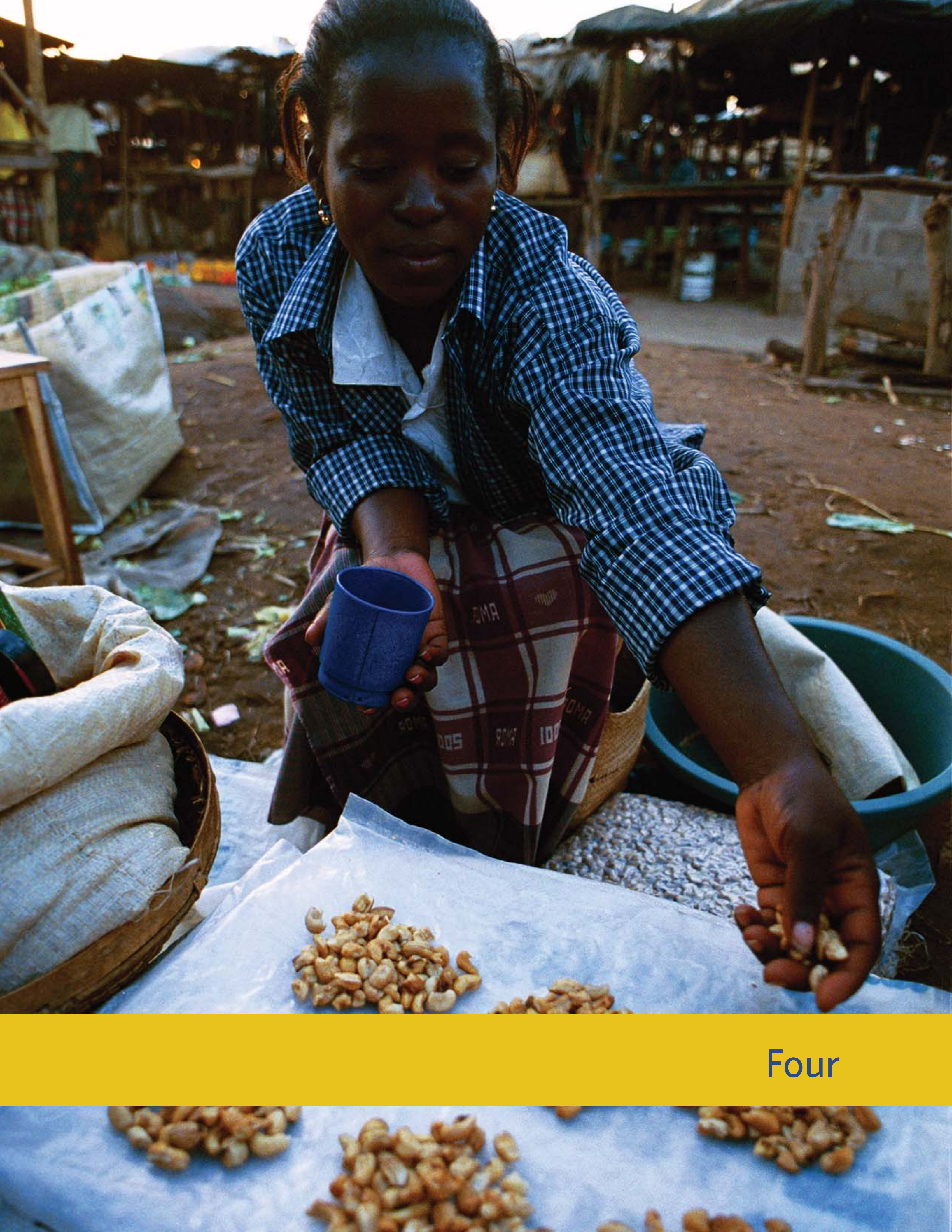
C. Though adaptation is costly, costs can be reduced. The clearest opportunities to reduce the costs of adaptation are in water supply and flood protection. Almost every developed country has experienced what can happen when countries fail to shift patterns of development or to manage resources in ways that take account of the potential impacts of climate change. Often, the reluctance to change reflects the political and economic costs of changing policies and (quasi-) property rights that have underpinned decades or centuries of development. Countries that are experiencing rapid economic growth have an opportunity to reduce the costs associated with the legacy of past development by ensuring that future development takes account of changes in climate conditions. Economists and others regularly urge the adoption of mechanisms for managing water resources that recognize the scarcity value of raw water. This advice is almost invariably ignored due to deeply embedded political and social interests. But the costs of misallocation of water resources will escalate even without climate change and could be overwhelming under conditions of climate change. A large share of the costs of adaptation in water supply and flood protection could be avoided by adopting better management policies.

For good practical reasons, this study focuses on the costs of adaptation that are likely to fall on the public sector, and it assumes limited or no change in technology, except in the agriculture sector analysis. But the boundary between public and private (autonomous) adaptation is almost infinitely flexible. So long as governments and the public sector ensure that incentives for innovation, investment, and private decisions reflect the scarcity of resources once the impact of climate change is taken into account, experience demonstrates that the costs of adaptation may be dramatically reduced by a combination of technical change and private initiative.

D. Uncertainty remains a challenge. The inherent uncertainty in climate projections—and the uncertainties about economic impacts and adaptation responses—makes climate-resilient development planning a challenge. While the science is clear on general global trends of climate change, current climate science can provide only limited guidance to public investment in specific countries or sectors, with the exception of sea level rise. This study has estimated the cost of adaptation under 2 (of 26) global climate models associated with the A2 scenario of the IPCC Special Report on Emissions Scenarios. The costs were estimated as though the countries knew with certainty what the climate outcome would be. This is clearly not the case. Also, the study estimates the costs relative to a development baseline, which in turn assumes a certain rate of growth of per capita GDP between 2010 and 2050. This is also not the case.

This implies that climate adaptation must be limited to robust measures such as education and climate-related research. For durable climate-sensitive investments, a strategy is needed that maximizes the flexibility to incorporate new climate knowledge as it becomes available. Hedging against varying climate outcomes, for example by preparing for both drier and wetter conditions for agriculture, would raise the cost of adaptation well above the estimates here.

There are three ways to deal with this uncertainty: wait for better information, prepare for the worst, and insure. Countries will select among these options, depending on specific investment decisions and their level of risk aversion. Since climate change is gradual, designing for limited or no change in climate conditions while waiting for better information might save money today but will likely result in high future costs for maintenance or earlier replacement of assets if climate conditions are worse than anticipated. Preparing for the worst might not be that expensive if the cost of adjusting design standards to accommodate future climate conditions is relatively small, as is the case for many infrastructure assets. Insurance is more complicated, because uncertainty about climate change also involves regional shifts in temperature and rainfall. What might be large uncertainties for individual countries might become much smaller when the costs of adaptation are pooled, particularly across regions. A funding mechanism that permits the reallocation of funds across regions as better information is collected about the actual outcome of climate change would provide a basis for pooling risks across countries.



Four

Results From the Country Analyses

The purpose of the country case studies is to help the governments understand the potential economic impacts of climate change and to support their efforts to develop sound policies and investments in response to these potential impacts. This chapter summarizes the results of the country studies and their main lessons. For each country, the analyses consist of (a) a brief description of the nature and degree of vulnerability of the country to climate change; (b) the EACC study approach and main results from the modeling exercises, as well as local-level perspectives; and (c) a summary of country-specific lessons and recommendations.

Choice of countries. The seven country case studies were selected based on overall vulnerability to major climate change impacts; differing environmental, social, and economic conditions; and adequate data at the national level. Government interest was also fundamental to select the countries. Although it was difficult to identify the best set of candidates in advance, as is always the case in similar exercises, it was considered important to have representativeness in terms of continents, size, population, and income level of the country, as well as richness of data and local capacity to work with the EACC core team to apply the proposed methodology in the country.

Mozambique, Ghana, and Ethiopia represent nearly the full range of agricultural systems in Africa. Mozambique is subject to flooding and extreme events, including tropical cyclones. Both Mozambique and Ghana are on the receiving end of water flowing out of major international river basins. With most of their economic activity and population concentrated along the coast and in low-lying deltas, Vietnam and Bangladesh are Asian countries widely recognized as among the world's most vulnerable to climate change, particularly from extreme weather events and flooding, with particular impacts on poorer populations. Bolivia is a poor Latin American country traditionally dependent on the Andean glaciers to supply good portions of water demand, and consisting of a wide range of agroecosystems—from small-scale family agriculture on the Altiplano (largely composed of native indigenous populations) to large-scale commercial agriculture in the lowlands of Santa Cruz. Finally, Samoa represents a low-lying Pacific island at increased risk of sea level rise and storm surge. See Table 4 for information on which sectors were covered by country.

Methodology in African countries. The overall methodology adopted in the three African countries closely follows the one used in the global track. Using a time frame of 2050, development baselines are first developed for each sector. The baseline represents the growth path the economy would follow in the absence of climate change. It is a reasonable trajectory for growth and structural change of the economy

TABLE 4

SECTOR ANALYSES CARRIED OUT IN EACH COUNTRY CASE STUDY

	Mozambique	Ethiopia	Ghana	Bangladesh	Vietnam	Bolivia	Samoa
Agriculture	Yes	Yes	Yes	Yes	Yes	Yes	
Water	Yes	Yes	Yes		Yes	Yes	
Roads	Yes	Yes	Yes	Yes			
Hydropower	Yes	Yes	Yes				
Coastal	Yes		Yes	Yes	Yes		Yes
Extreme events	Yes	Yes	Yes	Yes			Yes
Social	Yes	Yes	Yes	Yes	Yes	Yes	
CGE/MIP	CGE	CGE	CGE	CGE	CGE	MIP	Macro

Note: The forestry and fisheries sectors were only carried out for Vietnam.

over a period of 40 years that can be used as a basis for comparison with the climate change scenario. The baselines for each sector utilize a common set of GDP and population forecasts for 2010–50 and a common set of climate scenarios to project temperature and precipitation changes to 2050. The changes in climate are provided by a few different climate models that attempt to represent the most extreme variations in the main two variables—temperature and precipitation. The different scenarios typically consist of the two considered in the global analyses (CSIRO and NCAR), plus two other country-specific extreme climate scenarios. They are used to predict impacts on economic sectors (agricultural output, consumption, water availability, and infrastructure). The final steps involve identifying and costing adaptation options for the key sectors. The costs of adaptation comprise the costs of public policy adaptation measures and exclude the costs of private (autonomous) adaptation.

The modeling of the impacts of climate change in the selected sectors is carried out using a suite of models. Output parameters from these models are then fed into a common dynamic computable general equilibrium (CGE) model where the economic implications of the modeled data are assessed. The African country studies use a common core dynamic CGE model (Box 1), incorporating comparable approaches to climate change impacts and adaptation strategies. There are significant differences across the three countries, given their very different economic structures—for example, Ethiopia has no coastline, while Ghana and Mozambique are subject to coastal impacts of climate change—but the common modeling framework supports comparative analysis of sensitivity to shocks and adaptation strategies.

Mozambique[25]

Vulnerability to climate change

Mozambique is subject to frequent droughts, floods, and tropical cyclones. These events threaten the country's economic performance, which is already highly affected by high rainfall variability. Drought is the most frequent disaster, with an average incidence of every 3–4 years. Floods in Mozambique are characterized by a number of geographical factors. More than 60 percent of Mozambique's population lives in coastal areas, which are very susceptible to flooding because they are in low-lying regions of river basins, and in areas with poor drainage systems. In the period 1958–2008, 20

BOX 1

CGE MODELS—PARTIAL AND GENERAL EQUILIBRIUM ANALYSIS

The impact of climate change is simulated using a dynamic computable general equilibrium (CGE) model. These models have features making them suitable for such analyses. First, they simulate the functioning of a market economy—including markets for labor, capital and commodities—and provide a useful perspective on how changes in economic conditions are mediated through prices and markets. Secondly, the structural nature of these models permits consideration of new phenomena, such as climate change. Thirdly, these models assure that all economywide constraints are respected. This is critical discipline that should be imposed on long-run projections, such as those necessary for climate change. For instance, suppose climate change worsens growing conditions, forcing Ethiopia to import food. These imports require foreign exchange earnings. CGE models track the balance of payments and require that a sufficient quantity of foreign exchange is available to finance imports. Finally, CGE models contain detailed sector breakdowns and provide a "simulation laboratory" for quantitatively examining how various impact channels influence the performance and structure of the economy.

In CGE models, economic decision making is the outcome of decentralized optimization by producers and consumers within a coherent economywide framework. A variety of substitution mechanisms occur in response to variations in relative prices, including substitution between labor types, capital and labor, imports and domestic goods, and between exports and domestic sales.

The relatively long time frame considered (40 years into the future) means that dynamic processes are important and need to be captured in the dynamic CGE model. To the extent that climate change reduces agricultural or hydropower output in a given year, it also reduces income and hence savings. This reduction in savings translates into reduced investment, which translates into future reduced production potential. In the same vein, increased infrastructure maintenance costs imply less infrastructure investment, which further implies less infrastructure both now and in the future. Extreme events, such as flooding, can wipe out economic infrastructure; that infrastructure is gone, both in the period in which the event occurs and all future periods. Generally, even small differences in rates of accumulation can lead to large differences in economic outcomes over long time periods. The CGE model employed is well-positioned to capture these effects.

The baseline development path adopted reflects development trends, policies, and priorities in the absence of climate change. It provides a reasonable trajectory for growth and structural change of the economy over about 50 years (the period 2003–50 is modeled) that can be used as a basis for comparison. We can, for example, run the CGE model forward imposing the implications of future climate on dry-land agricultural productivity. Within the model, the decisions of consumers, producers, and investors change in response to changes in economic conditions driven by a different set of climate outcomes.

major flood events were recorded, affecting more than 9 million people (RMSI 2009). These extreme events have been followed by outbreaks of disease, causing even more death and economic loss. Sea level rise is predicted to increase the negative effects of storm surge and flood events along the coast. Over the next 40 years, all such consequences of climate change are likely to complicate the already considerable development challenge in Mozambique.

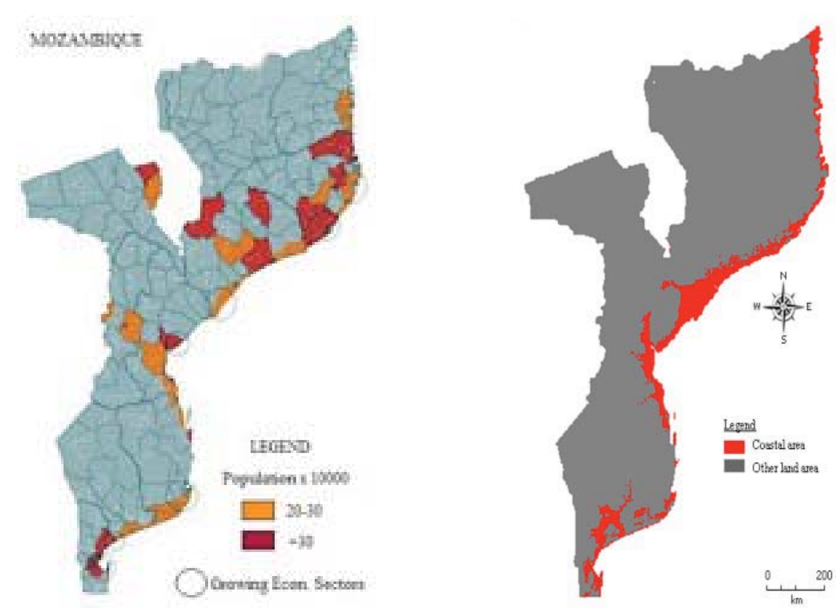
The most vulnerable sectors to the impacts from climate change in Mozambique are agriculture, which employs over 70 percent of the Mozambican population; energy, particularly hydropower generation which is dependent on water runoff; transport infrastructure, notably roads; and coastal areas, which do not conform to a "sector" but characterize specific geographical areas vulnerable to floods and storm surges directly and indirectly related to sea level rise (Figure 7). These sectors are vulnerable to current climate variability and are most likely to remain vulnerable to future climate change. Other sectors or issues of importance—such as health and urban infrastructure—were not included in the EACC analyses due to lack of data at the required scale.

Findings from the social component suggested that livelihood activities most sensitive to climate change impacts continued to take place in areas most exposed to these impacts. For example, subsistence farmers continued to farm in areas prone to drought, rendering them even more vulnerable. In the case of fishing, artisanal fishers reported venturing further out to sea in search of better fish stocks, even though this was increasingly dangerous due to the occurrence of more frequent and intense storms.

FIGURE 7

POPULATION DENSITY AND COASTAL AREA

(land less than 30 meters above mean sea level, in red)



EACC approach and results

Impacts. Changes in precipitation and temperature from four GCMs (the two global scenarios plus two extreme scenarios for Mozambique, MOZDRY and MOZWET) were used to estimate (a) the changes in yield each year for both irrigated and rainfed crops, as well as irrigation demand for six cash crops and eight food crops; (b) flow into the hydropower generation facilities and the consequent changes in generation capacity; and (c) the impact on transport infrastructure and the increased demand and costs of road maintenance. Simulations of sea level rise were constructed independently of the climate scenarios.[26] Two approaches were undertaken. First, an integrated model of coastal systems was used to assess the risk and costs of sea level rise in Mozambique. Second, analyses of the interactions between cyclone risk and sea level rise were undertaken for Beira and Maputo, the two largest cities in Mozambique.

Analysis at the sector level suggests, for example, net negative changes in crop productivity over all of Mozambique in all scenarios (Figure 8), with central Mozambique being hit hardest. Over the next 40 years, climate change would lead to a 2–4 percent decrease in yields of the major crops. This, combined with the effects of more frequent flooding on rural roads, would result in an agricultural GDP loss of 4.5 percent (conservative) to 9.8 percent (most pessimistic), translating into a total GDP loss between 0.8 to 1.6%. In addition, the potential energy deficit due to climate change relative to the base generation potential (2005–50) is approximately -110,000 GWh.

The results from the integrated models of coastal systems (DIVA) show that in the 2040s, if there is no adaptation, Mozambique could lose up to 4,850 km^2 of land existing today (or up to 0.6 percent of national land area) and a cumulative total of 916,000 people could be forced to migrate away from the coast (or 2.3 percent of the 2040s population). In the worst case, the total annual damage costs are estimated to reach $103 million per year in the 2040s, with the forced migration being a large contributor to that cost. These damages and costs are mainly concentrated in Zambezia, Nampula, Sofala, and Maputo provinces, reflecting their low-lying topography and relatively high population.

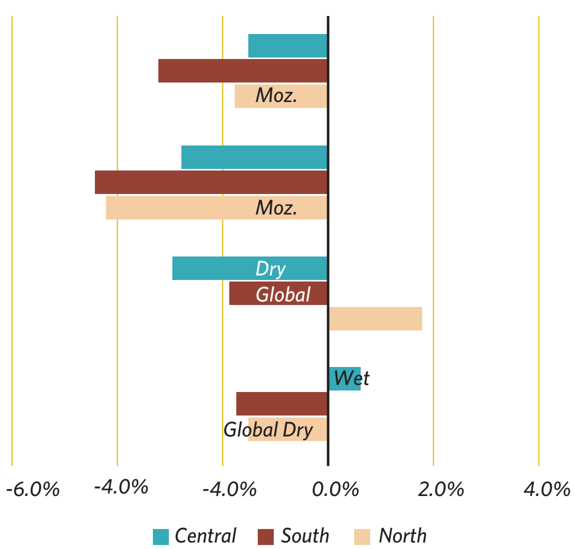
The analysis of the interactions between cyclone risk and sea level rise performed for Beira and Maputo illustrate that relatively small levels of sea level rise can dramatically increase the probability of severe storm surge events under the assumption of no change in the intensity and frequency of cyclone events. Results are more dramatic for Beira than for Maputo City. The probability of a cyclone strike in Maputo is lower due to greater latitude and the positioning of Maputo City relative to Madagascar.

The estimated impacts on agriculture, transport, hydropower, and coastal infrastructure are fed into a macroeconomic CGE model that complements the sector models by providing a complete picture of economic impacts across all sectors within a coherent analytical framework. The CGE model looks at the impact of climate change on aggregate economic performance. As indicated in Figure 8, climate change has potential implications for rates of economic growth. These growth effects accumulate into significant declines in national welfare by 2050. In the worst case scenario, the net present value of damages (discounted at 5 percent) reaches about $7.6 billion, equivalent to an annual payment of a bit more than $400 million.

Figure 9 breaks down the climate change shocks into three groups: (1) crop yields and sea level rise (the latter is very small), (2) transportation system, and (3) hydropower. The graph illustrates the dominant role played by transport system disruption, principally as a result of flooding. The global dry scenario is in fact a very wet scenario for the Zambezi water basin as a whole, and thus causes significant and enduring damage to roads. By contrast, the local dry scenario is a very dry scenario for Mozambique and causes greater damage to agriculture.

FIGURE 8

AGRICULTURE: EFFECTS ON YIELD IN 2050 COMPARED TO BASELINE

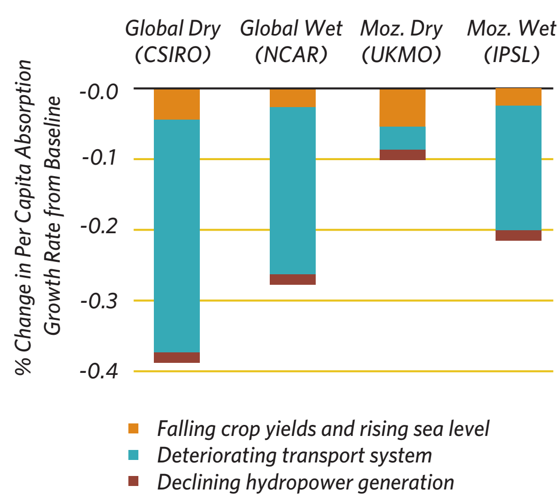


Note: Bars represent the average change in crop productivity. Regional averages are weighted by historic crop yield rates per crop in the region.

Source: World Bank 2010g.

FIGURE 9

DECOMPOSITION OF IMPACT CHANNELS FROM A MACROECONOMIC PERSPECTIVE



Source: World Bank 2010g.

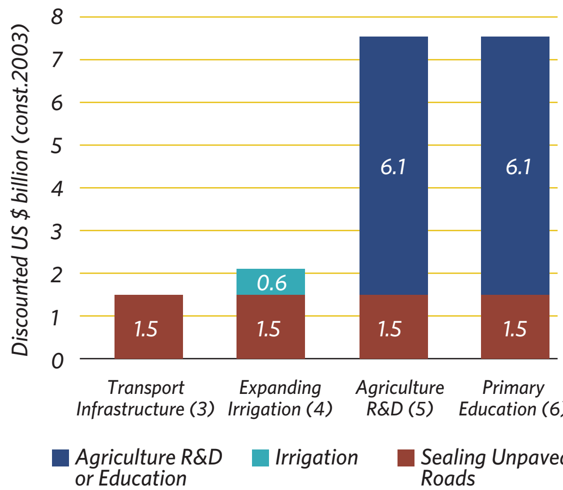
Adaptation. After calculating the impacts, the CGE then considers potential adaptation measures in three sectors (hydropower, agriculture, and transportation).[27] Four adaptation strategies are then introduced in the model to minimize the damages: (1) transport policy change,[28] and then the transport policy change plus (2) increased agricultural research and extension, or transport plus (3) enhanced irrigation, or transport plus (4) enhanced investment in human capital accumulation (education).

The results are shown in Figure 10. Sealing unpaved roads reduces the worst-case climate damages substantially, restoring approximately one-fifth of lost welfare,[29] and with little additional cost; it is thus a no-regret action advisable even under the baseline. Remaining welfare losses could be regained with improved agricultural productivity or human capital accumulation (education). Irrigation investments appear to be a poor alternative: 1 million hectares of new irrigation land would only slightly reduce CC damages. In terms of softer adaptation measures, investing in agricultural research in order to raise agricultural productivity (through increases in crop yield and reductions in post-harvest loses) by 1 percentage point each year over baseline productivity trends offsets remaining damages to agriculture (for example, a further 50 percent maize yield increase by 2050). Increasing rates of human capital accumulation by slightly more than 1 percentage point also offsets damages. Increased investments in education helps increase aggregate labor force productivity and this translates into higher GDP. Lastly, investment costs required to restore welfare losses are subject to debate, but are reasonably less than $390 million per year over 40 years.

