EACC

THE ECONOMICS OF ADAPTATION TO CLIMATE CHANGE

A Synthesis Report

FINAL CONSULTATION DRAFT

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1818 H Street, NW

Washington, DC 20433

Telephone: 202-473-1000

Internet: www.worldbank.org

E-mail: feedback@worldbank.org

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ABBREVIATIONS

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
DALY	Disability-adjusted life years
DIVA	Dynamic and Interactive Vulnerability Assessment
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 Oscillation
GCM	General Circulation Model
GDP	Gross Domestic Product
IMPACT	International Model for Policy Analysis
IPCC	Intergovernmental Panel on Climate Change
LAC	Latin America and Caribbean (World Bank Region)
MIP	Mixed Integer Programming
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	Organization for economic Co-operation and Development
PNC	National Watershed Program (by its Spanish acronym)
PPM	Parts per million
PSD	Participatory Scenario Development
RMSI	Regional Maritime Security Initiative
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 Programme
UNFCCC	United Nations Framework Convention on Climate Change
WCRP	World Climate Research Programme
WHO	World Health Organization

I. OVERVIEW

I.1 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" (UNFCCC 2008[1]) to help them adapt to climate change. 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 and others 2009[2]). 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 cost 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 of the governments of Bangladesh, Plurinational State of Bolivia, Ethiopia, Ghana, Mozambique, Samoa, and Vietnam and the World Bank 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.

I.2 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 decisionmakers 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 socio-cultural 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.

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[1] UNFCCC (United Nations Framework Convention on Climate Change). 2007. *Climate Change: Impacts, Vulnerabilities, and Adaptation in Developing Countries*. Bonn, Germany: United Nations Framework Convention on Climate Change.