With respect to specific coastal adaptation measures, the integrated coastal system analysis examined two protection measures: beach/shore nourishment and sea and river dike building and upgrading. When these are applied, the physical and socioeconomic impacts are significantly reduced. For instance, the total land area lost could be reduced by a factor of more than 80 to 61km^2, and the number of people

FIGURE 10

REDUCTION IN CC DAMAGES, 2003–50
(5% discount rate, constant 2003 $)



Source: World Bank 2010g.

forced to migrate could be reduced by a factor of 140 to 7,000 people. Hence, the total annual damage cost is reduced by a factor of 4 to $24 million per year. However, the total investment required to achieve these adaptation options is estimated at $890 million per year in the 2040s for the high sea level rise scenario, which appears much higher than the benefits of the adaptation in terms of damages avoided. At the same time, more targeted investments in high value and more vulnerable locations can provide positive returns. The range of costs of more economically viable adaptation options in the 2040s varies from $190 million to $470 million per year, depending on the sea level rise scenario. Note that these costs are higher than the benefits from adaptation that accrue through 2050. But these adaptation measures such as dikes are long-lived and would also yield long-term benefits well beyond 2050, the scope of this analysis, and in fact through 2100 as sea-level rise and storm surge risks accelerate.

The analysis of the interactions of cyclone risk and sea level rise for Beira and Maputo provides more impetus for investment in the near term, particularly for Beira. While the full cost of the necessary infrastructure for protecting Beira city and port has not been estimated to date, the dramatic fall in return periods for sea inundation due to sea level rise strongly suggests that protection schemes should be reassessed.

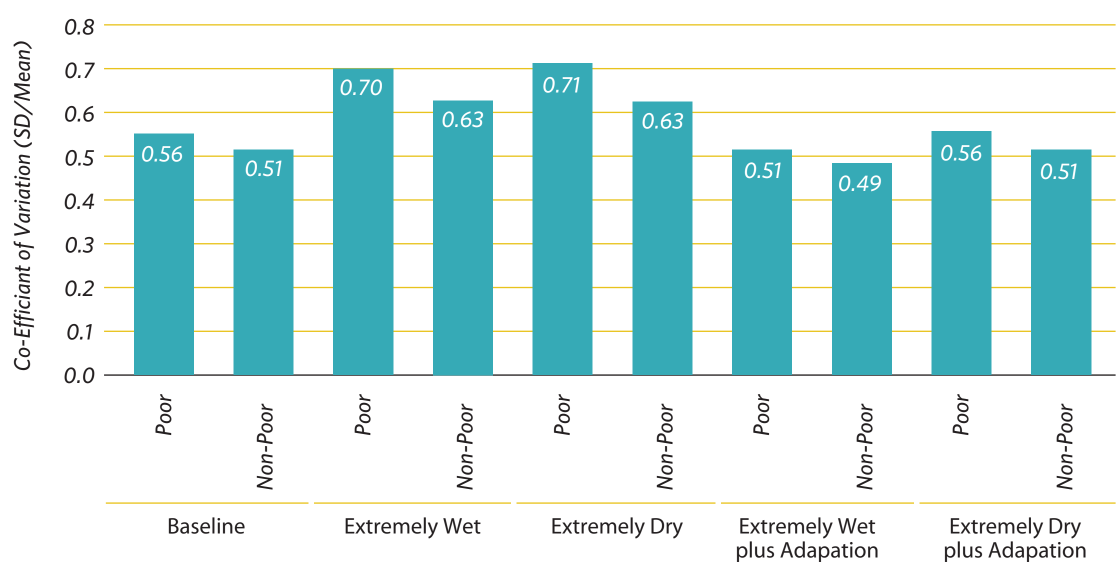
Equity issues. The incidence of impacts from climate change between households categorized as poor and non-poor in the base year are approximately similar. This result is somewhat surprising but follows from the fact that the biggest impacts of climate change are on infrastructure which permeate across the economy and impacts the poor and the non-poor. The same holds true for adaptation measures; poor and non-poor households both benefit from the adaptation measures, and the incidence of these benefits is not substantially different. Poor and non-poor do appear to differ in terms of their vulnerability to shocks.

Figure 11 shows the impact of the extreme wet and dry scenarios, with and without road network adaptation investments, on the coefficient of variation (CV)[30] of the year-to-year growth rates of total household consumption. They represent the year-to-year changes in consumption to which households must adjust. A value of 0.56 in the baseline indicates that poor households must manage annual swings in the change in consumption of 56 percent. These swings in income in the base model reflect current climate variabilities—droughts, floods, and tropical cyclones. In all scenarios, the CVs for poor households are slightly higher than those for non-poor households—poor households must deal with more income variability than the non-poor. The impact of the climate change scenarios on the CVs is significant—rising to about 0.70 in the two global scenarios. However, it either remains constant or falls in the two Mozambique scenarios.

Local-level perspectives on adaptation. Results from the social component in Mozambique were remarkably consistent with the economic analyses and with adaptation priorities previously identified in the Mozambique NAPA. The most common adaptation preferences emerging from participatory scenario development workshops and fieldwork results are presented in Table 5.

FIGURE 11

HOUSEHOLD CONSUMPTION: COEFFICIENT OF VARIATION OF YEAR-TO-YEAR GROWTH RATES



Source: World Bank 2010g.

TABLE 5

KEY ADAPTATION OPTIONS IN MOZAMBIQUE

	Planned Adaptation	Autonomous Adaptation
Hard	■ Flood control dikes and levies ■ Coastal flood control gates ■ Dams and irrigation channels ■ *Improved roadways* ■ *Improved communication infrastructure* ■ *Improved hospitals and schools*	■ More robust buildings ■ Farm-scale water storage facilities ■ Deep wells to provide drinking water for people and animals ■ *Grain storage facilities* ■ *Improved food processing equipment*
Soft	■ Improved early warning of climatic hazards, and of dam releases ■ Better planning and management of forest, fish, and other natural resources ■ Resettlement of populations to lower risk zones ■ *More credit and financial services for small businesses and rural development* ■ *Better education and information for rural areas* ■ *Improved health care, social services, and social support for all people*	■ Better utilization of short-season, drought-resistant crops to prepare for drought, floods, and cyclones ■ Diversification of flood and drought risk by maintaining fields in both highland and lowland areas ■ Better household and community management and use of natural resources, including wild fruits ■ Practice of soil conservation agriculture ■ Migration to lower risk areas ■ *Diversification of livelihoods away from agriculture* ■ *Better planning of how much grain to save for personal consumption, and how much to sell for income generation*

Note: The options in plain text respond directly to climate hazards, while those in *italics* represent measures to increase the adaptive capacity of the population, or to make them more resilient to shocks to their livelihoods in general.
Source: World Bank 2010g.

All of the planned options in the left column represent potential government interventions. The right column represents autonomous measures that people can undertake on their own. These results indicate that more vulnerable groups will not have the resources or skills to undertake all measures they deem a priority. This is particularly true for the hard options that require resources. For example, during participatory scenario development workshops, the most frequently mentioned approach for reducing impacts was the construction of irrigation systems, while the most frequently listed barrier to this was lack of finance. However, in the absence of an enabling economic and political environment, many of the soft options are also challenging to undertake. For example, many participants noted the fact that people would like to diversify income, but there are few opportunities for diversification.

Education and overall knowledge about climate events are also needed so that vulnerable groups can expect disasters to be a constant feature in the future. Specifically, more technical assistance for improving land management practices and access to real-time weather forecasts—effective early warning— will be crucial to enhancing local adaptive capacity. Box 2 describes the social component in Mozambique.

Lessons and recommendations

Several important lessons emerge from the Mozambique work.

- Adaptation entails increasing the climate resilience of current development plans, with particular attention to transport systems and agriculture and coastal development.

BOX 2

METHODOLOGY AND FIELD WORK OF SOCIAL COMPONENT IN MOZAMBIQUE

In Mozambique, the vulnerability assessment included a literature review; the identification of six sociogeographic "hotspots;" and fieldwork in 17 districts across 8 provinces, including 45 focus group discussions, 18 institutional stakeholder interviews, and a survey of 137 households. Fieldwork included the use of participatory rural appraisal (PRA) exercises (village history; focus group discussions of men, women and different age groups; wealth ranking; and community risk mapping), as well as key informant interviews with local government officials, NGOs, and traditional leaders. Household interviews also were undertaken, with 10 per site from different income tiers, with questionnaire modules covering household composition, income sources, agricultural practices, household shocks and coping strategies, past climate adaptation practices, and perceptions about climate change.

In parallel, three participatory scenario development (PSD) workshops were held in Mozambique: one in Xai-Xai, one in Beira, and one national-level workshop in Maputo. PSD workshops began with technical presentations to characterize current climate and socioeconomic projections for the coming decades. Thereafter, participants characterized visions of a "preferred future" for 2050. They considered how climate change could impact this future vision, and then identified autonomous and planned adaptation options necessary to achieve the desired vision. Finally, participants identified prerequisites, synergies, and tradeoffs among their adaptation and development visions and prioritized action for the short, medium, and long term. The PSD component of the social component had a capacity-building emphasis, including participation of national teams in regional training on workshop design and implementation.

- Changes in design standards, such as sealing unpaved roads, can substantially reduce the impacts of climate change even without additional resources.

- The imperative of increasing agricultural productivity and the substantial uncertainties of climate change argue strongly for enhanced investments in agricultural research.

- It is unlikely to be cost effective to protect the vast majority of coastal regions of Mozambique from sea level rise; however, high value and vulnerable locations, such as cities and ports, merit specific consideration, especially those at risk for severe storm surge events.

- "Soft" adaptation measures are potentially powerful. Because the majority of the capital stock in 2050 remains to be installed, land use planning that channels investment into lower risk locations can substantially reduce risk at low cost.

- Viewed more broadly, flexible and more resilient societies will be better prepared to confront the challenges posed by climate change. Hence, investments in human capital contribute both to the adaptation agenda and to the development agenda.

Ethiopia[31]

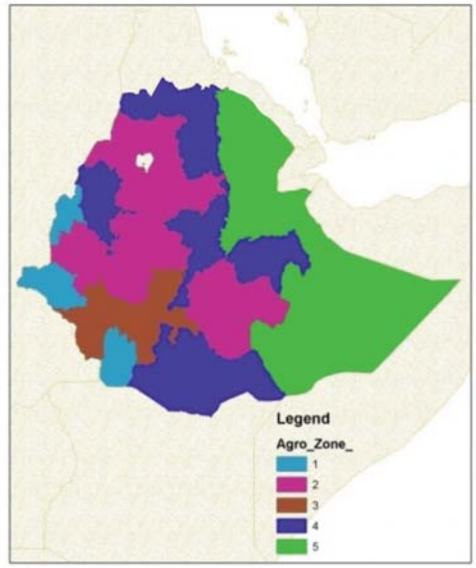
Vulnerability to climate change

With around 75 million inhabitants, Ethiopia is the second most populated country in Sub-Saharan Africa (SSA). The country is divided into five agro-ecological zones (Figure 12). Around 45 percent of the territory consists of a high plateau—comprising zones 2 to 4—with mountain ranges divided by the East African Rift Valley. Almost 90 percent of the population resides in these highland regions (1,500 meters above sea level). Within the highlands, zones 2 and 3 generally have sufficient moisture for the cultivation of key crops, whereas zone 4 is prone to droughts. The arid lowlands in the east of the country—zone 5—are mostly populated by pastoralists.

Ethiopia is heavily dependent on rainfed agriculture. Its geographical location and topography, in combination with low adaptive capacity, entail a high vulnerability to the impacts of climate change. Historically, the country has been prone to extreme weather variability—rainfall is highly erratic, most rain falls with high intensity, and there is a high degree of variability in both time and space. Since the early 1980s, the country has suffered seven major droughts, five of which have led to famines, in addition to dozens of local droughts. Major floods also occurred in different parts of the country in 1988, 1993, 1994, 1995, 1996, and 2006.

FIGURE 12

AGROECOLOGICAL ZONES IN ETHIOPIA



EACC approach and results

To capture uncertainties on future climate, this study utilizes the two "extreme" GCMs used in the global track of the EACC (labeled Wet1 and Dry1), as well as two additional models that are better suited to represent climate model uncertainty in the specific case of Ethiopia (labeled here Wet2 and Dry2). For the baseline (no-climate change scenarios), the analysis uses historical monthly climate data and projects the historical pattern into the future. For the climate change scenarios, stochastic representations of weather variability in each global circulation model (captured through a single draw) are superimposed on the baseline to capture the variability of the future. The scenarios include projections of extreme weather events such as droughts and floods.

Climate projections obtained from these four GCMs suggest an increase in rainfall variability with a rising frequency of both severe flooding and droughts due to global warming. The Dry2 scenario shows reductions in average annual rainfall over 2045–55 of (a) 10–25 percent in the central highlands, (b) 0–10 percent in the south, and (c) more than 25 percent in the north. The Wet2 scenario shows increases in average annual rainfall of (a) 10–25 percent in the south and central highlands, and (b) more than 25 percent in most of the rest of the country. If the Wet2 scenario is accompanied by an increase in the variability of short-duration rainfall intensity, there would be an increased chance of severe episodic flooding caused by storm runoff in highland areas.

The economic analyses focus on three main channels of climatic vulnerability that already affect the Ethiopian economy, and are likely to be of major significance under the climate of the future as well. These channels include (1) agriculture, which accounted for 47 percent of Ethiopian GDP in 2006 and is highly sensitive to seasonal variations in temperature and moisture; (2) roads, the backbone of the country's transport system, which are often hit by large floods, causing serious infrastructure damage and disruptions to supply chains; and (3) dams, which provide hydropower and irrigation and are affected by large precipitation swings.

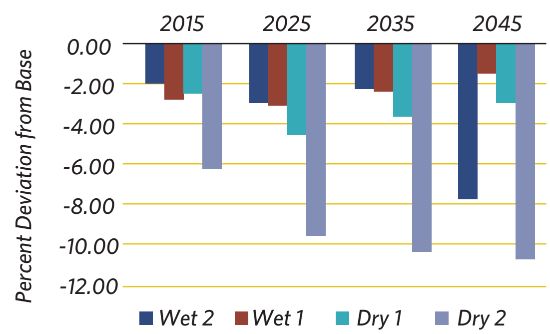
Specifically, changes in precipitation and temperature from the four GCMs were used to estimate

(a) changes in yields for major crops and impacts on livestock, (b) flow into hydropower generation facilities and the consequent changes in power generation, (c) the impact of flooding on roads; (d) the effects of more frequent droughts on government expenditure on vulnerability and food security (VFS); and (e) the loss of irrigation and hydropower due to conflicts among competing demands. The analyses assess deviations in GDP and other variables from the no-climate-change baseline growth path for the four climate change scenarios mentioned above.

Impacts. Economy wide impacts of climate change were assessed using a CGE model. The results of the modeling (Figure 13) suggest a large loss of GDP under the Dry2 scenario (6 percent to 10 percent) that is fairly evenly distributed across the entire time horizon. In contrast, in the case of the Wet2 scenario, the loss of GDP is quite substantial in the 2040–49 decade, because of the costs of coping with damage caused by extreme weather events, especially floods, from the 2030 decade onward. The 10-year average GDP for the final decade is nearly 8 percent lower than the baseline. While these are not forecasts of future climate impacts, they highlight the high degree of vulnerability of Ethiopian agriculture and infrastructure to future climate shocks.

FIGURE 13

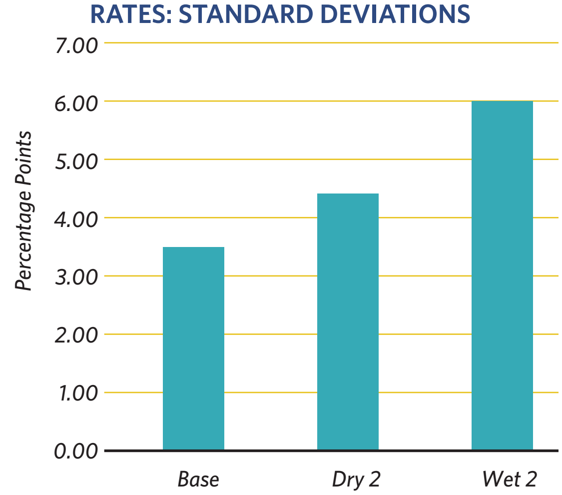
DEVIATIONS OF GDP FROM BASE SCENARIO



Source: World Bank 2010e.

FIGURE 14

AGRICULTURAL YEAR-TO-YEAR GROWTH RATES: STANDARD DEVIATIONS



Source: World Bank 2010e.

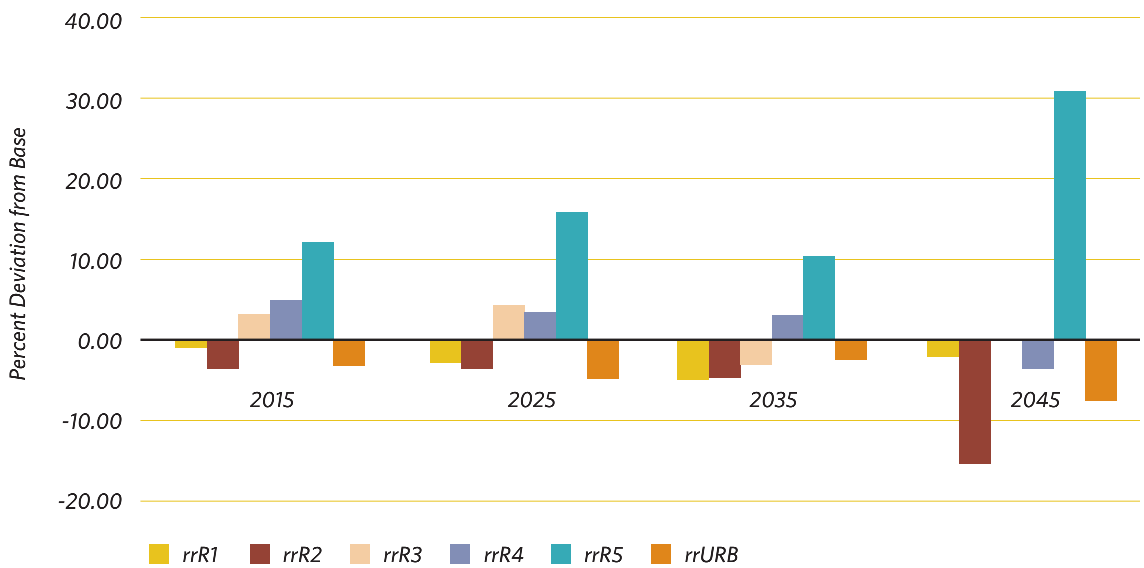
Climate change brings about increased weather variability, which translates into large swings in the growth rate of agriculture GDP, illustrated by the increase in standard deviation compared to the baseline in Figure 14. While the simple means of annual growth rates are similar across the scenarios, high variability leads to significant welfare losses.

Variability in agricultural income tends to affect the poor more, with standard deviation values on average some 10 percent higher than for the non-poor under both wet and dry scenarios. As shown by Figure 154 for the Wet2 scenario, climate change impacts also are likely to vary significantly across regions. The arid lowland zone 5 (R5) derives substantial benefits from the increase in total rainfall, which supports livestock, while relative losses are concentrated in the cereals-based highlands zone 2 (R2) and in urban areas. The latter reflects the downstream consequences of flooding and weather variability. The dry scenarios have reverse impacts, with the arid lowlands and livestock suffering greatly.

In addition to analysis of the three priority sectors (agriculture, roads, and hydropower), the study also analyzed potential conflicts under climate change in the use of water across sectors. A water planning model was used to evaluate the potential interactions among growing municipal and industrial (M&I), irrigation,

FIGURE 15

REGIONAL GDP, DEVIATION FROM BASE, WET2 STANDARD DEVIATIONS



Source: World Bank 2010e.

and hydropower demands under climate change. The model evaluates these inter-sectoral effects between 2001 and 2050, and generates time series of impacts on irrigated agricultural yields and hydropower generation under each of the climate scenarios.

The results suggest that hydropower production is impacted by irrigation and M&I withdrawals. Under the Dry2 scenario, giving priority to agricultural demands results in a loss of hydropower capacity equivalent to 100 percent of the 2000 installed capacity and 10 percent of the hydropower capacity planned by the government for the period 2011–15. If, on the other hand, priority is given to hydropower, up to a billion m^3 of water might be taken away from irrigated agriculture. That would cause a 30–40 percent yield drop in an area of some 250,000 hectares that would be forced to revert to rainfed conditions.

Adaptation. The investment program included in the no-climate-change baseline established in consultation with the government is likely to enhance Ethiopia's resilience to climate change. However, additional efforts are required to attenuate climate change impacts. Adaptation strategies were therefore identified as additions to—or modifications of—current government programs.

More specifically, adaptation in agriculture included increasing the cropland to be equipped for irrigation and investing in agricultural research and development. In the transport sector, adaptation options included increasing the share of paved and hardened roads, as well as "soft" measures such as changes in transportation operation and maintenance, development of new design standards that consider projected climate changes, transfer of relevant transportation technology to stakeholders, and the enhancement of transportation safety measures. Adaptation policy considered in the hydropower sector included altering the scale and timing of planned projects, as well as constraining total downstream flow and irrigation flow.

These strategies were first assessed on a sector-by sector basis. When the full set of economy wide linkages is taken into account, direct plus indirect adaptation costs increase significantly, as indicated in Table 6.

To evaluate its welfare implications, the adaptation strategy was analyzed in a CGE framework by comparing a no-climate-change baseline—reflecting existing development plans—with climate change scenarios reflecting adaptation investments. The main findings are that adaptation (a) reduces, but does not eliminate, welfare losses; (b) that such welfare gains can be achieved at relatively low cost; and (c) that adaptation lowers income variability.

As shown in Figure 16, adaptation greatly reduces the welfare loss due to climate change (measured here by the difference from the baseline of total absorption—GDP plus imports minus exports, discounted over the 40-year time horizon).

Finally, adaptation restores the variability of agriculture GDP growth close to the baseline scenario (Figure 17).

While the benefits of adaptation investments are significant, they do not fully offset the negative impact of the climate change scenarios. Two options were explored to close the "welfare gap" caused by climate change. The first is to estimate the "residual damage costs" as the transfers (in $) that would be required to completely offset the loss of absorption from CC shock, after implementing adaptation investments. Closing the "welfare gap" through residual compensation would entail mobilizing significant resources compared to direct project-level adaptation costs (Table 7).

The second approach is to include an additional labor-upgrading program in the adaptation strategy. In this scenario, 0.1 percent of rural unskilled labor is assumed to be transferred to the urban region, with additional upgrading so that all the urban labor categories, skilled and unskilled, grow uniformly faster than in the base run. When tested under the Wet2 scenario, an adaptation strategy including such a labor-upgrading program appears to be able to more than offset the negative impacts of climate change.

While no information was available within the time frame of the analysis to properly cost the skill upgrading program, this finding points to the significant potential benefits of accelerating the diversification of the economy away from highly climate sensitive sectors such as agriculture. In the Wet2 scenario, for any value of the program cost below $0.4 billion/ year, a development strategy including a skill upgrading program like the one considered here would appear to be preferable to the residual compensation approach.

TABLE 6

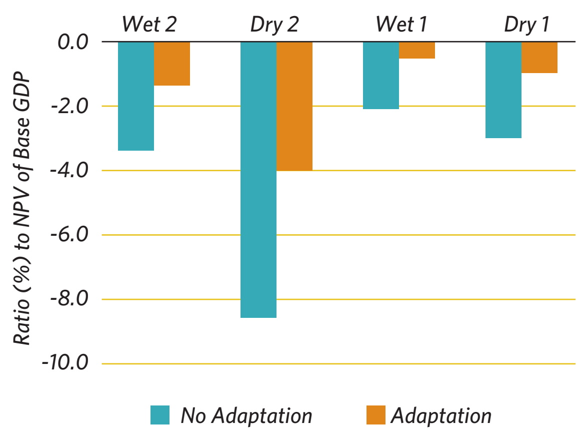
ADAPTATION COSTS *(annual average, 2010-50, $ billions)*

	Direct, sector level costs	Indirect costs	Total costs
Wet2	0.19	0.60	0.79
Wet1	0.17	0.77	0.94
Dry1	0.16	2.30	2.46
Dry2	0.26	2.55	2.81

Source: World Bank 2010e.

FIGURE 16

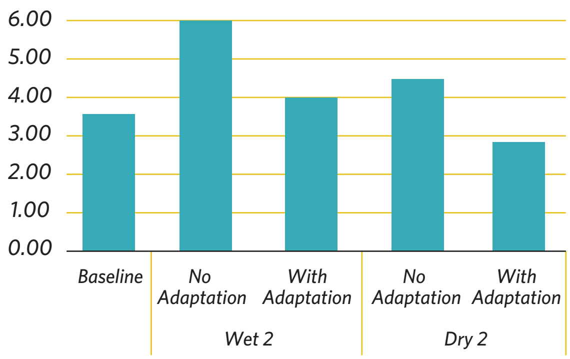
NET PRESENT VALUE (NPV) OF WELFARE DIFFERENCES



Source: World Bank 2010e.

FIGURE 17

STANDARD DEVIATION OF YEAR-TO-YEAR AGRICULTURE GDP GROWTH RATES, WITH AND WITHOUT ADAPTATION



Source: World Bank 2010e.

TABLE 7

ADAPTATION COSTS AND RESIDUAL DAMAGE *(annual average, 2010–50, $ billions)*

Scenario	Adaptation costs	Residual damage	Total
Wet 2	0.79	0.43	1.22
Wet1	0.94	0.81	1.75
Dry1	2.46	1.52	3.97
Dry2	2.81	3.03	5.84

Source: World Bank 2010e.

Local-level perspectives on adaptation. Land and water management are central concerns in Ethiopia, which is subject to extremes of drought and floods. Vulnerable groups identified through community discussions included asset-poor households with very limited means of coping with climate hazards, the expanding group of rural landless who lack income opportunities, the urban poor living in flood-prone areas of cities, and the elderly and the sick due to their limited adaptive capacity. Women and children left behind as male adults migrate for employment during drought-related production failures were also identified as vulnerable during and after extreme events. Other vulnerable groups identified included communities living on already degraded lands, and pastoral communities who face severe conflicts over natural resources (especially access to land for herd mobility) with agriculturalists and the state.

Local participatory scenario development (PSD) workshops identified soil and forest rehabilitation, irrigation and water harvesting, improved agricultural techniques and drought-resistant varieties, education, and land use rights for pastoralists as adaptation preferences. Regional development and the need for structural shifts toward service and industry sectors to improve employment outcomes were also raised as issues. At the national level, similar options were identified, along with a focus on early warning systems and flood control measures, agricultural technology, finance and market development, renewable energy, and urban planning. The adaptation options identified at local and national levels generally aligned with the natural resource and agriculture focus in the NAPA, which also identifies needed investments in crop insurance, wetlands protection, carbon livelihoods, agroforestry, and anti-malaria initiatives.

Lessons and recommendations

The findings of this analysis suggest that impacts of climate change will be quite significant, particularly as Ethiopia approaches the middle of the century. The magnitude of the impacts remains considerable, irrespective of whether the climate of the future will be wetter or drier. Given the large uncertainty on future climate outcomes, the approach to enhance Ethiopia's climate resilience should be couched in terms of a gradual, adaptive, and learning paradigm. Such an approach could be articulated for both the shorter term—including the implementation of the Growth and Transformation Plan (GTP) recently issued by the government—and for the long term.

Shorter term (up to 2015). By and large, the Growth and Transformation Plan supports a number of actions that—by boosting growth—will contribute to the enhancement of Ethiopia's resilience to climatic shocks. Robust growth based on infrastructure investment is likely to be the first line of defense against climate change impacts. Relatively small deviations from the ambitious investment targets set forth by the government for roads, dams, hydropower, water management, and irrigation would significantly increase long-term vulnerability to climate change and thus make adaptation costlier.

However, there are a number of additional issues that the government could consider to further enhance the contribution of GTP to Ethiopia's climate resilience—and thus, ultimately, to the ability of the country to support sustained, long-term growth.

Agriculture. The GTP purports to "continue the ongoing effort of improving agriculture productivity in a sustainable manner so as to ensure its place as the engine of growth." The analysis of this report indicates that agricultural production as an engine of growth is vulnerable to climate change and climate variability. While the more pronounced effects on crops and livestock are likely to materialize in later decades, efforts to enhance the resilience to climate shocks of crop yields and livestock production should be stepped up as soon as possible, particularly on account of the lead time needed to strengthen research systems, and to transfer and adapt findings from the lab to the field.

Investments in improved agricultural productivity—such as watershed management, on-farm technology, access to extension services, transport, fertilizers and improved seed varieties, and climate and weather forecasting—will enhance the resilience of agriculture, both to droughts and to waterlogging caused by floods. National and local actions will need to be supported by international efforts—for example, through the CGIAR system—to develop climate resilient agricultural technologies, given the global public good nature of these innovations.

Road infrastructure. The GTP aims to expand the coverage and enhance the quality of infrastructure: "Focus will be given to the development of roads, railways, energy, telecommunication, irrigation, drinking water and sanitation and basic infrastructure developments; (…) With regard to roads, rural roads will be constructed on all regions and all rural kebeles will be connected (through) standardized all weather roads with main highways."

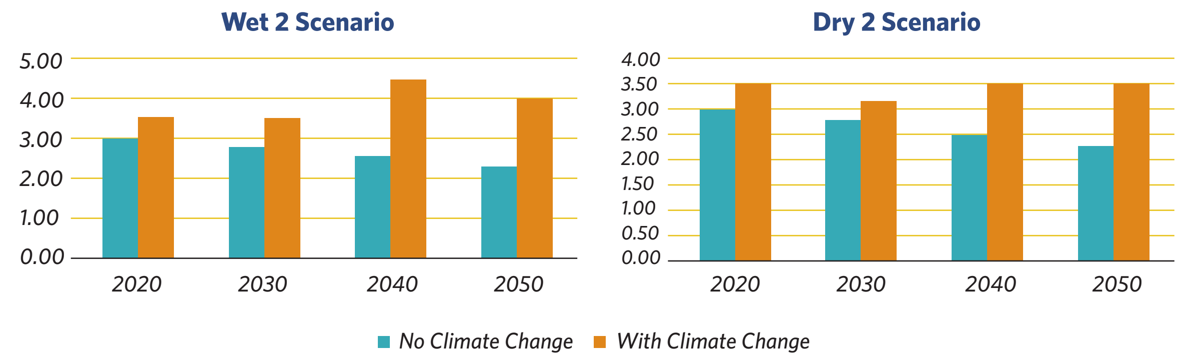
Modeling results show that existing infrastructure design standards—that is, the level of prevention against extreme events such as local and regional flooding—are inadequate to address current climate variability and will impact economic growth rates in the near to medium term. Results from climate change analyses show this issue is likely to become worse in the medium to long term. The government should consider enhancing infrastructure design standards as soon as possible.

Even under current climate, the direct benefits—in terms of increased lifetime—of roads designed following higher standards outweigh the corresponding costs in a discounted benefit/cost analysis. The case for improved design standards is even stronger under climate change, irrespective of climate outcomes: the benefit/cost ratio of adopting higher design standards is 17 to 75 percent higher than in the baseline under the Wet2 scenario, and 16 to 55 percent in the Dry2 scenario (Figure 18). In addition, there are important indirect economy wide benefits: a more climate-resilient road network can avoid costly disruptions of communications links and supply chains that increased flood frequency might bring about.

Energy. Current water resources and Ethiopian topography indicate an overall potential of more than 30,000 megawatts in economically viable hydropower generation capacity. The GTP approach is to focus on "the development of water and wind energy options to fulfill the energy demand of the country," with targets for hydropower of 6,000 to 8,000 MW in additional generation capacity. The hydropower analysis of this report (conducted at the monthly scale, which is adequate for sector-wide planning purposes, although not for plant-level design and operation) provides support, from a

FIGURE 18

BENEFIT/ COST RATIO OF UPGRADING ROAD STANDARDS



Source: World Bank 2010e.

climate change perspective, to the GTP targets. The projects likely to go online in the next 5 years have very low risk of being impacted by climate change.

While in the longer term (see below) hydropower development will become increasingly more climate sensitive, projects in the current pipeline are likely to be less vulnerable to shocks as the overlap between their life span, and the time when stronger climate change effects will materialize, is relatively limited. Some climate change scenarios actually project an increase in Ethiopian runoff, resulting in larger volumes of hydropower generation, and thus making the case for investment in hydropower stronger.

In the nearer term, the economics of hydropower investments will be influenced less by climate, and more, on the demand side, by the evolution of domestic and external markets. A sustained expansion of national and foreign demand for power will be key to support the expansion of Ethiopia's hydropower sector, which in turn will be vital to support the country's accelerated economic growth.

In the short run, expansion of hydropower generation should be accelerated as a way to support growth and to facilitate the economy's transition from being highly agriculture-dependent to having a broader productive base in industry and services. Given the vulnerability of the agricultural sector to current climate shocks (let alone those to be expected in the future), strengthening of the electricity sector, and in particular the promotion of regional and Africa-wide power grids to receive Ethiopia's excess power, should be a priority in the investment strategy. Strengthened hydropower development can both increase near-term economic growth and make the energy system more climate-resilient. Additional reservoir storage distributed over the country also will provide more reliability and protection from regional droughts.

Medium to long term. As Ethiopia looks into the next stages of development—starting with preparation of the next growth plan following the GTP 2011–15—it might want to evaluate more closely the implications of climate change for its overall policies and infrastructure development programs. Early planning for the more severe climate impacts of mid-century is desirable, so as to avoid locking the country into a climate-vulnerable development trajectory, particularly when it comes to economic processes with a high

degree of inertia, or investment decisions concerning infrastructures with a long life span.

Due to the uncertainty of future climate, a risk-based investment planning approach should be adopted. Robust decision-making principles are needed to minimize the "regrets" of climate-sensitive decisions. As climate shocks become more frequent and severe, the "opportunity costs of capital" invested in projects and programs that are viable only under a limited set of climate outcomes becomes too large. Some key areas for consideration to develop a climate risk management approach to support long-term development include the following.

Macroeconomic management. Historically, the Ethiopian economy has been vulnerable to climate fluctuations. The analysis of this report shows that climate variability will increase under all scenarios. Since agriculture (the economy's most climate sensitive sector) is likely to remain for some time one of Ethiopia's main engines of growth, climate-induced shocks will continue to be a threat to macroeconomic stability because of the impacts on income, employment, fiscal revenues, capital formation, the drain on government expenditures, and aid flows to support disaster relief.

Under climate change, renewed efforts will be necessary to buffer the economy from more frequent and/ or severe climate shocks. These include strengthening social safety nets, access to relief funds, drought early warning systems, crop insurance programs, grain banks, and strengthening infrastructure design.

Promote diversification. In the longer term, however, accelerated diversification of income and employment sources away from climate-sensitive sectors such as agriculture is likely to become increasingly important under a more erratic climate. It be should explored in closer detail, particularly because it holds promise to be a cost-effective way to eliminate residual welfare damage caused by climate change.

The government may want to look into ways to accelerate the absorption of the rural labor force into non-agriculture activities, including through skills-upgrading programs and encouragement of growth poles around medium-size municipalities.

Evaluate the climate resilience of large infrastructure projects. As we move toward mid-century, the range of possible climate futures broadens to encompass markedly different "wet" and "dry" scenarios. This has implications for the optimal timing of dams and other investments in water infrastructure, which is likely to be quite sensitive to climate outcomes. Large projects of this type should be subject—on account of the large capital outlays involved—to careful climate-robustness tests.

To adequately inform the design of subsequent generations of water infrastructure projects, investments in enhancing national hydro-meteorological services, data collection, and analysis are crucial to assist identifying which climate change path Ethiopia is actually on, and to provide inputs to the adaptive management process for resource management. Better data on hydro-meteorological processes, and stronger capacity to analyze and model the data, is key to making more informed decisions on issues such as the number of hydropower plants, the design of individual plants, and the operation of the grid.

Proactively address conflicts in water uses. Under "dry" future climate scenarios, competition among water users —municipal and industrial consumption, hydropower generation, and irrigation—might become more acute, particularly in certain river basins. The availability of water to downstream riparian countries might also be affected.

Given the significant pay-off of addressing internal and transboundary conflicts on water use before they arise, the government might want to consider investments in river basin planning systems and institutional arrangements that can facilitate information sharing, dialogue, and dispute resolution.

Ghana[32]

Vulnerability to climate change

Ghana's economy is particularly vulnerable to climate change and variability because it is heavily dependent on climate-sensitive sectors such as agriculture, forestry, and hydropower. The agricultural sector, in particular, is highly vulnerable because it is largely rainfed with a low-level of irrigation development. The country's 565km coastline is inhabited by about a quarter of the population and is the location of significant physical infrastructure.

The inheritance system, local governance and customary law, and multiple forms of land tenure systems disproportionately harm both women and migrants' adaptive capacity. Rural-rural migrants, for example, forgo income by not planting long-gestation cash crops for lack of a secure title in receiving areas. Seasonal floods, which are indicated by projected climate change scenarios, could cause significant impacts in highly populated urban and peri-urban areas in Greater Accra, particularly given poor housing and the possibility of disease outbreaks in the "*zongo*" slums dominated by in-migrants.

In line with the approach taken in the global track study, climate projections from the NCAR and CSIRO models were used to generate the "Global Wet" and "Global Dry" scenarios for the Ghana case study. In addition, the climate projections from the two GCM/SRES combinations with the lowest and highest CMI for Ghana were used to generate a "Ghana Dry" and a "Ghana Wet" scenario (Table 8). Note that in the case of Ghana, the globally "wettest" GCM actually projects a drier future climate for Ghana than the globally "driest" GCM under emission scenario A2.

The projections indicate fairly wide fluctuations in annual temperatures in all four Ghana agroecological regions (northern savannah, southern savannah, forest, and coastal) for all the four scenarios. However, the trend over the period 2010–50 indicates warming in all regions, with temperatures increasing the most in the northern savannah region—with increases of up to 2.2–2.4°C, leading to average temperatures as high as 41°C—while also presenting the widest range of temperature variability (5.7°C range). All agroecological regions show significant precipitation variability compared to the baseline scenario. The coefficient of variation of annual precipitation in Ghana varies between -9 percent (global wet scenario) to -14 percent (Ghana dry scenario).

As shown in Figure 19, there may be wide variations in stream flows and runoff changes. The southwestern part of Ghana is expected to experience increases in runoff under both Ghana specific scenarios, with the opposite occurring with the Black Volta basin. The fluctuations in stream flows and runoffs, particularly in the Volta River, increase the risk of floods and/or droughts in urban and rural areas. Given that Ghana has very little control over the upper streams of rivers across its borders in Burkina Faso and Togo, there is a need for regional cooperation in the management of water resources among the neighboring countries sharing the Volta basin.

TABLE 8

GCM SCENARIOS FOR THE GHANA CASE STUDY

Scenario	GCM	SRES	CMI Deviation
Global Wet	ncar_ccsm3_0	A2	-17%
Global Dry	csiro_mk3_0	A2	9%
Ghana Wet	ncar_pcm1	A1b	49%
Ghana Dry	ipsl_cm4	B1	-66%

Source: World Bank 2010f.

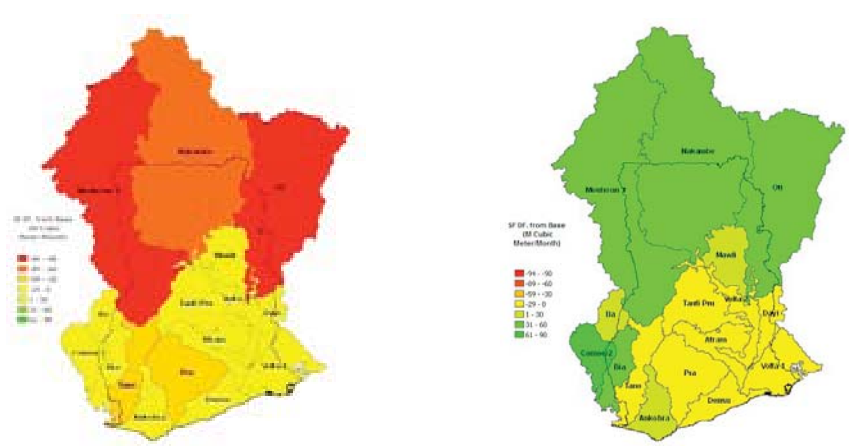
EACC approach and results

Impacts. All four GCM scenarios suggest significant adverse economywide effects, which become stronger toward 2050. Although there is considerable variation in real GDP growth over the simulation period, the overall trend relative to the baseline is clearly downward. Toward 2050, annual real GDP is projected to be 1.9 to 7.2 percent lower than in the baseline scenario without anthropogenic climate change. Real household consumption also declines relative to the base scenario in all the four climate change scenarios analyzed in this study.

FIGURE 19

SURFACE FLOW AVERAGE DIFFERENCE FROM THE NO-CLIMATE-CHANGE SCENARIO, 2010–50
(million m3/month)

Ghana Dry Scenario (ipsl_cm4-B1) *Ghana Wet Scenario (ncar_pcm1 A1b)*



Source: World Bank 2010f.

In comparison to the baseline growth path without climate change, the output of the agricultural sector is estimated to decline by between 10.1 percent (Global Wet) and 3.0 percent (Ghana Wet) by 2050 (Figure 20). The projections for cocoa show considerable variation across the climate scenarios, regions, and decades. Under the Ghana Wet climate, cocoa production is projected to experience significant adverse effects, while under the Global Dry and Global Wet climates the impacts turn out to be predominantly positive from a nationwide perspective. The variance of annual cocoa yields rises across all climate change scenarios.

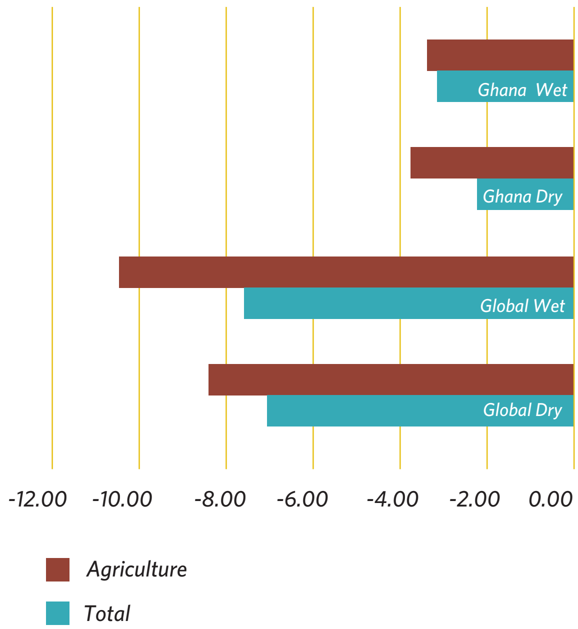
Ghana's coastal zone is of immense significance to the economy. There are five large cities located in the coastal zone and about a quarter of the population lives in this area. It is estimated that over 240,000 people living in the coastal zone are at risk of seal level rise (Ghana Statistical Services, 2008). Like most coastal cities around the world, Ghana's coastal areas are vulnerable to extreme events above the current defense standards of structural protection, and are especially vulnerable to coastal flooding. Additional threats include coastal erosion and reduction in freshwater resources in deltas and estuaries.

The total cost of damage from flooding, land loss, and forced migration is estimated to reach $3.7 million/yr by the 2020s, rising to $6.5 million/yr by the 2040s using the high sea level rise scenarios. Damage costs are estimated at $4.7 million/yr for the 2040s using the low sea level rise scenario.

Ghana's water and energy sectors have already shown signs of vulnerability to climate change, particularly the effect of highly variable precipitation patterns on hydropower production. The 1980–83 drought not only affected export earnings through crop losses, but also caused large-scale human suffering and called into question the nation's continued dependence on hydroelectric power. By 2050, the annual average output of the water and energy sector is expected to decline to within a range of $2.19 billion to $2.26 billion from a 2050 baseline output of $2.33 billion. This represents a decline of between 3 and 6%.

FIGURE 20

DEVIATION OF REAL TOTAL AND AGRICULTURAL GDP FROM BASE, TERMINAL YEAR (%)



Source: World Bank 2010f.

Adaptation. Adaptation actions were considered in four key sectors in Ghana—roads, agriculture, hydropower, and coastal. In each case it is important to look at the resource envelope available to fund adaptation, which can begin with the existing government budget (or projected budget), and increase to a higher level if one assumes that funding will be available from different sources.

Road Transport. Adaptation of road infrastructure is considered in order to make the road network more climate-resilient at no additional cost compared to the baseline. That is, the baseline road infrastructure budget is just reallocated through changes in road design standards. This is more costly initially and reduces the amount available for the expansion

of the road network, but at the same time there is less climate change damage to the road network later on. The economywide simulation analysis assumes that the same road infrastructure adaptation strategy is adopted in all adaptation scenarios under consideration.

Agriculture. The whole adaptation resource envelope considered is spent on gradual expansion of irrigated land area from 2012 onwards. The assumed upfront investment cost of irrigation is $18,000 per ha, taking account of Ghana-specific cost estimates for recent and planned irrigation projects, plus the need for complementary investment in water harvesting etc, as this strategy requires the irrigable land area to expand. For example, under the Ghana Dry scenario, the share of irrigated land rises gradually from less than 0.4 to 23 percent of the current total cultivated area. The resulting average annual factor productivity increase for crop agriculture as a whole is an additional 0.54 percent above baseline productivity growth. This scenario can also be interpreted as representing other productivity-rising agricultural adaptation measures with a comparable yield impact per dollar spent.

Energy. In this sector, part of the available resource envelope is spent on additional investments in hydropower relative to the baseline, minimizing negative climate change impacts on power generation. The remaining part of the resource envelope is spent on agricultural productivity improvements. The present value of the additional power investment up to 2050 is estimated to be $859 million, which reduces the amount available for agricultural investment. For example under the Ghana Dry scenario, 32 percent of the resource envelope goes to power and the rest to agriculture.

Coastal Zone. Coastal adaptation analysis and options have been used as an example for now, while a more detailed analysis is being completed using the DIVA Model and SRTM 90-m resolution data. The largest cost component is the construction of sea dikes, estimated to be about $87 million per year under a high sea level rise scenario, and $30–34 million a year under a low sea level rise scenario. Annual maintenance costs of the sea dikes under the high sea level rise scenario will be about $9 million in the 2010s, rising to $35 million by the 2040s. Total annual adaptation costs for the coastal zone are estimated to be $19–$156 million. These results are based on a partial equilibrium model (assuming no interaction between the coastal sector and the rest of the economy) and are not part of the CGE adaptation analysis. They also do not include other adaptations measures, such as protection for the fishery industry. Compared to 1990, sea levels were assumed to gradually increase from 4 cm in 2010 to 15.6 cm by 2050 using the low sea level rise scenario (and from 7.1 cm to 37.8 cm using the high sea level rise scenario).

Macroeconomic/integrated analysis. In the dynamic CGE analysis, it is assumed that the maximum resource envelope available for adaptation measures over the simulation period (2010–50) is equal to the present value of the aggregate welfare loss due to climate change in the absence of adaptation measures (Table 9). From an economywide perspective, these figures represent the lump-sum income transfers Ghana would have to mobilize from external sources in order to be fully compensated for the economic impacts of climate change.[33] Similar to the other case studies for Africa, the CGE analysis also includes an adaptation scenario in which the resource envelope available for adaptation measures is spent on additional broad-based education and training that raises labor productivity across all skill groups.

Results from simulations. Table 9 shows that in the absence of adaptation, aggregate real welfare losses up to 2050 will range (in present value terms) from $2.7 billion (Ghana Dry) to $13.1 billion (Global Dry). In annualized values, these estimates range from $157 million (Ghana Dry) to $765 million. On a per capita basis, they amount to $6.50 and $31.46 for Ghana Dry and Global Dry, respectively. The equivalent annual value of the real welfare impacts with no adaptation range from $157.9 million (Ghana Dry) to $764.5 million (Global Dry). These results translate to an annual equivalent per capita impact that range from $6.5 (Ghana Dray) to $31.46 (Global Dry).

Table 10 reports deviations of the present value of welfare from the baseline for the three alternative adaptation strategies (these strategies are built in combination with the road adaptation strategy). In order to generate a meaningful comparison across alternative adaptation investment paths, the total resource envelope for adaptation investments is the same across the different strategies (but different across the four climate scenarios).

Changes in road design standards alone provide significant reductions in welfare losses with the notable

TABLE 9

REAL WELFARE IMPACTS WITH NO ADAPTATION INVESTMENTS

Climate Scenario	Present value of lost welfare ($ Billion)	Equivalent annual value ($ Million)	Annual equivalent per capita
Global Dry	13.118	764.5	31.46
Global Wet	10.095	588.3	24.21
Ghana Dry	2.709	157.9	6.50
Ghana Wet	4.050	236.0	9.71

Notes: (i) Discount rate = 5%. Welfare is measured by real absorption, the constant-price value of domestic and imported final goods and services available for household consumption, government consumption, and capital stock investment.
Second column: constant annual flow with same present value. Third column: second column / 2010 population (UN medium projection: 23.4 Million).
Source: World Bank 2010f.

TABLE 10

DEVIATIONS OF REAL WELFARE FROM BASELINE UNDER ALTERNATIVE ADAPTATION STRATEGIES *(present value, in $ billions)*

			Adaptation Investment in		
No Adaptation scenario		Road Design	Agriculture	Hydro /Agric.	Education
Global Dry	-13.118	-10.308	-0.121	-0.941	-2.090
Global Wet	-10.095	-5.854	-2.973	2.116	0.584
Ghana Dry	-2.709	-3.009	-1.193	-1.782	-1.308
Ghana Wet	-4.050	-0.766	1.936	1.358	1.795

Note: Key assumption: Resource envelope is externally financed and does not reduce Ghana's baseline investment path.
Source: World Bank 2010f.

exception of Ghana Dry. In this scenario, the reallocation of funds from road network expansion to road hardening slows down road network growth without generating net benefits, because climate shocks to the road system turn out to be very mild. Thus, this result suggests, that in the case of Ghana (and contrary to the case of Mozambique), road design change is not an unequivocal no-regret adaptation measure.

The simulated adaptation investments in agriculture in combination with road design slightly overcompensate for the climate change damages in a macroeconomic sense under Ghana Wet. This means that in this case the total cost of returning aggregate welfare to the baseline is actually lower than the assumed adaptation investment expenditure of $4.05 billion. In the other three scenarios, the agriculture-focused strategy restores aggregate real absorption close to the baseline level, but the negative signs in Table 9 indicate some residual damage. In these cases it would appear advisable to channel the investments selectively to crops and regions with high expected returns and use the remaining part of the resource envelope for lump-sum compensation payments.

The comparison of the combined hydropower/agriculture adaptation strategy with the pure agriculture adaptation strategy suggests that only under the Global Wet climate scenario is it preferable to divert a fraction of the adaptation envelope from agriculture to hydropower investments. This is the climate scenario with the strongest adverse impacts of climate change on hydropower generation.

Finally, the results for investment in education serve to represent an adaptation strategy that does not directly address climate change impacts in particular sectors, but is aimed at spurring growth performance in general in order to reduce vulnerability to negative climate change shocks. The illustrative results reported here suggest that a broad-based education strategy is cost-effective under the wet scenarios but not under the dry scenarios. As with the strategy based on agricultural investments this argues for a more targeted education-based adaptation strategy, targeting sectors where labor productivity gains are likely to be large.

Local-level perspectives on adaptation. While the economic analyses prioritized improved road infrastructure, energy, and regional integration (including transboundary water management), these issues were not raised in the social investigation. However, identified adaptation options in the areas of agriculture and coastal zone development did largely echo those raised by participatory scenario development (PSD) stakeholders and respondents in fieldwork. In addition, adaptation preferences expressed in the PSD workshops largely coincided with priority action areas in the National Adaptation Plan of Action (NAPA) as well as related climate strategy priorities in-country. Discussions also focused on the need for improved governance, social protection, land tenure, and training and education in order to accelerate development and build resilience to climate change.

Interestingly, local participants in the zonal workshops were more concerned with declining living standards due to degraded natural resources and with the lack of public services as drivers of vulnerability than with exposure to climate-related events. Specific priorities included a focus on improving agricultural production techniques and land management practices; managing migration; closing the gap in gender equity; and strengthening governance and institutional structures. National workshop participants also focused on adaptation measures that would offer cobenefits with sustainable development, yet preferred adaptation measures that were often more expensive and left little room for integration of inputs of local communities.

Lessons and recommendations

In view of the expected change in temperature and precipitation, strategic planning in Ghana should take regional climate change variability into consideration. At the national level, the National Development Planning Commission's draft Medium-Term National Development Policy Framework for 2010 to 2013 lays out the priorities of the government installed since February 2009. This framework was used to establish the baseline scenario of development upon which this study is based. As the government moves to implementation of this new plan, recommendations from adaptation options presented in this study should be considered.

For each of the ten regions in Ghana, the possible sets of climate change impacts described need to be addressed through the Regional Coordinating Councils, and at District-level through District Development Plans. Specific needs in each sector are discussed below. As in the other countries of the EACC study, policy recommendations for adaptation to climate change go hand-in-hand with "good" development policies:

Agriculture: Invest in R&D related to impacts of climate change on crops and livestock products and pest control, as well as early-maturing varieties; improve water storage capacity to utilize excess water in wet years; and improve agricultural extension services and marketing networks. Other required measures include construction of small to mid-size irrigation facilities, improvement of the land tenure system, and improved entrepreneurial skills to generate off-farm income.

Roads: Proper timing of road construction (for example, during dry season); routine and timely road maintenance; upgrade road design specifications, including choice of materials; and consider drainage and water retention, road sizes, and protection of road shoulders.

Energy: Diversify current thermal and large hydro sources to include renewable sources such as the planned mid-size hydro Bui Dam and mini hydro.

Coastal Zone: Improve shoreline protection in areas with economically important urban and port infrastructure; upgrade peri-urban slums and control development of new ones; protect, manage, and sustainably use coastal wetlands; and review Ghana's coastal development plans to take into consideration climate change adaptations, including coastline and port protection, flood protection, and coastal communities and fishery industry protection.

Social: Improve social safety nets, community-based resource management systems, and disaster preparedness. It is also necessary to accelerate the decentralization process to devolve decision making to the local level to promote local-level adaptation and preparedness.

West Africa Regional Integration: Ghana needs to enhance dialogue with neighboring countries regarding the management of shared water resources, and explore possible regional water resource management coordination in order to effectively deal with the challenges of climate change such as droughts, floods, and possible regional migration.

Bangladesh[34]

Vulnerability to climate change

Bangladesh is one of the most vulnerable countries in the world to climate risks. Two-thirds of the nation is less than 5 meters above sea level and is susceptible to river and rainwater flooding, particularly during the monsoon. Due to its location at the tail end of the delta formed by the Ganges, Brahmaputra, and Meghna (GBM) rivers, the timing, location, and extent of flooding depends on the precipitation in the entire GBM basin, not just on the 7 percent of the basin that lies within the country. Nearly 80 percent of the country's annual precipitation occurs during the summer monsoon season, when these rivers have a combined peak flow of 180,000 m^3/sec, the second highest in the world. Once every three to five years, up to two-thirds of Bangladesh is inundated by floods that cause substantial damage to infrastructure, housing, agriculture, and livelihoods. Low-lying coastal areas are also at risk from tidal floods and severe cyclones. On average once every three years, a severe cyclone makes landfall on the Bangladesh coastline, either before or after the monsoon. The largest damages from a cyclone result from the induced-storm surges, sometimes in excess of 10 meters. Bangladesh is on the receiving end of about 40 percent of the impact of total storm surges in the world. Crops and the livelihoods of the rural poor in low-lying coastal areas are also devastated by saline water intrusion into aquifers and groundwater and land submergence. In addition, seasonal droughts occasionally hit the northwestern region.

Climate-related disasters continue to result in large economic losses, reducing economic growth and slowing progress in reducing poverty. The direct annual costs from natural disasters to the national economy—in terms of damages to infrastructure and livelihoods and losses from forgone production—have been estimated at 0.5 percent to 1 percent of GDP. These statistics do not include the significant loss of life that has also occurred during these events. These damages and losses are geographically concentrated in areas that also have higher concentrations of the poor, who are the most vulnerable and have the lowest capacity to address the impacts, hence are also affected disproportionately. They live in thatch or tin houses that are more susceptible to direct damages from cyclones, storm surges, and floods. Additionally, most rural households depend on weather-sensitive sectors—agriculture, fisheries, and other natural resources—for their livelihood. Destruction of their assets and livelihoods leaves the poor with a limited capacity to recover.

The importance of adapting to these climate risks to maintain economic growth and reduce poverty is thus very clear (Figure 21). Since the sixties, Bangladesh has invested $10 billion on disaster reduction measures, both structural and non-structural, and enhanced its disaster preparedness system (Box 3). These measures have significantly reduced damages and losses from extreme events over time, especially in terms of deaths and injuries. In addition, public sector agricultural support services have enabled rural households to reduce exposure to these risks and to maintain their livelihoods. For instance, they have adapted to "normal floods" by switching from low-yielding deepwater rice to high-yielding rice crops, resulting in increased agricultural production. However, it is the low-frequency, high-magnitude floods that have adverse impacts on livelihoods and production, particularly of the poorest and most vulnerable. The cost of strengthening and expanding these measures to further reduce the risks from existing climate-related hazards is less than the avoided damages.

A warmer and wetter future climate that goes beyond historical variations will exacerbate the existing climate risks and increase vulnerability by increasing the extend and depth of inundation from flooding and storm surges and by reducing the arable land due to sea level rise and salinity intrusion. The median predictions from these models are for warming of 1.55°C and an increase in precipitation of 4 percent by 2050. The median temperature predictions exceed the 90^{th} percentile of historical variability across GCMs during the summer months by the 2030s. Unlike temperature changes, the predicted changes in precipitation (and discharges) through 2050 are not distinct from the historically observed variability for all months and seasons, reflecting the large historical variability in precipitation levels and the even larger uncertainty in future precipitation predictions. Current trends for water levels in coastal areas suggest a rise in sea levels of over 27 cm by 2050. Further, the increased severity of cyclones in the Bay of Bengal is expected to increase risks of inundation in coastal areas by 2050.

EACC approach and results

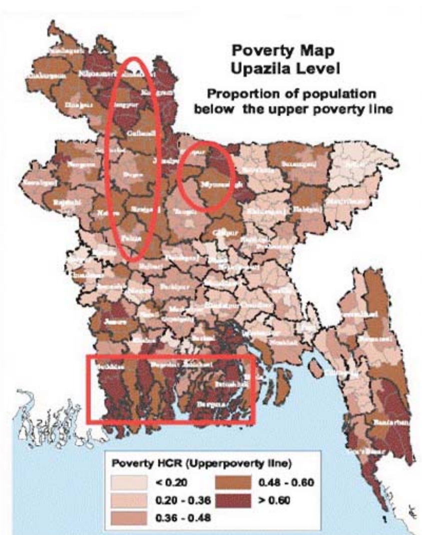
The Bangladesh case study builds on a parallel study on the impacts of climate change and food security (Yu et al. 2010) and focuses on two specific climate hazards: storm surges induced by tropical cyclones and inland flooding. The study (a) estimates the additional damages that would result in key economic sectors and in the overall economy if no additional adaption measures are put in place to address current and expected hazards, and (b) estimates the costs of additional investments that would be needed to protect against these hazards. The study also analyzes the differential impact of climate change on vulnerable populations and how they cope with such impacts.

Tropical cyclone-induced storm surges. The potential damages and the adaptation cost necessary to

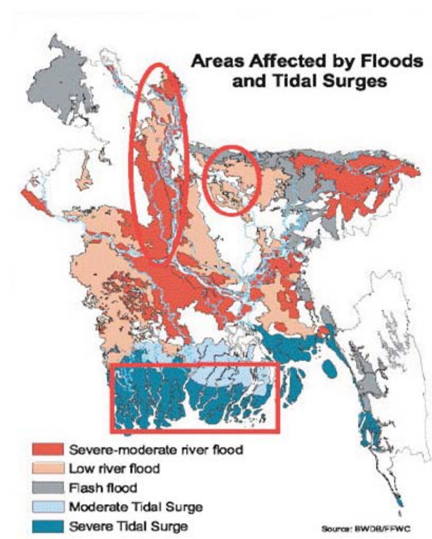
FIGURE 21

MAPS OF POVERTY, FLOODING AND TIDAL SURGES

Poverty Map



Map of Flooding and Tidal Surges



Source: BBS, World Bank, WFP 2009.

BOX 3

PAST EXPERIENCE ADAPTING TO EXTREME CLIMATE EVENTS IN BANGLADESH

Given its vulnerability to extreme climate events, a number of adaptation measures are already in place in Bangladesh, including both hard infrastructure as well as soft policy measures combined with communal practice. Hard infrastructure has included coastal embankments, foreshore afforestation, cyclone shelters, early warning systems, and relief operations; soft measures have included design standards for roads and agricultural research and extension, such as the introduction of high-yielding varieties of *aman* and *boro* rice crops. Both types of adaptation measures have made the country more resilient in facing hazards, as evidenced by the decline in the number of fatalities and the share of GDP lost as a result of these events.

Coastal embankments. In the 1960s and 1970s, 123 polders (including 49 facing the sea) were constructed to protect low-lying coastal areas. Polders have been an effective measure for protection against storm surges and cyclones, but breaching of embankments has been a recurring phenomenon due to overtopping, erosion, inadequate O&M, and other problems.

Foreshore afforestation to protect sea-facing dikes. Foreshore afforestation is a cost-effective way to reduce the impacts of cyclonic storm surges on embankments by dissipating wave energy and reducing hydraulic load on the embankments during storm surges. The limited damages from Cyclone Sidr (2007) and Aila (2009) have been partially attributed to foreshore afforestation. Government officials have recommended that the existing forest belt include at least a 500-meter wide mangrove forest. Currently 60 km of forest belts exist on the 49 sea-facing polders, span a total combined length of 957 km, leaving over 90 percent of the polder length unprotected.

Cyclone shelters. Cyclone shelters are currently essential to protect human lives and livestock during cyclones hitting the coast. During the Cyclone Sidr in 2007, 15 percent of the affected population took refuge in cyclone shelters, saving thousands of lives. Focus group interviews with area residents revealed that shelters have been limited in their use and effectiveness, mainly due to existing design, distance from the homestead, difficult access, the unwillingness to leave livestock behind, lack of user-friendly facilities for women and people with disabilities, overcrowding, and lack of sanitation facilities. Although the need for cyclone shelters is expected to decline with more effective protection through embankments combined with autonomous adaption with rising incomes, cyclone shelters will nevertheless be needed in areas where dikes are not cost effective (such as in small less inhabited islands).

Early warning systems. Early warning and evacuation systems have played an important role in saving lives during cyclones. The Bangladesh Meteorological Department tracks cyclones and issues a forewarning that indicates areas that are likely to be affected by the cyclone storm. These warnings are broadcast through newspapers, television, and radio stations throughout the affected area. The existing evacuation operations managed by the local governments can be improved by increasing the spatial resolution of the warning and indicating the severity of expected inundation. Repeated warnings in areas that are not ultimately affected reduce the confidence of the inhabitants in the early warning system.

Decentralization of relief operations. Relief operations were historically centralized in Dhaka, away from the actual impacts and affected population, resulting in a long chain of command and delayed effective relief. Recent efforts to decentralize operations have proven quite successful. They include the establishment of a forward operation center with a government appointed commander-in-chief to oversee operations, the use of high frequency and ultra high frequency transceiver radios, and cell phones as an emergency communication system. Pre-positioning of emergency relief materials and life-saving drugs and medical supplies is playing an increasingly important role in quickly initiating relief and rehabilitation activities.

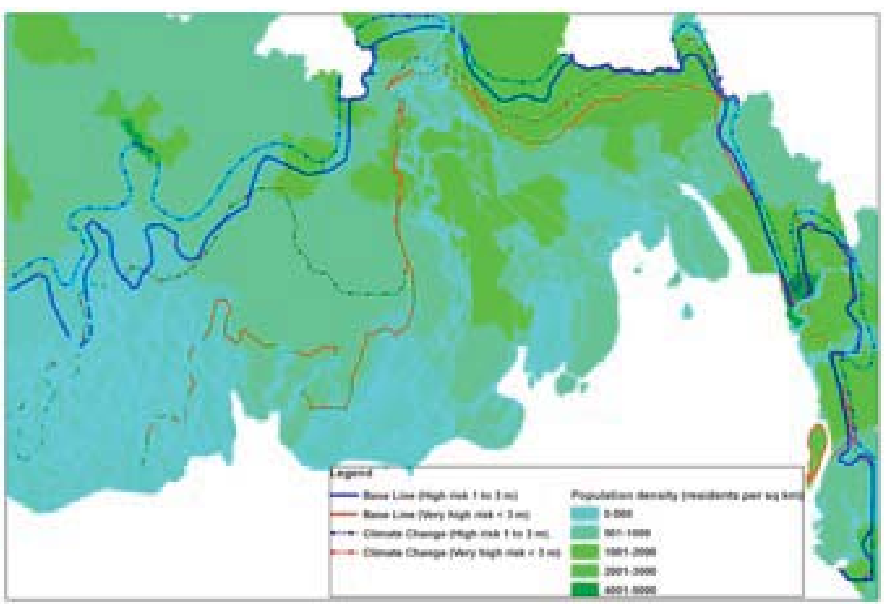
avoid these damages are estimated separately for two scenarios—a baseline scenario without climate change and another with climate change. The baseline scenario is developed from all 19 major historical cyclones making landfall in Bangladesh between 1960 and 2009, and represents the risk in the absence of climate change currently, as well as in 2050. Climate change is expected to increase the severity of cyclones by 2050. The storm surge conditions in 2050 under the climate change scenario are simulated based on three anticipated effects: (a) sea level rise of 27cm, (b) an increase in the observed wind speed by 10 percent, and (c) landfall during high tide.

Cyclone-induced storm surges due to climate change are expected to inundate an additional 15 percent of the coastal area and also increase the inundation depth in these areas (Figures 22 and 23). Households have adapted to the existing risks by moving further inland into areas with lower current risks; as a result, current population density is lower in areas with a higher risk of inundation (Figure 21). However, not all households are able or can afford to migrate away from higher risk areas. Poverty rates are also highest in the higher risk areas (Figure 23).

The population and assets at risk and the damages from cyclone-induced storm surges in 2050 under the two scenarios are computed assuming an economy with "normal" development patterns that is the same for both the baseline and climate change scenarios. The population is projected to increase 1.15 percent annually (reaching replacement fertility by 2021) with increases concentrated in urban areas. GDP is projected to continue to grow at the current annual rates of growth of 6 to 8 percent, but is expected to be less dependent on agriculture by 2050. Damages from storm surges are based on spatially disaggregated projections of the population and assets potentially at risk. If additional public adaptation measures

FIGURE 22

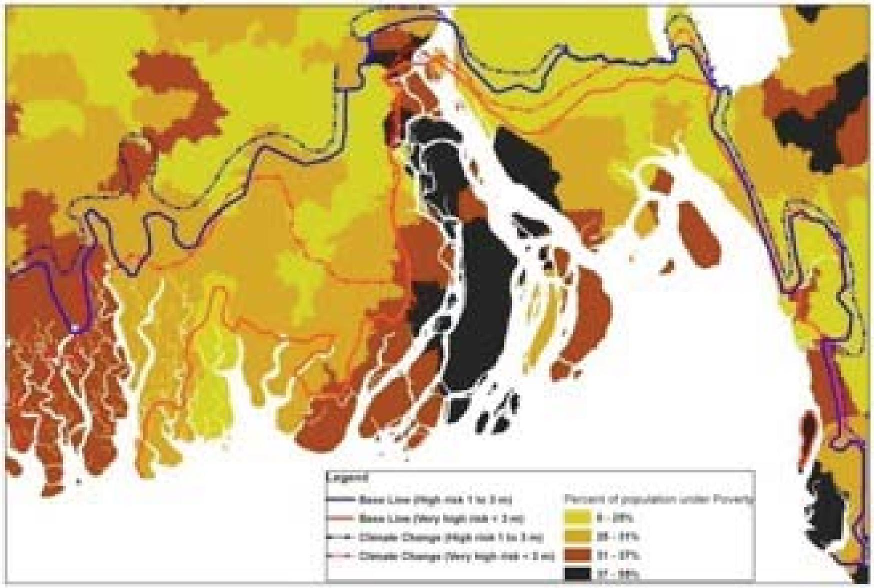
INUNDATION RISK FROM STORM SURGES IN COASTAL AREAS WITH AND WITHOUT CLIMATE CHANGE IN RELATION TO CURRENT POPULATION DENSITY



Source: World Bank 2010c.

FIGURE 23

INUNDATION RISK FROM STORM SURGES IN COASTAL AREAS WITH AND WITHOUT CLIMATE CHANGE IN RELATION TO CURRENT POVERTY RATES



Source: World Bank 2010c.

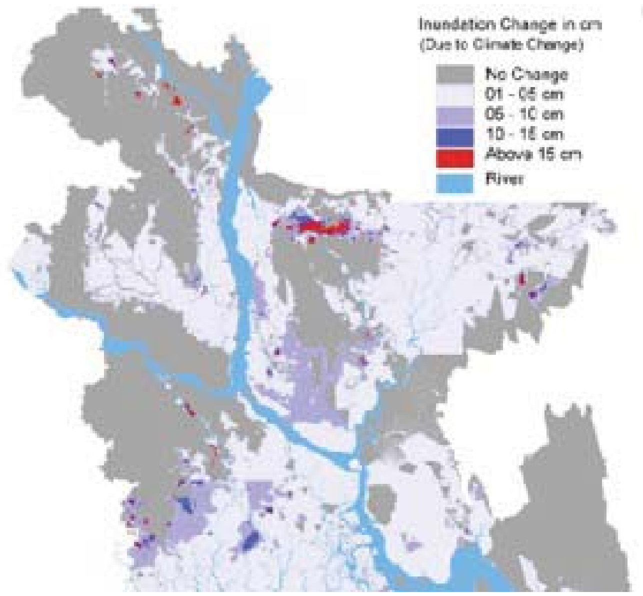
are not put in place, the damages from a single typical severe cyclone with a return period of 10 years is expected to rise nearly fivefold to over \$9 billion by 2050, accounting for 0.6 percent of GDP, with the burden likely falling disproportionately on the poorest households.

Inland flooding. Rural households have adapted their farming systems to the "normal floods" that typically inundate about a quarter of the country every year by switching to high-yielding rice crops instead of low-yielding deepwater rice. As a result, agricultural production has actually risen over the past few decades. Severe flood events, however, continue to cause significant losses, both to agriculture and to the transportation and communication networks and to the livelihoods of the poor once every three to five years. The 1998 flood inundated over two-thirds of Bangladesh and resulted in damages and losses of over \$2 billion (4.8 percent of GDP), approximately equally split between infrastructure, agriculture, and industry/commerce.

Increased monsoon precipitation, higher transboundary water flows, and rising sea levels resulting from climate change are expected to increase the depth and extent of inundation. The impacts of climate change are measured by comparing the inundation levels predicted by simulations using the MIROC 3.2 GCM predictions under the A2 emission scenario for 2050 with the inundation levels in the 1998 floods. Climate change places an additional 4 percent of land area at risk of inundation. Further, inundation depth increases in most areas currently at risk, with increases greater than 15 cm in about 544 km^2, or 0.4 percent of the country (Figure 24).[35] These are underestimates of the actual increased risk from climate change as they do not account for the frequent river course changes. The total inundation risks in 2050 are actually substantial, considering the increased risks are measured relative to the 1998 flood. Despite the higher risks, the rural population exposed to flooding is expected to decline from current levels due to the rural-to-urban migration projected to occur by 2050. These risks are in addition to the substantial baseline risks

FIGURE 24

CHANGE IN INUNDATION DEPTH (CM) FROM MONSOON FLOODING (WITH AND WITHOUT CC)



Source: World Bank 2010c.

that currently exist from inland flooding. Damage estimates from the agriculture component indicates that climate change increases the existing damages by about one-third, suggesting that actions to manage current severe floods are a good no-regrets strategy for adapting to future climate change.

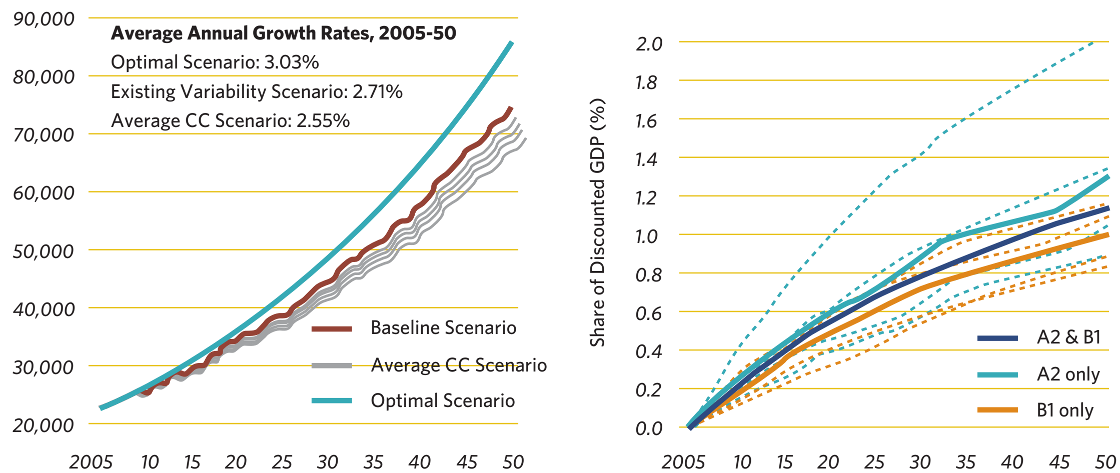
Agriculture. The climate change and food security study examines the impacts of predicted changes in climate on crop yields, agricultural production, GDP, and household welfare. Crop yields are separately modeled for 16 different agroecological regions, with rice split by seasonal varieties using climate predictions from 16 GCMs for three emission scenarios. In addition, the impacts of severe flooding on agricultural production are assessed using five GCMs and two emission scenarios. The models predict that higher yields of the main rice crops *aman* and *aus*—resulting from higher concentrations of CO_2, rising temperature, and heavier precipitation—will be more than offset by declines in the yield of the *boro* crop, crop damages from severe flooding, and losses of cultivable land due to rising sea levels. Considering all climate impacts (CO_2 fertilization, temperature and precipitation changes, flooding, and sea level rise), cumulative rice production is expected to decline by 80 million tons (about 3.9 percent each year) over 2005–50, driven primarily by reduced *boro* crop production (Figure 25). Agricultural GDP is projected to be 3.1 percent lower each year ($36 billion in lost value-added) and total GDP $129 billion lower due to climate change over the 45-year period 2005–50.

Adaptation

The costs of adaptation under the two climate scenarios are estimated through a gap analysis taking into account the adaptation investments already in place. The costs under the baseline scenario correspond to the adaptation deficit, while the cost difference between the two scenarios represents the cost of adaptation due to climate change.

FIGURE 25

PROJECTED NATIONAL RICE PRODUCTION WITH AND WITHOUT CLIMATE CHANGE



Source: Yu et. al 2010.

Tropical cyclone-induced storm surges. Since the 1960s, Bangladesh has made significant investments in embankments, cyclone shelters, coastal afforestation and in disaster preparedness to address the risks from cyclones and storm surges. However, these investments are not sufficient to address the existing risks and much less the future risk from climate change. Adaptation measures evaluated were (a) embankments, (b) afforestation, (c) cyclone shelters, and (d) early warning systems. Protecting Bangladesh against existing storm surge risks requires $3,090 million in initial investments and $62 million in annual maintenance costs. Addressing the additional risks due to climate change will require additional investments of $2,426 million and annual maintenance costs of $50 million by 2050 (Table 11). Despite differences in methodology, climate scenarios, economic assumptions, and scope of coverage, these costs are of the same order of magnitude as the adaptation costs estimated for Bangladesh from the global track of the study of around $13 billion over the 40-year period.

Inland flooding. The analysis focuses on adaptation measures to avoid further damage from additional inundation on existing infrastructure—road network and railways, river embankments, and embankments to protect highly productive agricultural lands, drainage systems, and erosion control measures for high-value assets such as towns. The total cost of adaptation due to climate change to address inland flooding risk is $2.7 billion in initial investment and $54 million in annual recurrent costs (Table 12). Full protection in 2050 will also require addressing the existing baseline risks of flooding, which are likely to be at least of the same of order of magnitude or larger.

Agriculture. While the public sector cost of adapting in the agriculture was not estimated, the relative merits of a number of short-term adaptation measures—namely the extension of currently available options into new areas—are examined from the farmer's perspective. Part of the longer term adaptation strategy will be to control the damages from inland floods. This has been partially costed in the inland floods component of the study. In addition, longer term adaptation has to also include development of alternatives, particularly to the *boro* crop in the southern region.

TABLE 11

COST OF ADAPTING TO TROPICAL CYCLONES AND STORM SURGES BY 2050

($ millions)

	Baseline Scenario (existing risks) (1)		(additional risk due to CC) (2)		CC Scenario (total risk = (1) + (2))	
Adaptation Option	**IC**	**AMC**	**IC**	**AMC**	**IC**	**AMC**
Polders	2,462	49	893	18	3,355	67
Afforestation			75		75	
Cyclone shelters	628	13	1,219	24	1,847	37
Resistant housing			200		200	
Early warning system			39	8	39	8
Total	3,090	62	2,426	50	5,516	112

Note: CC = climate change; IC = investment cost; AMC = annual maintenance cost

Source: World Bank 2010c.

TABLE 12

TOTAL ADAPTION COST FOR INLAND FLOODING BY 2050 *($ Million)*

Adaptation Option	Investment Cost	Annual Recurrent Cost
Transport – Road height enhancement	2,122	42
Transport – Road cross-drainage	5	-
Transport – Railway height enhancement	27	1
Embankment – height enhancement	96	2
Coastal Polders – cross drainage	421	8
Erosion Control Program		1
Total Costs	2,671	54

Source: World Bank 2010c.

Local-level perspectives on adaptation

Past adaptation practices by households vary according to hazard type and asset base holdings. The most common form of adaptation is temporary migration for day labor work by adult men (undertaken by 37 percent of surveyed households). Storage of food and drinking water before extreme events is also common, and 25 percent of surveyed households also reported building livestock platforms to guard animals during such events. Adaptive capacity among all field sites was low; in particular, poor urban dwellers face few options for livelihood diversification and also have low social capital.

Participants in local and national participatory scenario development workshops identified preferred adaptation options in environmental management (mangrove preservation, afforestation, coastal greenbelts, and waste management); water resource management (drainage, rainwater harvesting, drinking water provisions, and flood control); infrastructure (roads and cyclone shelters); livelihood diversification and social protection for fishers during cyclone

season; education; agriculture (development of salt tolerant and high-yield varieties, crop insurance); fisheries (storm resistant boats, conflict resolution between shrimp and rice farmers); governance (especially access to social services for the urban poor); and gender-responsive disaster management (separate rooms for women in cyclone shelters, mini-shelters closer to villages, use of female voices in early warning announcements, and mobile medical teams in Char areas).

Lessons and recommendations

Given the pervasive impacts of climate-related risks over time, Bangladesh is also one of the most climate resilient countries and can provide many lessons on developing climate resilient strategies for other developing countries. Yet, damages from recent cyclones and floods indicate that substantial risks remain. Deficiencies in costal protective measures weaken resilience to existing cyclone-induced storm surges, and climate change is expected to nearly double these risks. Further, the aggregate additional costs of the proposed adaptation measures needed to mitigate climate change risk from extreme events are generally smaller than the expected damages. As a result, a no-regrets strategy would be to begin by addressing the adaptation deficit and strengthening early warning systems. Additional embankments and shelters can be constructed in the medium term as the geographic incidence of risk becomes more certain.

The impacts of existing climate variability are concentrated in areas that also have higher concentrations of poor and socially vulnerable populations. Climate change does not shift these distributions, but just exacerbates them. The rural poor in the southern region in particular are expected to face the largest declines in per capita consumption, as well as declining productivity in the *aus* and *aman* rice crops, severe yield losses in the *boro* crop, and land losses due to increased salinity brought forth by sea level rise. Though the government has made substantial investments to increase the resilience of the poor (e.g. new high-yielding crop varieties, protective infrastructure, disaster management), the scale of the current efforts remains limited and will need to be scaled up commensurate with the probable impacts from climate change.

By 2050, the number of people living in cities will triple while the rural population will fall by 30 percent. The long-term challenge is to move people and economic activity into less climate-sensitive areas. A strategic balance between protecting existing populations and encouraging the mobility of future populations must be sought. Current policies will determine where this urban population settles and how prepared it is to adapt to a changed climate. Good policy will encourage future populations to move away from areas of high natural risk. This requires avoiding perverse incentives to remain in high-risk areas and adopting positive incentives to promote settlement and urban growth in low-risk areas.

Lastly, although Bangladesh accounts for only 7 percent of the Ganges-Brahmaputra-Meghna (GBM) basin, due to its geographical location at the tail end of the basin, flooding in Bangladesh depends on the rainfall in the entire GBM basin. Institutional arrangements on the sharing and management of water resources with its neighbours will be just as important in managing floods.

Bolivia[36]

Vulnerability to climate change

The Bolivian population has always been exposed to hydro-meteorological extremes and climate variability, particularly because of the influence of the El Niño oscillation (ENSO), which—regardless of climate change—occurs periodically in different areas across the country. The impact of El Niño 2006–07 in Bolivia cost approximately $443.3 million in damages. Direct damage to property accounted for about half of the total; the remaining 45 percent included losses in cash flow, declines in production, reduced income, and disruption of services. Floods, landslides, and droughts, all of which have serious implications for food security and water supply, are common climate-related events.

Figure 26 shows the influence of accumulating extreme events on agricultural GDP. The negative impact of strong El Niño events (red) is clear in the years 1982–83, 1991–92, and 2005–06. Also visible is the slight improvement in agriculture management in 2003–04. The less severe effects from La Niña (blue) also are evident in the years 1985–86, 1988–89 and 1994–95.

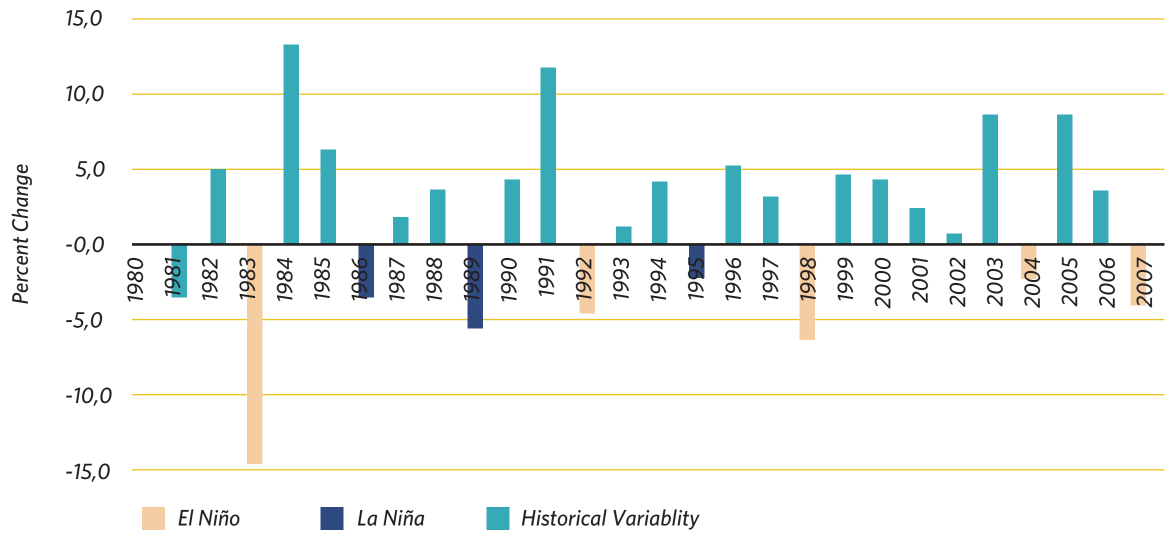
Most of the climate models for future projections do not agree with regard to rainfall estimates in terms of the sign of the change, intensity, and geographical distribution within Bolivia (Figure 27), showing a range of plausible wet and dry scenarios.[37] The economic and population welfare impacts under a changing climate are thus somewhat uncertain. Higher temperatures and fewer frosts might stimulate agricultural production in the Altiplano and the valleys. The key uncertainties concern the total amount, timing, and intensity of precipitation. If the dry scenarios are correct, then the benefits of higher temperatures will be more than offset by more frequent and severe periods of low rainfall, especially in the southwest, together with an uncertain effect in the north, making the case for improved water storage and irrigation infrastructure.

On the other hand, if the wet scenarios are correct, then agricultural yields should increase throughout much of the country, but this would also require upgrades in infrastructure (water storage and flood control) together with improved agricultural practices and land management.

Bolivia's economic mainstays—mining and hydrocarbon extraction—suggest the nation is relatively insensitive to climate change. However, it is the large majority of its rural and urban population who are quite vulnerable to changes in climate. Bolivia's rural population relies mostly on rainfed agriculture,

FIGURE 26

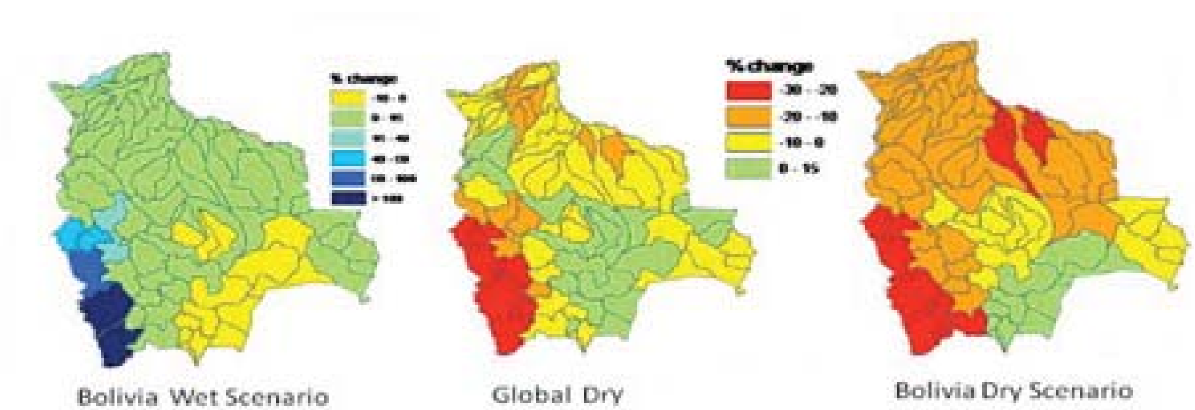
ANNUAL PERCENT CHANGE IN AGRICULTURAL GDP FROM EL NIÑO AND LA NIÑA EFFECTS



Source: World Bank 2010d.

FIGURE 27

PROJECTED PRECIPITATION CHANGES TO 2050 UNDER DIFFERENT CLIMATE SCENARIOS



Source: World Bank 2010d.

small-scale livestock farming, and seasonal labor in agriculture. Approximately 30 percent of Bolivia's rural residents reside in the valleys and high plateau areas, where water availability is already problematic. In addition, a high proportion live in extreme conditions without the necessary resources to adapt to climate change.

Climate change will not only affect rural areas within Bolivia. Several major cities located in the upper watersheds in the Altiplano and Valley regions—such as La Paz-El Alto, Sucre, Potosí, and Cochabamba—are significantly vulnerable to climate variability and water scarcity. These cities are highly vulnerable to decreasing rainfall trends, to unexpected changes in seasonality, and to prolonged droughts. Water shortages have already incited social conflicts in Cochabamba, Sucre, and Tarija.

Investment in better water management will enhance the resilience of Bolivia's population, both to systematic changes associated with annual levels of rainfall, as well as greater year-to-year volatility in rainfall patterns. Improved water management practices are conducive to smart development even in the absence of climate change, making this a robust no-regrets investment given the prevailing uncertainty about future climate change in the area.

EACC approach and results

Based on continuous dialogue with the government, the EACC study in Bolivia focused on two vulnerable sectors: agriculture and water resources. In addition, a social component complemented the sector-based economic analysis and shed light on the implications of different adaptation options on poor and vulnerable groups. The study considered two extreme climate scenarios in terms of water availability in order to simulate the worst case scenarios, assuming that changes in the Bolivian climate are likely to occur somewhere between these two. The wet scenario forecasts an average temperature increase of 1.5°C and an annual mean precipitation increase of +22 percent, whereas the dry scenario shows a temperature increase of 2.4°C and a decrease in precipitation of -19 percent averaged across the Bolivian territory. Models indicate that the frequency of extreme weather events might increase, including the onset of El Niño and La Niña events. The accumulation of such extreme events within shorter time frames can easily threaten the development-as-usual patterns in Bolivia, given the serious public sector financial limitations to reconstruct and recover to previous levels of welfare.

As one of its main objectives, the EACC study evaluated the robustness of planned adaptation measures under different climate scenarios in terms of financial values and socioeconomic terms. Results demonstrated that most current planned investment in agriculture and water resources continue to be robust to climate change, at least under extreme conditions. Thus, current adaptation measures in Bolivia are representative of primarily no-regret development strategies under climate variability.

The EACC in Bolivia consisted of three different economic assessments regarding the costs, benefits, and sequencing of alternative adaptation measures at different levels. The first exercise assessed the robustness of planned investments in the water sector by evaluating costs and benefits of government-selected adaptation measures reflecting the types of needed adaptation actions previously identified by the Bolivia National Mechanism of Adaptation. The second exercise evaluated the cost of stylized adaptation options for the water sector—mainly infrastructure needs for increased irrigation.

The third assessment comprised the development of a planning investment tool to evaluate the sequencing and prioritization of adaptation options under climate and development constraints. The analysis was able to identify the most vulnerable population, and how to restore watershed-level benefits to their baseline levels through accelerated investment. This type of planning model permitted a detailed comparison of investment alternatives and the potential effect of climate change on each alternative. The approach facilitates investigation of the sequencing and prioritization of actions in a certain time frame, as well as the robustness of alternative investment and policy strategies to possible climate outcomes. The watershed planning model developed for this investigation is a practical, useful planning tool that can be used by Bolivian authorities, refined, and updated as additional climate and watershed data become available.

Impacts

Water. Water resources are abundant in Bolivia. Average rainfall is about 1,200 mm[38], and despite high evaporation rates, average water allocation is high at approximately 45 m^3 per capita per year.[39] However, natural water supply presents both a marked geographical and seasonal variability: 45 percent of the rainfall falls within 3 months (December–February), with values from 100 to 600 mm in the cold Altiplano and less cold central and southern valley regions, up to 2,000 mm in the warm lowlands, and maximum values of 5,000 mm in certain transition areas from the valley to the lowlands.

- *Rural Areas.* According to most future climate projections, access to water resources in rural areas will be impacted by two major water-related climate risks: gradual changes in the magnitude and distribution of precipitation and temperature, and changes in the frequency and magnitude of extreme events. In addition, local evidences of rapidly melting glaciers may exacerbate water shortages in the arid and semi-arid valleys and in the highlands, which already lack water storage capacity. Glaciers act as a buffer for water availability during dry periods, and in Bolivia they are shrinking at an alarming rate.

- *Water Supply and Sanitation in Urban Areas.* In many cases—such as in Cochabamba, Sucre, or Tarija—the competition for water resources is high, and social conflicts are frequent between

the urban utility and different user communities. The case of La Paz-El Alto, is particularly worrying due to disappearance of the glacial contribution to the superficial runoff, which, though not properly quantified, will provoke a reduction in the amount of natural water supply and pose an extra threat on this metropolitan area, where demand has already matched supply.[40]

Agriculture. The crops analyzed were quinoa, potato, maize, and soy, which are cultivated from the Altiplano to regions of lower elevation. Generally, Bolivia's agriculture would benefit significantly from a warmer and wetter climate, so long as the varieties and crops that are grown can be adjusted to changes in rainfall patterns during critical phenological time periods and/or any shortening in the growing season. Yields for maize and soybeans would increase by 40–45 percent, while that for potatoes and quinoa by 60–90 percent. On the other hand, the dry scenarios would lead to a substantial reduction in agricultural yields in the Altiplano, the valleys, and the El Chaco regions. The effects of less rainfall and higher evaporation could only be offset by (a) a substantial investment in water storage and irrigation infrastructure, and (b) the adoption of more drought-resistant varieties and crops in the lower lands. Potential losses from a drier climate are on the order of 25 percent for maize and 10–15 percent for soybeans, potatoes, and quinoa. This suggests that rapid and timely implementation of irrigation (at least at the initial phases of crop development), would be even more attractive under a scenario of warmer climate.

Adaptation

Water. Investment in better water management will enhance the resilience of Bolivian agriculture both to systematic changes in annual levels of rainfall and to greater year-to-year volatility in the rainfall patterns. Such investments are "no-regret" measures and would be desirable under most development strategies for a stable climate, so that climate change is likely to reinforce the benefits of such investments.

While water resources are abundant for the whole country, improving the storage efficiency of wet periods to meet irrigation demands in deficit areas such as the south of the Altiplano and El Chaco is essential. Improvements in irrigation need to be accompanied by better water management, particularly integrated watershed management where the resource competition between rural and urban populations is likely to increase. In addition, there is a need to reinforce, improve, protect, and diversify water sources in order to strengthen the production capacity of the urban utilities, especially in cities of the arid regions like La Paz, Cochabamba, or Sucre.

Under the wet scenarios, there will be an increase in flooding, especially in the valleys and the eastern lowlands. Reforestation, as well as the development of flood warning and disaster prevention systems, can help reduce the economic and social costs of flooding in lowland areas. More expensive forms of flood prevention such as dikes are rarely justified.

Agriculture. According to the estimated impact of climate change, similar adaptation options for the four studied crops were identified as crucial, irrigation being clearly the most important. In addition, for quinoa, the application of deficit irrigation and changes in the sowing dates and crop varieties are viable options; for potatoes, better management of the different varieties, changes in sowing dates, and application of irrigation in critical phenological periods; for soybeans, investments in flood control measures as well as the introduction of input saving varieties; and for maize, specific additional adaptation measures include flood control in wet periods, as well as improved soil management practices. Most adaptation strategies will require significant institutional support in order to avoid negative social and ecological impacts due to intensification of crop production.

Adaptation measures indicated by local populations include the need for better information and capacity building initiatives geared toward working with new and adapted seed varieties, as well as better infrastructure for conservation and storage of crops during warm periods. Extension services, crop insurance, and improved access and availability to hydro-meteorological data will also be vital to improve agriculture adaptation policies and meet the needs of livelihoods based on rain-fed agriculture. Some measures that remain to be explored include the potential role of investments in rural roads in providing the infrastructure required to facilitate shifts in the location of agricultural production linked to changes in comparative advantage. Robust adaptation options should be accompanied by large cobenefits and interlinkages. For example, investments in rural roads can be an important adaptation strategy because they increase access to markets for agricultural inputs and outputs. The implementation of policies that increase access to markets—bridging two vulnerable sectors, infrastructure and agriculture—could be implemented for small-scale farmers, and complemented by additional macroeconomic measures for large-scale farmers.

Finally, the agriculture study suggests that planned adaptation actions—including increased irrigation resources and flood control measures, as well as the implementation of knowledge support for improved analysis of climate science—are highly costly and hard to implement in Bolivia, based on qualitative assessments of cost, benefits, and viability of these adaptation actions.

Economic analysis of adaptation investment options

The cost-benefit analysis illustrates the use of an economic tool for the evaluation of robustness of investment projects under a changing climate. The analysis evaluated projects selected primarily based on the availability of data. Water projects included water supply and water management, and the agricultural projects consisted primarily of irrigation projects. The analysis excluded the assessments of larger infrastructure projects in urban areas, as these projects are usually excluded from national budgets and mostly financed by international cooperation.

The analysis was made in terms of financial (market) values and in socioeconomic terms (shadow prices), and integrated climate change variables (temperature and precipitation) under a dry (worst case) and a no-climate-change scenario. The objective was not to evaluate the projects themselves, but rather their economic feasibility and robustness as appropriate adaptation measures to climate variability in Bolivia (Table 13).

The results suggest that the Altiplano will be favored by increased temperatures, while the oriental and Chaco zones will be negatively affected by increased temperatures and reduced precipitation. These results are in accordance with the spatial distribution of the projects where, depending on the area, the Internal Rate of Return (IRR) is reduced due to these regional impacts. The agriculture projects show a slight increase of the IRR under the climate change scenario in the highland zones (except the B.R.Paraisito project). This suggests that current planned investment in agriculture and water resources continue to be robust to climate change, at least under dry extreme conditions.[41] Thus, adaptation measures in Bolivia represent primarily good development strategies under climate variability.

Two other economic exercises explored the possible effects of climate change on a long-term irrigation program (National Watershed Program – PNC by its Spanish acronym) at the watershed level.

The first exercise considered the cost of providing the required level of additional water storage infrastructure to meet PNC's planned irrigation expansion to 2011 and estimated up to 2050. The analysis was based on balances of water deficit and water surplus months, and therefore the necessity and potential to reallocate additional water through storage, under a wet and a dry extreme climate scenario. The estimated cost of the additional water storage required to match monthly water deficits due to climate change under the wet climate scenario would be on the order of an additional $12 million over the projected baseline (estimated at around $480 million for 2050 under no climate change), and an additional $60 million under the dry climate scenario up to 2050.

The second exercise[42] explored the effect of climate change on PNC's planned investment program for the Mizque watershed. This is a watershed that has been identified as being particularly susceptible to climate effects. The study evaluated the effect of a changing climate on decisions to make durable investments. As irrigation must compete with potable water and water for agriculture practices, two policies were explored under extreme climate conditions and budget constraints: (1) decentralization of budgets to the sub-basin level versus centralized Mizque watershed-level watershed planning; and (2) maximizing the number of families receiving irrigation versus maximizing the economic benefits from irrigation.

Results showed that incorporating the effects of climate change appears to slightly modify the original national watershed development plan, suggesting that most of the potential irrigation investments in the Mizque watershed are robust to climate impacts. This is the case because major vulnerability problems are upstream and related to urban water supply, sanitation, and threats of floods and droughts. This analysis suggests that farther downstream in the Mizque River watershed, annual rainfall would remain sufficient for nearly all the irrigation projects identified in the PMIC-Mizque study, assuming sufficient storage was built as part of the program. Under a "dry scenario," the effect would be to reduce potential social benefits by 1–3 percent as water becomes scarce

TABLE 13

COST-BENEFIT ANALYSIS OF ADAPTATION MEASURES IN THE AGRICULTURE AND WATER SECTORS

Project	Investment Costs (000)	Beneficiaries	NPV[1] (000)	IRR (%)	NPV* (000)	IRR (%)
			Baseline		Dry scenario	
WATER						
Distribution in Sapecho	3,440	2,199 persons	3,428	24	3,331	24
Potable water S.P. Cogotay	408	140 persons	8	13	3	13
Well drills Chapicollo	317	50 families	187	17	151	17
Flood Control Caranavi	4,052	528 houses	2,658	22	2,658	22
AGRICULTURE						
Irrigation dam S.P.Aiquile	11,476	147 ha	2,583	16	4,195	18
Dam restoration Tacagua	313,623	907 ha	(184,275)	3	(171,580)	3
Wall elevation Tacagua dam	120,457	907 ha	9,705	14	21,563	16
Irrigation B.Retiro S Paraisito	3,686	178 ha	17,260	71	14,874	63
Catchment Atajados/Aiquile	1,951	32 ha	115	14	347	16

Notes: parenthesis values indicate a negative NPV, suggesting that dam restoration is not economically feasible in this location. * NPV = Net present value.

Source: World Bank 2010d.

and there are diminishing economic returns from sequenced investment projects. The effect of the wet scenario is to increase benefits by 1–3 percent. These results vary with varying assumptions regarding the budget available each year and the degree of budgetary decentralization policies.

In general, the effect of budgetary decentralized management[43] at the subwatershed level overwhelms the effect of a dry or a wet climate change scenario, regardless of whether the objective is to maximize social benefits or to maximize the number of families directly benefitting from the projects. According to the model exercise, decentralizing budgets at the subwatershed level actually reduces social benefits and/or the number of families directly benefitting from the projects by between 2 percent and over 30 percent.

Local-level perspectives on adaptation. Communities in the valleys and highlands considered drought to be the principal threat to their livelihoods and prioritized adaptation measures related to water management—including improving water storage capacity and irrigation infrastructure—followed by improved agricultural and livestock practices. In contrast, communities from the Chaco and Plains regions asserted that improved agricultural practices were most important and considered water management measures to be of secondary significance. These local perceptions coincided with the adaptation measures identified in the sector analyses.

Yet results from participatory scenario development workshops and fieldwork demonstrate that communities view adaptation strategies not as isolated "hard" measures nor as single projects, but rather as a set of complementary measures comprised of both hard and soft adaptation actions. Thus, while infrastructure investments would be necessary, they emphasized that these would be insufficient if complementary efforts are not made to promote capacity, institutional development, and in many cases, fundamental transformation to underlying logic and livelihood strategies. Notably too, local authorities tended to favor investment in discrete, hard measures, while community members tended to favor more comprehensive strategies that consisted of a mix of hard and soft options.

Lessons and recommendations

There is little practical difference between Bolivia's development agenda and the adaptation agenda. Thus, there is a need to accelerate the development agenda, as in most cases, good development policies are the most robust adaptation policies. While the country has always experienced a high degree of climate variability, climate change is expected to intensify the phenomenon. Since the Bolivian economy is heavily dependent on minerals and gas, it is not expected to be highly impacted by climate change. However, the majority of the rural and indigenous populations are dependent on agriculture, which in turn is highly impacted by changes in climate. Climate change therefore will tend to intensify the already severe distributional problems of the country, thus calling for an even stronger people-centered development.

The two possible climate trends—warmer and wetter, and warmer and drier—will imply quite different outcomes. Even in the more optimistic scenario of wetter conditions, agricultural productivity can only increase if the capacity to store and use the needed additional water is available for farmers and poor peasants. Given the great uncertainties about future precipitation patterns, strategies that will work well under both wet and dry conditions are called for. Such a strategy should include a combination of improved water resources management and building water storage and irrigation infrastructure. These are no-regret strategies that should be pursued irrespective of climate change.

Vietnam[44]

Vulnerability to climate change

Vietnam is a long narrow country consisting of an extensive coastline, two major river deltas, and mountainous areas on its eastern and northeastern

BOX 4

LOCAL FACTORS INFLUENCE LOCAL ADAPTATION PREFERENCES IN BOLIVIA

The social component in Bolivia identified the very wide variety of envisaged livelihood strategies in fourteen communities and highlighted the importance of past experience and support from local institutions in determining local adaptation preferences. More specifically, adaptation strategies tended to reflect the order of priority assigned to the same type of adaptation measure in the past. In effect, this shows how preferred adaptation strategies depend on the recent history of a particular community. For example, communities that have benefited from investments in water management schemes that have resulted in safer drinking water do not consider water management for improved drinking water as necessary for their future, as they do not view the current system as inadequate.

The presence or lack of institutions is a second determinant for identifying, prioritizing, and sequencing adaptation strategies in Bolivia. Where local authorities and privatized institutions have a history of supporting development, community members will count on their continued support and prioritize measures that require external support. Where institutions do not have a strong presence, prioritized adaptation options will not be based on major external support.

borders. As such, Vietnam is heavily exposed to the risks of weather variability and climate change. Its vulnerability to weather risks has given the country experience in designing and implementing measures to mitigate the effects of droughts, flooding, storms and similar events on agriculture and other sectors of the economy. Assessing the potential impacts of climate change and determining how best to adapt represents a new challenge, for which past experience may be a guide but which is accompanied by large uncertainties.

In June 2009, the Ministry of Natural Resources and Environment (MoNRE) published Vietnam's official scenario for climate change. The MoNRE scenario falls in the middle of a range of alternative climate scenarios for Vietnam when these are arranged by their climate moisture indexes. In addition to the MoNRE scenario, the EACC study has made use of two other climate scenarios—Dry (IPSL-CM4) and Wet (GISS-ER)—which represent the extremes of the distribution by climate moisture indexes.

Rainfall projections across seasons are of particular interest. The dry seasons are projected to get drier, with the March–May rainfall reductions being higher in the southern part of the country; the wet seasons are projected to get wetter, with the June–August rainfall increases being higher in the northern part of the country. Hence, it is expected that rainfall will be concentrated even more than now in the rainy season months, leading to an increase in the frequency, intensity, and duration of floods, and to an exacerbation of drought problems in the dry season. Sea level is projected to rise approximately 30 cm by 2050 and up to 75 cm by 2100 under the medium scenario.

An analysis of vulnerability to climate change at the regional level was carried out as part of the social analysis. Exposure to climate change is assessed by considering the numbers of households potentially threatened by the effects of storms, flooding, salinity intrusion, sea level rise and storm surges, landslides and flash floods, and drought. Each region is assigned to categories ranked from 0 (low exposure) to 4 (severe exposure). Similarly, sensitivity to the impacts of climate is assessed on criteria that reflect vulnerability to the consequences of climate change based on specific socioeconomic characteristics—poverty, economic diversification, education, and health and sanitation—and for specific social groups, such as ethnic minorities, women and children, migrant populations, and urban populations. Again, each region is assigned to categories ranked from 0 (low sensitivity) to 4 (extreme sensitivity). Unweighted averages of the classifications were computed to give indices of exposure and sensitivity. These are shown in Table 14.

The analysis indicates that exposure to the effects of climate change is highest in the Central Coastal regions (NCC & SCC) and in the Mekong River Delta. On the other hand, sensitivity to the effects of climate change is highest in the North West and Central Highland regions. The correlation between exposure and sensitivity is negative, so that regions with high exposure tend to have low sensitivity and vice versa. The only region with indexes that are above the average on both measures is the Mekong River Delta.

EACC approach and results

Methodology. The sector studies concentrated primarily on Vietnam's rural economy because that is

TABLE 14

REGIONAL VULNERABILITY TO CLIMATE CHANGE

Region	North West	North East	Red River Delta	North Central Coastal	South Central Coastal	Central Highland	South East	Mekong River Delta
Exposure								
Storms	1	3	4	4	4	2	2	3
Flooding	1	1	4	4	4	2	2	4
Salinity	0	0	1	2	2	0	1	4
SLR	0	0	2	2	2	0	3	4
Landslides	3	3	1	3	3	2	1	1
Drought	2	2	1	4	4	4	2	2
Average	1.2	1.5	2.2	3.2	3.2	1.7	1.8	3.0
Sensitivity								
Poverty	4	3	2	4	2	4	1	2
Economic diversification	4	4	2	4	3	4	2	2
Education	4	3	1	2	2	2	1	3
Health & sanitation	4	1	2	1	1	1	1	3
Ethnic minorities	4	3	0	1	1	4	1	2
Women & children	4	3	1	2	3	3	1	2
Migrants	0	0	2	2	1	4	4	1
Urban households	0	0	2	1	1	0	4	3
Average	3.0	2.1	1.5	2.1	1.8	2.8	1.9	2.3

Source: World Bank 2010i.

where the effects of climate change are likely to be most immediate and serious. Detailed studies were carried out for agriculture (crop production), aquaculture, forestry, and coastal ports. Each of the sector studies follows a broadly similar approach that involved the following steps:

Step 1: Establish a baseline scenario consisting of projections of land use, production, value-added, population growth, urbanization, and other variables without climate change. This provides a reference scenario against which the impacts of climate change without and with adaptation are measured.

Step 2: Consider the relevant climate variables for the sector and identify changes projected to 2050 or beyond for each of the climate scenarios. This made use of detailed information on precipitation by season and/or region.

Step 3: Identify the impact of changes in climate on resource productivity and land use. This included the effect of changes in seasonal temperatures on rice yields or of seasonal precipitation on coffee yields, as well as the effect of flooding or saline intrusion on the amount of land that can be used for rice production in the Mekong River Delta.

Step 4: Using GIS and other techniques, combine the information collected in steps 2 & 3 to estimate the overall impact of climate change on land use and production of crops, freshwater fish, timber, and so on by comparing estimates of yields and production under no climate change and with climate change but no adaptation.

Step 4A: For agriculture, incorporate the results from Step 4 into a macroeconomic model to assess the consequences of changes in agricultural output on agricultural prices, trade, GDP, and economic activity in other sectors and household consumption.

Step 5: Identify opportunities for (a) autonomous adaptation undertaken by farmers and other producers in response to changes in climate and other conditions, and (b) planned adaptation, which is likely to be initiated and at least partly funded by the government.

Step 6: Estimate the production of crops, timber, and so on under the new climate conditions after the adaptation measures have been implemented. This provides the basis for identifying (a) the effect of climate change with adaptation (the difference between the baseline scenario and the scenario of climate change with adaptation), and (b) the impact of adaptation itself (the difference between the scenarios of climate change without and with adaptation).

Step 6A: As for Step 4A, incorporate the results from Step 6 into the macroeconomic model to assess the benefits of adaptation in terms of aggregate and sectoral economic activity and household consumption.

Many of the adaptation options are "no regrets" options that increase yields or production even without climate change. This is not invariably the case, because there is no need to upgrade ports if sea level and storm surges do not change. However, for agriculture and other sectors it is difficult to identify measures that are only justified under a specific set of climate conditions. For these sectors, adaptation is often a matter of doing things that would in any event have been economic under a wide range of climate conditions.

Agriculture. The impact of the alternative climate scenarios on crop production has been examined using projections of runoff, which affects the availability of irrigation water, plus agronomic models that take account of temperature and rainfall patterns, water availability for rainfed and irrigated crops, and other factors to estimate the impact of climate change on crop yields.

Changes in yields without adaptation vary widely across crops, agroecological zones, and climate scenarios. As for other EACC studies, the results reported do not take account of CO_2 fertilization, partly because of the uncertainties about the extent of the effect and partly to assess how far adaptation can mitigate the worst-case outcome. For rice, the Dry scenario would lead to reductions in yields ranging from 12 percent in the Mekong River Delta to 24 percent in the Red River Delta. The primary influences on rice yields are the increase in average temperatures and reductions in runoff in many months of the year (Figure 28).

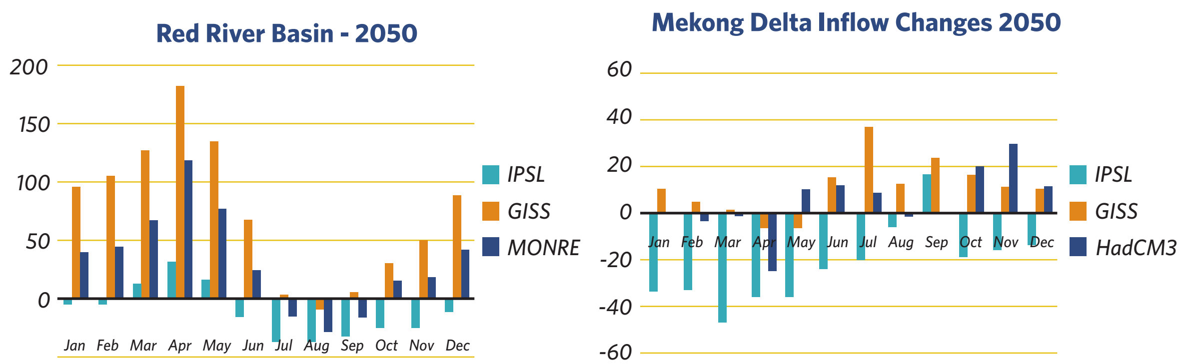
There would be more extensive inundation of crop land in the rainy season and increased saline intrusion in the dry season as a consequence of the combination of sea level rise and higher river flooding. For the Mekong River Delta, it is estimated that about 590,000 ha of rice area could be lost due to inundation and saline intrusion, which accounts for about 13 percent of today's rice production in the region.

Table 15 shows the potential impact of climate change without adaptation under alternative climate scenarios on production of six major crops or crop categories relative to the baseline for 2050 if there were no climate change. Paddy rice production may fall by 5.8 (MoNRE) to 9.1 (Dry) million metric tons (mmt) per year.

Note that these figures are not forecasts of what will actually happen. Farming involves a continuous

FIGURE 28

CHANGES IN RUNOFF FOR THE RED RIVER AND MEKONG DELTA BY CLIMATE SCENARIO



Source: World Bank 2010i.

TABLE 15

CHANGE IN CROP PRODUCTION IN 2050 DUE TO CLIMATE CHANGE WITH NO ADAPTATION

(million metric tons)

Climate scenario	Paddy rice			Maize	Cassava	Sugar cane	Coffee	Vegetables
Impact	Yields	Sea level	Total	Yields	Yields	Yields	Yields	Yields
Dry	-6.7	-2.4	-9.1	-1.1	-1.9	-3.7	-0.4	-1.7
Wet	-5.8	-2.5	-8.4	-1.0	-2.6	-2.9	-0.4	-3.1
MoNRE	-3.4	-2.4	-5.8	-0.3	-0.6	-1.4	-0.1	-0.9

Source: World Bank 2010i.

process of adaptation to weather, technology, economic and other influences, so adaptation will certainly occur to a greater or lesser extent in practice. Rather, these projections provide a starting point—based on the best available information and subject to substantial uncertainty—for (a) understanding the potential importance of climate change for crop production, holding other factors constant; and (b) assessing the type and scale of adaptation that may be required, which will require a combination of autonomous adaptation (by farmers) and planned adaptation (as a consequence of government policy).

Further, this assessment of the potential impact of climate change on crop production needs to be interpreted in a larger context. Changes in diets and consumer preferences with falling demand for rice, market liberalization, trade (which will expose Vietnam to lower-cost competition), and conversion opportunities to aquaculture and more salt-tolerant varieties will all have important effects on the demand for and the supply of agricultural products over the coming decades. The impacts of climate change have to be assessed against a background of wider economic and social development.

Macroeconomic impacts. As in other country studies, a CGE model has been used to examine the macroeconomic impacts of climate change. In Vietnam the GCE model was only used to examine the effects of climate change and adaptation for the agricultural sector, so it does not attempt to take account of all of the macroeconomic impacts of climate change. The CGE model establishes a baseline composition of economic activity up to 2050 given data and assumptions about inter-industry linkages for 158 sectors, including regional crop production for the six crops examined above, consumption for 10 rural/urban household groups, population, investment, and productivity growth. This is used to simulate the effect of exogenous "shocks;" that is, deviations from the baseline scenario such as a reduction in crop production due to climate change. The model is run assuming that the aggregate level of investment and savings remains constant in real terms, so that aggregate consumption moves with national income (GDP). The model takes account of the effects of exogenous shocks on industry and services, international trade, commodity prices, and the distribution of consumption. A broad picture of its results may be obtained by examining changes in total GDP, aggregate consumption, and other variables under the alternative climate scenarios in 2050 relative to a baseline with no climate change.

As shown in columns 1–3 of Table 16, total GDP and aggregate consumption in 2050 with no adaptation will be 2.4 and 2.3 percent lower than the baseline under the Dry/Wet scenarios, respectively, but only 0.7 percent lower under the MoNRE scenario. The reason for the reduction in GDP is the decline in agricultural value-added of 13.9/13.5 percent under the Dry/Wet scenarios, which is marginally offset by small increases in value-added in industry and services. There are significant differences between the impact of climate change on different regions, as illustrated by the estimates for changes in regional GDP for the North-Central Coast and South-East regions. The gain in the South-East is a consequence of the concentration of industry and services in the region.

The impact on household incomes is skewed, with greater losses for those in the bottom rural quintile (the poorest 20 percent of rural households arranged by expenditure per person) than for the top quintile. Poor rural and urban households are most vulnerable because they rely more heavily on the agricultural sector for their incomes and they spend a higher proportion of their income on food, which becomes relatively more expensive.

Adaptation in agriculture. The study examined a range of adaptation options that combine autonomous adaptations undertaken by farmers with planned adaptation underpinned by government spending in areas that will enhance the capacity of farmers to adapt. The autonomous adaptations include changes in sowing dates, switching to drought-tolerant crops, adoption of salinity-tolerant varieties of rice, adoption of new varieties for other crops, and switching to rice-fish rotations. The planned adaptations focus on (a) increased spending on research, development and extension, with the goal of raising average crop yields by 13.5 percent relative to the baseline; and (b) extending the area of irrigated land by about 688,000 ha, roughly half for rice and the remainder mainly for maize and coffee. The total cost of these measures is estimated at about $160 million per year at 2005 prices without discounting over the period 2010–50.

Deviations in GDP and other macroeconomic variables from the baseline with adaptation for the alternative climate scenarios are shown in columns 4–6 of Table 16, while columns 7–9 give the net benefits of adaptation after allowing for the costs that are incurred. The adaptation measures substantially reduce the impact of climate change under all scenarios. The expenditures on adaptation for agriculture are clearly justified as the ratio of their benefits to the costs that are incurred is much greater than 1. The combination of the MoNRE scenario with adaptation leads to an increase in aggregate consumption, indicating that some, perhaps many, of the adaptation measures are "no regrets" options that would be justified even without climate change.

TABLE 16

MACROECONOMIC EFFECTS OF CLIMATE CHANGE WITHOUT/WITH ADAPTATION IN 2050
(Percentage deviations from baseline with no climate change)

	No adaptation			With adaptation			Adaptation benefits		
	Dry	Wet	MoNRE	Dry	Wet	MoNRE	Dry	Wet	MoNRE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GDP	-2.4%	-2.3%	-0.7%	-1.1%	-0.7%	0.7%	1.3%	1.6%	1.3%
Aggregate consumption	-2.5%	-2.5%	-0.7%	-1.4%	-0.8%	0.6%	1.1%	1.7%	1.3%
Agricultural value-added	-13.9%	-13.5%	-5.8%	-3.8%	-3.4%	5.4%	10.0%	10.1%	11.2%
Regional GDP									
North Central Coast	-6.6%	-6.1%	-2.6%	0.5%	-0.3%	4.8%	7.1%	5.8%	7.4%
South East	1.1%	0.8%	1.0%	0.0%	1.1%	0.2%	-1.1%	0.3%	-0.9%
Rural household consumption									
Bottom quintile	-6.5%	-6.3%	-2.6%	-1.9%	-1.4%	2.4%	4.7%	4.9%	5.0%
Top quintile	-1.6%	-1.7%	-0.4%	-1.5%	-1.0%	0.0%	0.1%	0.7%	0.4%

Source: World Bank 2010i.

An important aspect of adaptation is that it offsets most of the disproportionate impact of climate change on poorer households. The bottom quintile of rural households benefit most from adaptation, and the gap between the changes in household consumption for the bottom and top quintiles is almost eliminated. Adaptation partly or wholly offsets both the reduction in agricultural incomes and the increase in food prices that accompany climate change without adaptation.

Investments in flood and coastal protection were not incorporated in the macroeconomic analysis. Separate studies have indicated that the costs of building/upgrading sea dikes and flood defenses to protect urban infrastructure and the most valuable agricultural land would be about 1 percent of total investment—about $540 million per year at 2005 prices.

Aquaculture. Aquaculture, especially in the Mekong River Delta, is an important source of employment and rural income. It is estimated that some 2.8 million people are employed in the sector, while export revenue is expected to be about $2.8 billion in 2010. Higher temperatures, increased frequency of storms, sea level rise, and other effects of climate change are likely to affect fish physiology and ecology as well as the operation of aquaculture. Some fish species, such as catfish, may grow more rapidly with higher temperatures, but be more vulnerable to disease. The main impacts of climate change on aquaculture seem likely to be a consequence of increased flooding and salinity.

Parts of the aquaculture sector, particularly catfish farming, face uncertain economic prospects, particularly as a result of rising prices for feedstuffs and the costs of maintaining water quality. Without adaptation, it is likely that climate change will significantly reduce the margins that can be earned from the business, so that only the most efficient farmers who adopt best farming practices will survive. Successful adaptation will require a combination of better feed conversion and improvements in marketing, together with investments in upgrading dikes to reduce flooding and salinity intrusion that will benefit other sectors as well as aquaculture. Semi-intensive and intensive shrimp producers may incur additional costs of water pumping to maintain water and salinity levels. Since the industry is both capital-intensive and growing rapidly, adaptation is likely to be autonomous with the costs borne by operators. The total cost of adaptation is estimated at an average of $130 million per year from 2010–50, which is equivalent to 2.4 percent of total costs.

Forestry. The impact of climate change on forests is likely to be complex and long term. For natural forests, the analysis suggests that there will be a substantial reduction in the area of land that is suitable for humid semi-deciduous forest, which would replaced by other forest types. Mangrove forests will be affected by sea level rise unless they are able to migrate inland. The area of land under plantation forests with short rotations has increased rapidly over the past 20 years. A forestry growth model suggests that climate change will increase the variability of plantation yields across the country without having a major impact on the average yield. Thus, an important aspect of adaptation will be to ensure the best match between soil, climate, and management practices to obtain the highest yields from plantations.

A range of adaptation options was considered. The key measures identified were (a) changes in land use planning to facilitate the migration of mangroves, (b) adoption of plantation species and methods of silviculture that are more resilient to droughts, (c) improvements in pest management, including genetic selection and integrated pest control strategies, and (d) use of herbicides or biological controls to limit the effect of exotic weed species on tree growth. The money costs of adaptation are likely to be modest, but the institutional issues may be more difficult to deal with.

Coastal ports. Along its 3,200km coastline, Vietnam has a total of 116 ports. In addition, new terminals are being constructed and planned all along the coastline, particularly in the south around Ho Chi Minh City and in the north around Hai Phong. Given the nature of its location, this infrastructure is at risk from sea-level rise and storm surges. Impacts include accelerated depreciation of structures and flooding of port facilities such as warehouses.

Adaptation options examined in the study include (a) raising quay walls, (b) improving surface drainage to reduce flooding, and (c) increasing expenditure on the maintenance and replacement of port infrastructure. The cost of adaptation for all ports would be less than $500 million, or about $12 million per year without discounting at 2005 prices.

Social analysis. To this point, government policies have focused on sector-wide assessments for the whole country and on "hard" adaptation measures—sea dikes, reinforced infrastructure, and durable buildings. Little attention has been paid to "soft" adaptation measures, like increasing institutional capacity or the role of collective action and social capital in building resilience. Most adaptation options identified at the field sites and during participatory scenario development workshops were aimed at improving response capacity and disaster risk reduction—forecasting, weather monitoring—and managing climate risk. Notably, adaptation options that reduce poverty and increase household resilience or that integrate climate change into development planning were not emphasized.

Overall, many of the adaptation options observed at the field sites and/or proposed in workshops were highly cost-effective and do not require large expenditures. Moreover, they were largely in line with the adaptation options considered for the climate scenarios in the sector analyses. These adaptation measures included shifting planting dates, adopting drought-tolerant crops, and switching to salinity-tolerant varieties of rice. The diversity of preferred adaptation responses reflected the impressive variety of Vietnam's vulnerability zones and confirm the need for a mix of both autonomous and planned adaptation, a mix of hard and soft options, and adaptation to be carried out at the national, subnational, and community levels.

Lessons and recommendations

Climate change will have a significant impact on some regions and sectors of Vietnam's rural economy. Still, in macroeconomic terms the impacts of climate change on agriculture and related sectors, even with no adaptation, appear to be relatively modest. In practice, there will be substantial autonomous adaptation even without active government intervention, since farmers will change the crops and crop varieties they grow and their methods of farming.

The major concern is the extent to which climate change will hit poor households, partly because of the decline in agricultural incomes and partly because of an increase in food prices relative to the general cost of living. The lowest 20 percent of households—either urban or rural—arranged by household expenditure per person will experience larger reductions in real standards of living due to climate change than the top 20 percent of households.

Thus, the primary focus of policies to adapt to climate change should be to protect the poor, the vulnerable, and those least able to respond to changing climatic stresses. The goal should be to provide farmers and others with the tools and resources that will enable them to respond to climate change itself and to the new risks that will accompany climate change. The key elements will be:

- Increased expenditures on research, development, and extension for crop production, aquaculture, and forestry to develop new crop varieties that are more tolerant to drought, salinity, and higher temperatures early in the growing season. Both the public and the private sectors should be involved in efforts to increase yields and productivity.
- Investment in expanding irrigation infrastructure, especially in the central regions where the opportunities for irrigation expansion are greatest. In the short term, this should build upon achieving fuller utilization of existing irrigation infrastructure and improvements in operations and maintenance.
- Increased spending on the maintenance and extension of coastal and flood defenses to minimize the impacts of sea inundations, salinity intrusion, and river flooding, especially in the Mekong River and Red River deltas.

Much of these expenditures would be justified even without climate change, so adaptation to climate change is primarily a matter of building upon no-regrets measures. Under the intermediate MoNRE climate scenario, the program of agricultural adaptation outlined in this study will increase agricultural incomes relative to the baseline, especially in the Central Highlands region, illustrating the general benefits of the strategy.

If this program of adaptation were to be implemented, the adverse impacts of climate change on poorer households would largely be avoided. There would still be a net loss of agricultural value-added and aggregate consumption in the Wet and Dry climate scenarios, but the magnitude of the losses would be significantly smaller and the skewed impact on the distribution of income would be corrected.

Year-to-year weather variability is much greater than the long-term trends associated with climate change. Policies and systems that can cope effectively with weather variability will be more successful in adapting to future climate change than those that cannot. Strengthening the capacity of the rural sector to cope with current weather variability and build resilience into such systems will yield benefits both now and in the future. It is also important to collect, analyze, and report data on how the climate is changing in different regions of the country, so that those who have to take account of climate change in planning new infrastructure or implementing investment programs should have access to the best possible information.

Climate change, including sea level rise, will affect the country's infrastructure and require expenditures on adaptation. The case study of coastal ports indicated the lesson that the costs of adaptation are likely to be modest. The total cost of protecting existing ports that are exposed to flooding—as a result of higher sea level combined with greater storm surges—is estimated at no more than $500 million in total over 40 years, equivalent to $12.5 million per year (at 2005 prices without discounting), or about 1 percent of planned investment in ports over the period 2010–30.

An equally important lesson from the case study is that it is essential to plan ahead for climate change. Ports that are built over the next 10–20 years should be designed to cope with sea levels and storms to which they may be exposed 50 or more years from now. It may be cheaper to build margins of resilience and safety into new infrastructure than to upgrade assets during the course of their life. The same lesson emerges from the countrywide analyses for infrastructure and coastal protection undertaken as part of the EACC Global study. The total cost of adaptation for these sectors amounts to about 2 percent of total investment for the Global Wet (NCAR) scenario and about 1.3 percent of total investment for the Global Dry (CSIRO) scenario on the assumption that adaptation measures are combined with new investments anticipating climate change up to 2100.

Samoa[45]

Vulnerability to climate change

Samoa is a country at extreme risk from a variety of natural disasters, including tropical cyclones and tsunamis caused by earthquakes. In addition, it is subject to inter-annual climate fluctuations associated with El Niño (ENSO), which affect precipitation as well as air and sea temperatures. Periods of drought in the islands have been linked to the ENSO. There is no simple association between increases in mean surface temperature and the frequency of tropical cyclones, partly because of the strong influence of ENSO cycles on tropical storms in the Pacific and partly because climate models have difficulty in simulating tropical storm activity (IWTC 2006). Still, many climate scientists believe that climate change will lead to some increase in the intensity of tropical cyclones—an increase of 3–5 percent in peak wind speed per 1°C rise in sea surface temperature—accompanied by greater variability of rainfall with more frequent episodes of very heavy rainfall and drought.

Approximately 70 percent of the population of Samoa lives in low-lying areas, which would be vulnerable to inundation as a consequence of the combined effects of sea level rise, more severe storm surges, and flooding caused by heavier rainfall. As an illustration of the risks, two major cyclones (Ofa and Val) hit or passed near to one of the two main islands in 1990–91, damaging a majority of buildings and causing a total economic loss including asset damage and the capitalized value of lost GDP of about $550 million at 2005 prices, equivalent to about 3.75 times GDP in 1990. While these events were considered to be unprecedented within the previous 100 years, an increase in the probability of such large losses from 1-in-100 years to 1-in-50 years or even 1-in-25 years would clearly be very significant.

EACC approach and results

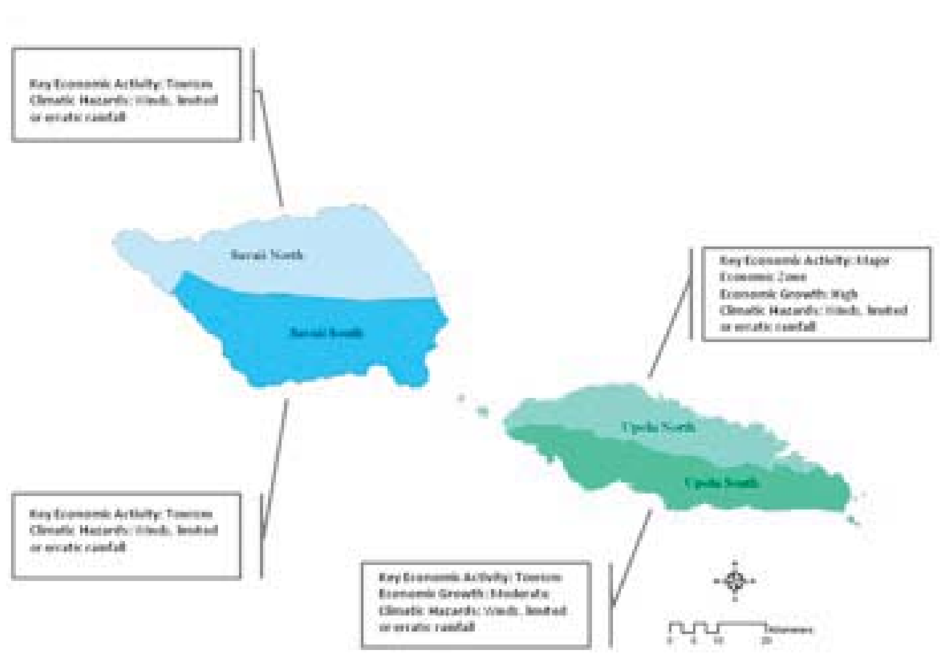
The EACC study focuses on the impact of, and adaptation to, a shift in the probability distribution of tropical storms affecting the islands. The severity of such storms is measured by their peak wind speed over a period of 10 minutes. Wind speed is associated directly with the amount of wind damage caused by a storm. Further, it serves as a proxy for the intensity of precipitation and the height of storm surges, which are associated with flood damage in coastal and non-coastal zones. Since storms that hit the islands and cause significant damage are infrequent events, the analysis examines how climate change will affect the expected annual value of storm damage expressed as a percentage of GDP under the alternative climate scenarios. The extent of such damage depends upon a combination of (a) the resilience to storm damage that is designed into buildings and other assets, and (b) other measures to reduce the vulnerability of communities to flooding and wind damage.

The study divided Samoa into four economic regions (Figure 29). North Upolu has a population of about 110,000, while the populations of the other regions fall between 17,000 and 28,000. Table 17 shows baseline values and changes in precipitation over different periods—the whole year, the rainy season from November to April, and the main cyclone season from December to February—and mean temperatures by region derived from the Global Wet (NCAR) and Global Dry (CSIRO) scenarios. The rise in mean temperature is consistent across regions and falls in the range of 0.8 to 1°C for the two climate scenarios. However, total precipitation declines marginally in three out of four regions under the NCAR scenario, but increases significantly in the CSIRO scenario. For all regions and both scenarios, precipitation tends to increase during the months of November, March, and April, leading to the likelihood that the length of the main cyclone season will increase. Because the impact of climate change on the intensity of the worst cyclones is uncertain, the analysis examined the effect of an increase in the peak wind speed for a 1 in 100 year storm in a range from 4 percent (low) to 8 percent (high) for 2050, and from 10 percent (low) to 25 percent (high) for 2100. In addition, the extent of potential damage caused by flooding at other times was linked to changes in the amount of precipitation during the rainy season, using the NCAR climate scenario as the low scenario and the CSIRO climate scenario as the high scenario.

The data available for Samoa cannot sustain a conventional CGE model, so a simple macro model of climate and economic growth has been used to examine the effects of climate change on the economy. To maintain the baseline level of economic growth, this assumes that changes in the expected value of damage

FIGURE 29

REGIONS OF SAMOA USED IN THE CLIMATE-ECONOMY MODEL



Source: World Bank 2010h.

TABLE 17

DEVIATIONS IN PRECIPITATION AND TEMPERATURE IN 2050 BY CLIMATE SCENARIO

Scenario	Region	Baseline values for NoCC				Deviations in 2050 relative to NoCC			
		Total precipit.	Precipit. Dec-Feb	Precipit. Nov-Apr	Mean temperat.	Total precipit.	Precipit. Dec-Feb	Precipit. Nov-Apr	Mean temperat.
		mm	mm	mm	°C	mm	Mm	mm	°C
NCAR	Savai'I N	2,958	1,062	1,921	26.87	-17	-39	5	0.99
NCAR	Savai'i S.	3,002	1,107	1,971	26.86	-19	-41	3	0.99
NCAR	Upolu N.	3,048	1,154	2,024	26.83	-21	-42	0	0.99
NCAR	Upolu S.	2,929	1,090	1,942	26.67	106	-8	118	0.97
CSIRO	Savai'i N	2,958	1,062	1,921	26.87	277	43	197	0.81
CSIRO	Savai'i S.	3,002	1,107	1,971	26.86	343	65	215	0.83
CSIRO	Upolu N.	3,048	1,154	2,024	26.83	344	68	218	0.83
CSIRO	Upolu S.	2,929	1,090	1,942	26.67	335	66	213	0.83

Note: NoCC=no climate change.
Source: World Bank 2010h.

caused by storms fall on total consumption, so that the economic impact of climate change is measured by the changes in the present value (discounted at 5 percent) of consumption over the period 2010–50 relative to the no climate change (NoCC) baseline.

Impacts. The gross economic losses under two scenarios of low and high impact when there is climate change without adaptation are shown in Columns (1) and (2) of Table 18. The impact of climate change under the high-impact scenario amounts to $212 million at 2005 prices in present value terms. On an annualized basis, this is equivalent to $12.1 million at 2005 prices per year, or 1.3 percent of total GDP in the baseline scenario.

There is one sphere in which the impacts of climate change may be smaller than is often assumed. Agriculture provides the main source of employment for about one-third of the labor force, but it represents a small and declining share of GDP—about 6 percent for agriculture in 2008. Variations in the ENSO cycle have had a statistically significant impact on taro production and agricultural imports. Even so, non-climate factors—for example, the taro blight in the 1990s—are more important sources of risk for agricultural incomes than climate change. Managing non-climate risks better will also reduce the potential impact of future climate variability on agricultural incomes.

Adaptation. The key form of adaptation is the implementation of design standards to ensure that buildings and other assets can cope with higher winds and more intense precipitation without damage. The effectiveness of this approach can be illustrated by analysis of the damage caused by Cyclone Heta in 2004. This was approximately a 1-in-11 year event with a peak wind speed of 110 kph, but it caused very limited economic damage. Had design standards in force in 2004 been similar to those in 1990–91, when Cyclones Ofa and Val hit the country, the economic loss would have been much higher at 35–40 percent of GDP. The reduction in potential damage was a consequence of changes in design standards and other measures that increased the effective threshold for storm damage from 1-in-5 year events (a peak wind speed of 90 kph) to 1-in-10 year events (a peak wind speed of 108 kph). The estimates of net economic losses with adaptation in Table 18 assume that the current standard of a 1-in-10 year

TABLE 18

LOSSES DUE TO CLIMATE CHANGE WITHOUT AND WITH ADAPTATION

	Gross losses without adaptation		Net losses with adaptation		Net benefits of adaptation	
	NCAR	CSIRO	NCAR	CSIRO	NCAR	CSIRO
	(1)	(2)	(3)	(4)	(5)	(6)
Present value @ 5%, $ million	103.9	212.4	4.5	5.4	99.4	207.0
Annualized equivalent, $ million per year	5.9	12.1	0.3	0.3	5.6	11.8
Loss/benefit as % of baseline GDP	0.6	1.3	0.0	0.0	0.6	1.3

Source: World Bank 2010h.

storm is applied in estimating the costs of adaptation and the residual damage after adaptation.

However, analysis carried out for the EACC global study indicates that the benefits of strengthening buildings and infrastructure to withstand the wind and precipitation associated with a 1-in-50 year storm (peak wind speed ~ 148 kph) would exceed the costs involved by a large margin even under an assumption of no climate change. The present value of adopting the stricter design standard as a consequence of a lower expected value of storm damage would exceed $275 million after allowing for the additional costs of construction. This would be a "no regrets" form of adaptation, because it would greatly reduce the economic impact of climate change under any climate scenario. With a 1-in-50 year standard, the present value of gross losses from climate change would fall from $212 million to $37 million for the high climate scenario.

Further spending on adaptation to protect against 1-in-50 year storms up to 2100 under the high scenario (peak wind speed ~ 184 kph) would also pass a cost-benefit test. The estimates of net economic losses with adaptation in Table 18 assume that a standard of a 1-in-50 year storm is applied in estimating the costs of adaptation and the residual damage after adaptation.

For agriculture the key element of an adaptation strategy is to increase expenditures on research, development, and advisory services so as to mitigate the higher risks that are likely to be associated with

climate change. Again, this is building upon policies that would form part of a sound development strategy. Samoan agriculture was hit hard by the taro blight in the mid-1990s, which devastated taro production and eliminated export revenues from taro for nearly 15 years. Vulnerability to disease, pests, and storm damage means that diversification of both crop varieties and crops is an important element in any policy to limit the impact of these risks on agricultural households. Since climate change is likely to reinforce these risks, the appropriate level of expenditure will be higher to reflect the greater value placed on risk reduction.

Other adaptation measures, largely drawn from NAPA, were considered in each of the regions. It is assumed that adaptation measures are only implemented in a particular region when or if the resulting reduction in the expected value of economic losses due to climate change exceeds the annualized cost of the adaptation measures. This is a simple cost-benefit test designed to optimize the timing of expenditures on adaptation.

- *Coastal zone infrastructure*. These include the construction of sea dikes to protect infrastructure along vulnerable parts of the coast or the relocation of key assets such as roads or schools out of potential flood zones. Measures to encourage villages to relocate away from flood zones entirely, such as extending the national power grid and building new roads, were also included. This approach is being applied in parts of the south coast of Upolu in response to the 2009 tsunami. The largest costs are associated with the relocation of utility infrastructure (power, roads, water reticulation, water treatment and telecommunications) for a village—estimated at $32 million—but the initial investment is expected to be partly offset by greater income from tourism, plantations, and other activities.

- *Water supply.* Ensuring better access to good quality water for communities was the main priority in the NAPA. This is an example of the overlap between development priorities and adaptation to climate change. There is little doubt that measures such as decreasing leaks in the reticulated water supply, improvements in catchment management, and better water treatment at the source are justified even without climate change.

- *Tourism.* Adaptation in tourism focuses on the provision of niche tourist facilities, including inland (rain-forest) resorts that are away from the coast.
- *Food security.* This includes improvements in the operation of existing plantations, the promotion of village based micro-enterprises, research into crop changes, and sustainable fishing.
- *Urban development*. This is particularly important in Upolu North, where a better approach to planning land use and urban development is needed. In view of the vulnerability of urban infrastructure to storm damage, adaptation must focus on enhancing the resilience of the key commercial and economic zones to extreme weather shocks.

Columns 3 and 4 of Table 18 show the net economic losses due to climate change with adaptation, allowing for the cost of implementing the adaptation measures. The net benefits of adaptation are shown in columns 5 and 6. They amount to $99 million at 2005 prices for the low scenario and $207 million for the high scenario.

Adaptation measures involving the adoption of more stringent design standards are clearly justified, even in the low scenario for which the gross losses due to climate change are relatively small. However, under the low scenario the other adaptation measures outlined above do not reduce climate losses by a sufficient margin to cover their costs, though they may be warranted for other reasons. Under the high scenario, these adaptation measures should be implemented in the period 2025–29 in both Savai'i North & Savai'i South and in the period 2030–35 in Upolu North, but not before 2050 in Upolu South. Again, several of the adaptation measures —for example, moving coastal infrastructure in Upolu South and improving water supply—would be justified for non-climate reasons.

Table 19 shows the composition of adaptation costs by category and decade. Most of the cost of adaptation for housing will fall upon households. This may be regarded as a form of autonomous adaptation, so the table shows the total cost of adaptation including and excluding housing. The main costs are incurred for housing, municipal infrastructure—which covers public buildings and storm water drainage—and agriculture and fisheries. When expressed as a percentage of the cost of providing the relevant services in the baseline scenario, the average increases vary from 1 percent of baseline costs for electricity and telecom to 6 percent for housing. As might be expected, the burden of adaptation rises over time as the probability distribution of severe storms shifts. Over the whole period from 2010 to 2050, the increase is 3.5 percent for infrastructure excluding housing, and 4.1 percent including housing.

Local-level perspectives on adaptation. The EACC study did not carry out a social assessment of climate change in Samoa. Nonetheless, the country has started to address the potential impacts of a greater frequency and intensity of cyclones through a combination of stronger institutions, better governance, and robust planning. This will underpin a variety of soft adaptation actions, such as re-orienting coastal infrastructure management and developing community disaster plans.

Samoa's cultural context is an important factor when selecting adaptation measures. The traditional model of community decision making is by consensus under the leadership of the *matai* (chief). The authority of a village *matai* and customary land ownership rights are respected, so negotiations between the government and village *matai* can often take a long time. There is a commitment to supporting village-based

TABLE 19

AVERAGE ADAPTATION COSTS BY DECADE, HIGH SCENARIO, 2005 $ MILLION/YEAR, NO DISCOUNTING

	2010–19	2020–29	2030–39	2040–49
Agriculture & fisheries	0.99	1.47	2.03	2.66
Coastal protection	0.03	0.03	0.03	0.03
Education & health	0.13	0.18	0.30	0.44
Electricity & telecom	0.08	0.11	0.17	0.20
Housing	0.55	1.07	1.93	3.16
Municipal	0.86	1.39	2.22	2.98
Other transport	0.08	0.13	0.22	0.36
Roads	0.52	0.68	0.82	0.93
Water & sewer	0.03	0.04	0.07	0.10
Total	3.26	5.11	7.78	10.86
Total excl housing	2.71	4.04	5.85	7.70

Source: World Bank 2010h.

consultations that include women and youth. Raising awareness of climate change and other development concerns through village-based consultation is an effective and sustainable way of supporting the traditional decision-making model. Nevertheless, women and migrants in the poorer communities remain among the most vulnerable groups in the community. Stakeholders at workshops held during the preparation of the NAPA identified the following areas as critical to a strategy for adapting to climate change: the protection of community water supplies, early warning systems, support for agriculture and forestry sectors, implementation of coastal infrastructure management plans, and integrated catchment management.

Lessons and Recommendations

Samoa is a small island nation with most of its population and infrastructure located along the coast, so it is highly vulnerable to extreme weather events. However, Samoa is also among the more climate-resilient Pacific Island countries, and there is much to learn from the way it is approaching climate change and related development issues. Over the last decade it has focused on increasing the capacity of its institutions, which are necessary for the implementation of soft approaches to adaptation, including land-use controls and coastal infrastructure management.

- One key lesson is that extreme weather variability in the coastal zone will involve significant costs for either investments in coastal protection or the relocation of assets. In the longer term, the relocation of assets—or, even whole villages—may be the best option as it can shift economic activity such as tourism, crops, and other businesses away from the coast.
- The uncertainty about climate outcomes and lack of baseline data has led to a focus on the collection of information in Samoa. More effort is needed to support the collection and analysis of this information and use of the information to inform decision making.
- Good development policies are a foundation for climate change adaptation. The participatory

consultations undertaken across the country in developing plans for managing coastal infrastructure are continuing with a focus on other development and adaptation issues.

- The analysis suggests that the country should consider, as a good development policy even in the absence of climate change, the adoption of design standards that would enable buildings and infrastructure assets to cope with 1-in-50 year storms under historical climate conditions without significant damage. This would imply that buildings and infrastructure should be designed to withstand storms with a peak wind speed of up to 148 kph. Such a policy is a "no regrets" form of adaptation whose benefits exceed its costs even without climate change, but will yield even larger benefits if climate change leads to more intense storms in future.

- Going beyond "no regrets" adaptation, the key measure identified in the study is the adoption of design standards that will enable buildings and other assets to cope with storms with higher peak wind speeds and associated precipitation looking forward to 2100 under alternative climate scenarios. Retaining the 1-in-50 year criterion would mean buildings and infrastructure should be designed to withstand storms with a peak wind speed up to 184 kph under the worst climate scenario. Under this strategy, the expected losses from climate change would be greatly reduced.

Five

Lessons

Extracting robust general conclusions across diverse countries with respect to an uncertain and broad phenomenon like climate change is a perilous task. Too much generality leads to banal and potentially uninformative conclusions. Excessive specificity is unhelpful as a basis for useful generalizations. We have attempted to strike an appropriate balance. The recommendations follow from the lessons of the country and global exercises.

The costs of adapting to climate change

Past and prospective future emissions mean that some amount of climate change is inevitable over the next century, even though the extent and nature of the changes are uncertain. Adapting to a climate that is about 2°C warmer will be costly, but our country studies show that the impacts of climate change without adaptation will be much more costly. The study puts the cost of adapting to climate change at an average of $70 billion to $100 billion a year at 2005 prices between 2010 and 2050. The cost amounts to 0.2 percent of projected GDP for all developing countries in the current decade and falls to about 0.12 percent of projected GDP for 2040–49. This cost is large when compared to current levels of development aid, as $100 billion is 80 percent of the total disbursement of ODA in 2008.

The averages across all developing countries hide a very uneven distribution of the burden of adaptation across regions as well as decades. Our estimates of the overall cost of adaptation are 0.6–0.7 percent of GDP for the Sub-Saharan Africa region in 2010–19, falling to about 0.5 percent of GDP in 2040—49. In contrast, the equivalent figures for the East Asia and Pacific region are 0.13–0.19 percent in 2010–19 and about 0.07 percent in 2040–49. Apart from Sub-Saharan Africa, the regions facing high relative costs of adaptation are the Latin America and Caribbean region and (under the dry climate scenario) the South Asia region.

The absolute costs of adaptation increase over time and will certainly continue to increase after 2050. Our projections suggest that real GDP will increase more rapidly than the costs of adaptation during the next four decades, even on quite conservative assumptions about growth in GDP per person. However, it would be unsafe to assume that this trend will continue into the second half of the current century.

LESSON 1:
The cost of developing countries to adapt to climate change between 2010 and 2050 is estimated at $70 billion to $100 billion a year at 2005 prices. This amounts to about "only" 0.2 percent of the projected GDP of all developing countries in the current decade, and at the same time to as much as 80 percent of total disbursement of ODA in 2008.

In a few of the country studies—Bangladesh, Samoa and Vietnam—it was possible to make limited comparisons between adaptation costs estimated in the global analysis and in the country study. Where like could be compared with like, the separate estimates were in reasonable agreement. However, the analysis suggested that the costs of strengthening infrastructure to provide resilience against the wind damage, precipitation and flooding caused by infrequent but severe tropical storms could increase the overall cost of adaptation by 10-20% under the worst scenario relative to the global estimates for countries that are most exposed to such storms. This cannot be directly linked to any particular climate scenario, since the worst storm scenario depends upon (a) how ocean temperatures respond to climate change, and (b) changes in the tail of the distribution of extreme weather events. This adjustment does not alter the overall range of adaptation costs, since the countries affected account while the range is based on estimates with a strong upward bias.

On the other hand, the analysis in the Ethiopia country study suggests that cross-sectoral effects of adaptation measures (not considered under the global track) could increase the overall costs of adaptation. It is hard to generalize from the one country case to estimate the extent of bias, but it is important that future research explore this bias which reflects the opportunity cost or forgone benefits from allocating resources to adaptation measures instead of allocating them to other development initiatives.

Economic development and adaption to climate change

The link between economic development and adaptation to climate change is fundamental.

- *Economic development is the most basic and cost-effective method of adaptation*, provided that it is properly managed. Richer countries are more resilient to weather variability. Economic development brings changes in economic activities that reduce vulnerability to climate, both in aggregate and for the poor when their interests are built into development strategies.

- Economic development generates both the resources and opportunities to adapt to climate change at a relatively low cost by ensuring that the design and location of new infrastructure, buildings, and other assets take account of the effects of climate change on their performance.

- Our country studies show that a failure to adapt to climate change may lead to very large weather-related losses, both in terms of the destruction of infrastructure and foregone opportunities for future growth. In Ethiopia, for example, robust growth based on infrastructure investment is the first line of defense against climate change impacts. At the same time the design of new infrastructure must take account of future weather stresses and existing infrastructure must be upgraded and/or replaced where it cannot cope with such stresses.

Bangladesh, Ghana, Mozambique and Vietnam rely upon large rivers that are affected by the investment and operational decisions made by upstream riparian countries. Such decisions determine the availability of water resources for irrigation, hydro-power and other uses as well as vulnerability to flooding. For example, Vietnam's capacity to respond to climate change will, in part, depend upon upstream developments in the Mekong River basin, but this will also affect investments in and the management of irrigation and aquaculture even without climate change. More extensive and effective cooperation between the countries that share international river basins will be crucial both for economic development and for adaptation to climate change.

The existing management of water resources and irrigation systems was highlighted as a key issue for both development and adaptation in the country studies for Bolivia, Samoa and Vietnam. In these studies, access to and the availability of water for public water supply and irrigation systems were identified as key concerns in the social vulnerability studies and for the economic impact of climate change. These studies identified a combination of more investment in and better management of existing water infrastructure as yielding immediate development benefits as well as enabling communities to adapt more easily to a range of future climate scenarios.

Another example of the overlap between development and adaptation concerns autonomous adaptation in agriculture in countries such as Bolivia, Ethiopia, Mozambique and Vietnam. The dissemination and adoption of improved agricultural practices including drought-resistant crop varieties, fertiliser use and better water management will be critical for maintaining agricultural production and incomes under different climate scenarios. But, equally, enhancing the capacity of small farmers to take advantage of more productive agricultural technologies is crucial for economic development under any scenario. This would include crop insurance and other mechanisms for redistributing the risks of weather and other agricultural risks with or without climate change.

LESSON 2:
Economic development is a central element of adaptation to climate change, but it should not be business as usual.

Countries that reach the middle of the 21st century with large shares of their populations engaged in subsistence agriculture, with substantial illiteracy, and with lethargic and/or inept institutions will be particularly vulnerable to the effects of climate change. Rapid development leads to a more flexible and resilient society, so that building human and social capital—including education, social protection, and health and skills training—are crucial to adaptation.

In all case-study countries, the burden of existing climate variability is especially heavy in areas that have high concentrations of poor and socially vulnerable populations. Climate change exacerbates this pattern. For example, the rural poor in the southern region of Bangladesh are expected to face the largest declines in per capita consumption, as well as declining productivity of subsistence crops and land losses due to increased salinity brought forth by sea level rise. The Vietnam study suggested that the impact of climate change falls disproportionately on households in the lowest quintiles of the rural and urban income distributions. Adaptation through agricultural improvement and expansion of irrigation largely offset this impact and may reduce inequality relative to the outcome with no climate change.

Rapid urban growth will be a key aspect of economic development in countries such as Bolivia, Ethiopia, Ghana and Mozambique. Some of the country studies examined investment in human capital as part of strategies to adapt to climate change. Under most climate scenarios, expenditure on equipping rural populations and urban migrants with better education and market-driven skills is a cost-effective response to climate change. At the same time, these country studies highlighted the risk that the growth of cities will expose more people to the consequences of poor urban management, such as flooding and lack of sanitation, that are likely to be exacerbated by climate change unless appropriate social and physical infrastructure is put in place.

LESSON 3:
Invest in human capital, develop competent and flexible institutions, focus on weather resilience and adaptive capacity, and tackle the root causes of poverty. Eliminating poverty is central to both development and adaptation, since poverty exacerbates vulnerability to weather variability as well as climate change.

Climate uncertainty: the need for robust strategies

The fundamental problem of making public policy in the face of climate change is one of uncertainty with regard to both climate outcomes and longer term projections of social and economic development. Even though the uncertainties regarding the socioeconomic projections are more frequently discussed in the context of broader development planning, they should not be entirely shadowed by climate uncertainties. In Bangladesh, for example, the number of people living in cities by 2050 is expected to triple, while the rural population falls by 30 percent. Current policies will determine where this urban population settles and how prepared it is to adapt to a changed climate. Adaptation decisions to be made now can prove to be significantly wrong, and thus costly, if such socioeconomic projections end up being wrong.

In terms of climate outcomes, such uncertainty is particularly large for patterns of precipitation. Some of the country studies have highlighted crucial differences between alternative wet and dry scenarios and their effects on agricultural production, water resources, and transport infrastructure. This uncertainty about the underlying trends in climate variables is exacerbated by the expectation that the variability of weather indicators around climate averages will increase, making it even more difficult to reach reliable conclusions on what is weather variability and what are climate trends.

The general economic equilibrium analyses in Ethiopia, for example, suggested that the cost of adaptation varies by a factor of 3, depending on the climate scenario considered. Thus the cost of selecting the "wrong" strategy may be considerable. Under these circumstances, the value of reducing uncertainty about future climate outcomes is extremely high, since it would help better define what kinds of adaptation (viewed as a form of insurance) are most appropriate. It also follows that making investment decisions based on any one climate scenario is no more justified than basing it on another. Attempting to hedge against most or all climate outcomes obviously may raise the cost of adaptation very substantially.

It also follows from this analysis that countries should want to delay adaptation decisions as much as possible and focus on low-regret actions, while awaiting greater certainty about climate and socioeconomic scenarios. Low-regret actions are those actions that are robust under most climate scenarios. *They are typically policies or investments that can be identified as priorities for development even without climate change.* Our country studies included a number of these strategies. For example, investments to expand the road system and increase the share of paved roads in Africa yield high returns by lowering transport costs and expanding markets. At the same time they lessen the impact of floods and enhance the ability of farmers to respond to changes in agricultural comparative advantage. Similarly, better management of water resources; improved access to extension services, fertilizers, and improved seed varieties; and better climate and weather forecasting will enhance the resilience of agriculture, both to droughts, and to waterlogging caused by floods.

Apart from promoting these low-regret measures, which include many "soft" adaptation alternatives, it is also important to subject long-lived, expensive infrastructure such as dams and other water infrastructure to careful climate-robustness tests. In Mozambique, the recommendation coming out of our study is clearly toward delaying investments in large coastal protection schemes, and focusing more on the people affected than on the land lost. The expensive option of constructing dikes would be justified only for vital coastal infrastructure, such as the port of Beira. In Bangladesh, a no-regrets strategy would be to begin by addressing the adaptation deficit and strengthening the early warning systems. Additional embankments and shelters can be constructed in the medium term as the geographic incidence of risk becomes more certain.

Bolivia and Ethiopia are two countries with large differences between the effects of the extreme Wet and Dry climate scenarios, especially in highland areas such as the Altiplano and the Rift Valley plateau. These are areas that are already prone to both intermittent droughts and intense rainfall causing severe flooding. Major investments to manage water resources might be warranted under some climate scenarios but not under others. Hence, the studies identify a variety of more limited measures which are designed to increase the resilience of agriculture and economic activity to existing weather risks and which can be justified under a wide range of possible climate outcomes. In the longer term, larger investments for adaptation may be warranted if the uncertainty about the effects of climate change has been greatly reduced.

LESSON 4:
Do not rush into making long-lived investments in adaptation unless they are robust to a wide range of climate outcomes or until the range of uncertainty about future weather variability and climate has narrowed. Start with low-regret options.

Current climate vulnerabilities

Climate change will always hide beneath weather variability. Systems that can effectively cope with existing weather risks will be more successful in adapting to future climate change than those that cannot. The short-term priority is to better prepare for the weather risks that countries are already facing.

One clear example concerns the impact of storms, especially in coastal areas. Despite the uncertainty over future rainfall, there is relative certainty that a warmer climate will lead to rising sea levels and an increased intensity of storms. With the inevitable increase in urban populations, the costs of failing to protect coastal cities against major storms will increase rapidly. At the same time, the deficiencies of storm water drainage in coastal or inland cities has already led to avoidable—and sometimes large—losses caused by urban flooding that have disproportionate effects on the health and welfare of the poor.

Many of the country studies illustrate the contribution that better methods of managing existing weather risks can make in lowering the costs of adapting to climate change. In each of the Africa case studies damage to roads and transport caused by intermittent flooding is a major factor determining the losses associated with alternative climate scenarios. This damage can be reduced, sometimes by a large amount, simply by reallocating the budgets for road construction and maintenance to build fewer but stronger roads. With a few exceptions this is a no regrets strategy that will pay off under a wide range of climate scenarios.

A similar conclusion emerges from the Samoa case study, in which strengthening buildings and infrastructure so that they can withstand 1 in 50 or 100 year storms under today's climate would reduce the potential losses due to climate change by more than 80% without any further adaptation. While resilience to extreme weather events was not examined in detail in all of the country studies, the analyses for Bangladesh, Mozambique and Vietnam all indicate that the adoption of construction standards and investment strategies which are more resilient to current weather risks can greatly reduce both storm damage in the near future and the costs of adaptation to climate change in the longer term.

LESSON 5:
Adaptation to climate change should start with the adoption of measures that tackle the weather risks that countries already face, such as more investment in water storage in drought-prone basins or protection against storms and flooding in coastal zones and/or urban areas. Climate change will exacerbate these risks.

The prospect of greater weather variability has an additional, rather more difficult, implication. Economic development has been accompanied by a tendency for more rapid urban growth in coastal areas than in inland cities. This may reflect relative differences in transport costs as well as government policies or individual preferences. There will be many opportunities to reduce weather risks and the associated costs via intelligent urban and land-use planning. Whether in rural or urban areas, the rule of thumb is simple: wherever possible, ensure that future growth and infrastructure takes place in locations that are less exposed to weather risks.

In addition to the need to subject large investments in protecting coastal infrastructure to great scrutiny to ensure robustness to different climate scenarios, appropriate incentives must be put in place that discourage the accumulation of physical capital in the shadow of dikes considered to be "safe." As the tragedy of New Orleans dramatically illustrated, a sufficiently extreme event will breach a dike. The combination of an increasing severity of extreme events, the high costs of providing physical protection, and the accumulation of capital behind such barriers can mean that the expected value of losses, including human suffering, may not be reduced, either at all or by as much as expected by investments in protection.

Similar concerns apply to efforts to maintain the welfare of populations engaged in agriculture and other resource-intensive activities that are sensitive to climate variability and change. Short-term measures to prevent suffering must be complemented by long-term measures such as education, job training, and resettlement designed to reduce reliance on resources and assets whose value may be eroded by climate change. Adaptation should not attempt to resist the impact of climate change, but rather it should offer a path by which accommodation to its effects can be made less disruptive and does not fall disproportionately on the poor and the vulnerable.

The country study for Samoa highlighted the difficulty of managing coastal development in a country with high exposure to natural hazards. Coastal locations are attractive and easy to develop but buildings and infrastructure have been badly damaged by storm surges or tsunamis. On the other hand, relocating existing infrastructure is expensive and may be hard to justify. Either such investments should be minimised or they should built/ upgraded so that they are capable of withstanding more severe weather and other risks.

Similarly, the country studies for Bolivia and Ethiopia highlight the importance of managing agricultural expansion in drought-prone areas, especially in places where droughts may become more frequent or severe as a consequence of climate change. This may be economic with sufficient investment in developing drought-resistant crop varieties and water infrastructure, but too often such expansion has been a response to pressure on land resources. Once such expansion has occurred it becomes more difficult and expensive to adapt to adverse climate outcomes.

A final example of the same mistake is permitting the development of housing and urban infrastructure in flood plains, which is a significant problem in Bangladesh, Ghana and Mozambique.

LESSON 6:
Beware of creating incentives that encourage development in locations exposed to severe weather risks. Where possible, build future cities out of harm's way, particularly flood plains or coastal zones that are exposed to sea level rise and storm surges.

Hard vs. soft approaches to adaptation

The distinction between "hard" (capital-intensive) and "soft" (institutions and policies) adaptation is easily exaggerated. The reality is that both approaches are necessary. There is no point in building the best type of road in the wrong place, while the best institutions will provide no protection against a storm that destroys buildings or power lines. Thus, the challenge is to get the balance between hard and soft adaptation right. In some field sites in Vietnam, re-establishment or migration of mangroves was ranked above spending money on sea walls, given the lower costs of mangrove planting and the potential for this activity to be more pro-poor.

Nonetheless, pouring concrete is often a very expensive and relatively ineffective method of adaptation. The importance of keeping infrastructure and urban

development out of harm's way is a key illustration of the costs of creating perverse incentives that encourage behavior and investments that worsen rather than reduce the prospective impacts of climate change. Equally, however, experience shows that the difficulties in devising and implementing soft measures are often underestimated because they may involve changes in expectations or (quasi-) established property rights that are strongly resisted.

The analysis of the global costs of adaptation relies heavily on the costs of hard measures. It is much simpler to estimate the costs of new or replacement investment to provide protection against the effects of climate change than it is to estimate the costs of creating new institutions and implementing better policies. In many cases the monetary costs of soft adaptation are zero or negative in the longer run, because the changes bring greater benefits than merely adaptation to climate change. Unfortunately, the political and social costs may be perceived as being very high, while the wider benefits are hard to assess and, sometimes, to achieve.

This is part of the larger theme that economic development is the best form of adaptation. Implementing good policies and developing effective institutions should be pursued simply because they yield large economic and social benefits. Once this is done, the incremental cost of planning for adaptation to climate change is minimal, because it should form a regular element of the responsibilities of institutions and the design of policies. All EACC estimates rely upon the assumption that investments in adaptation take place within a framework of appropriate development policies and efficient management of the economic sectors.

The social analyses in all countries pointed to the need and importance of improvements in safety nets, community-based resource management systems, and disaster preparedness. It is also necessary to accelerate the decentralization process and devolve decision making to the local level to promote local-level adaptation and preparedness. Some of the economic models incorporated soft adaptation measures in agriculture, such as improvements in extension services and marketing networks. Others should be exploited, such as research and development of early maturing plant varieties and other innovations related to impacts of climate change on crops, livestock products, and pest control, as well as improvements in land tenure systems and improved entrepreneurial skills to generate off-farm income. In the transport sector, some significant soft approaches include proper timing of road construction, routine and timely road maintenance, and upgraded road design specifications (including the choice of materials).

In Ghana, a number of soft measures were given priority over hard measures, including (a) upgrading peri-urban slums and controlling the development of new ones; (b) the protection, management, and sustainable use of coastal wetlands; and (c) a review of Ghana's coastal development plans to take into consideration climate change adaptation, including strengthened protection of coastlines and ports; additional flood protection measures; and greater attention to the protection of coastal communities and fishery industry.

Several of the country studies—e.g. Bolivia, Mozambique and Vietnam—emphasise the links between autonomous and planned adaptation in agriculture, forestry and aquaculture in responding to the effects of climate change. Usually the planned adaptation involves some combination of expenditures on agricultural research and extension and investment in irrigation development. At the same time, it is important to ensure that market structures and incentives support the adoption of improved methods of production. This was particularly evident for catfish cultivation in Vietnam for which autonomous adaptation is likely to be dominant, provided that producer margins are not squeezed by processors and export companies.

LESSON 7:
Hard and soft approaches to adaptation are two sides of the same coin. Good policies, planning, and institutions are essential to ensure that more capital-intensive measures are used in the right circumstances and yield the expected benefits.

Conclusion

The related messages of uncertainty, flexibility, and time are central to this report. Some specific conclusions may be drawn about the implications of climate change and appropriate adaptation measures. But even more remains uncertain, so that the essence of adaptation is learning how to cope with greater levels of uncertainty. Shifting resources toward more productive uses and away from less productive ones in the context of uncertainty is already a principal aim of development. Climate change increases the importance of achieving this aim, but it makes the task more complex. Time is also crucial. On some issues it is possible—and necessary—to implement adaptation measures within the next 5–10 years, but the whole process will extend over many decades. It is trivial to note that investments designed for a future that never materializes should be avoided. It is much less trivial to identify what those investments are. It may be wise to undertake some forms of adaptation now, especially those that provide resilience to a wide range of climate outcomes. But, equally, it may be better to postpone expensive investments in adaptation until there is less uncertainty about whether they will be justified.

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Notes

1. UNFCCC (United Nations Framework Convention on Climate Change), 2007. *Climate Change: Impacts, Vulnerabilities, and Adaptation in Developing Countries*. Bonn, Germany.
2. This number is slightly smaller than the original (US$75 billion) reported in the World Bank 2010a, reflecting our revised estimates in the agricultural sector.
3. This number is slightly smaller than the original (US$75 Billion) reported in the World Bank 2010a, reflecting our revised estimates in the agricultural sector.

4 Hughes et al 2010.

5 Nicholls et al 2010.

6 Ward et al 2010.

7 Nelson et al 2010.

8 Pandey 2010.

9. The UNFCCC study only works with our equivalent gross-sum, but we still use our X-sum as the best estimate of the costs. This eventually narrows the difference between the two study results.

10 Climate change after 2050 is not ignored in the analysis. It is assumed that major investment decisions for coastal protection and infrastructure look at climate risks 50 years ahead of the date of investment. Hence, climate conditions projected for 2100 are taken into account in designing and costing sea defenses, roads, buildings, etc that are constructed in 2050.

11 See Kellerer et al. (2004). A widely used approach is to formulate the problem of selecting and scheduling climate-resilient investment alternatives as a project selection model related to the knapsack problem (Weingartner, 1963) and solved as a mixed integer programming problem. A more practical approach is to use real option analysis, where uncertainty (or the risk) is incorporated into the business decision of undertaking or not a certain investment – in this case alternative adaptation actions. Given the paucity of data and the levels of uncertainty, simpler approaches may be called for.

12 In the global analyses, investments in coastal protection and infrastructure have a time horizon of 2100, so that investment decisions can be made 50 years ahead, i.e., in 2050.bb

13 It is important to note that this is the result of both government's desire to work with research teams they have experience with and the project's desire to produce results.

14 Institutional issues were only to be looked at in the context of the social work, and are more widely discussed in the EACC-Social Synthesis Report.

15 These additional costs for the provision of public goods must not be confused with overall economic damages and cannot be usefully compared with mitigation costs.

16 There are a number of reasons why it has not been possible to optimize cross-sectorally and inter-temporally; for example, the CGE models and the sectoral models have been developed separately and generally do permit resources to flow across sectors for which adaptation strategies have been developed.

17 See footnote to Table 2 below. This number is slightly smaller than the original ($75 billion) reported in the EACC global report (World Bank 2010), reflecting our revised estimates in the agricultural sector.

18 Hughes et al 2010.

19 Nicholls et al 2010.

20 Ward et al 2010g.

21 Nelson et al 2010.

22 Pandey 2010.
23 Blankespoor et. al 2010.
24 The UNFCCC study only works with our equivalent gross-sum, but we still use our X-sum as the best estimate of the costs. This eventually narrows the difference between the two study results.
25 World Bank 2010g.
26 The study of sea level rise in Mozambique considers three sea-level rise scenarios—low, medium, and high, ranging between 40cm and 126cm by 2100—following the approach used in the global study.
27 The CGE model takes into account the full transportation sector, including coastal infrastructure. Coastal adaptation options are studied and presented separately.
28 Options include both hard and soft infrastructural components; for example, changes in transportation operation and maintenance, new design standards, transfer of relevant technology to stakeholders, and safety measures.
29 Welfare is measured by aggregate final demand (sum of consumption, investment, and government expenditure).
30 Coefficient of variation (CV) is the standard deviation (SD) divided by the mean of the year-to-year growth rates.
31 World Bank 2010e.
32 World Bank 2010f.
33 It makes no economic sense to invest more than this amount in adaptation measures aimed at making Ghana as well off as it would be in the absence of climate change. If the costs of adaptation policy measures aimed at restoring aggregate welfare to the baseline are higher than the welfare loss from climate change, it would be cheaper to restore welfare through lump-sum compensation payments.
34 World Bank 2010c.
35 The inundation depths and potential vulnerable zones are estimated based on a hydrodynamic modeling system of the Bay of Bengal combined with historical data of inundation depths of all 19 cyclones for the base case, and 5 potential cyclone tracks consisting of the 4 large cyclones of 1974, 1988, 1991, and 2007 for the second scenario.
36 World Bank 2010d.
37 The global wet scenario was drier than the Bolivia Wet Scenario, so it was not considered in the study.
38 1146 mm reported by Aquastat, 1459 mm from PNCC (2007), 1189 mm own estimations from CRU data.
39 Ministry of Environment and Water, 2008.
40 The water supply system of La Paz - El Alto, had suffered a scarcity alert in the wet season of 2008, which was repeated on the fall of 2009. Emergency measures, such as drilling emergency wells were implemented to be able to meet demand levels in those periods.
41 A wet climate scenario was not available at the time of the analysis. Only the Bolivia dry scenario was used for this exercise.
42 Seventy four potential projects have been identified in 16 of the 22 sub-basins. Of these 16 sub-basins, only 3 experience water scarcity prior to 2050, even under the “dry” scenario.
43 The budgetary decentralization rule at the sub-watershed level that was investigated was to provide equal per capita investment resources across all sub-basins and to allow them to optimize independently.
44 World Bank 2010i.
45 World Bank 2010h.

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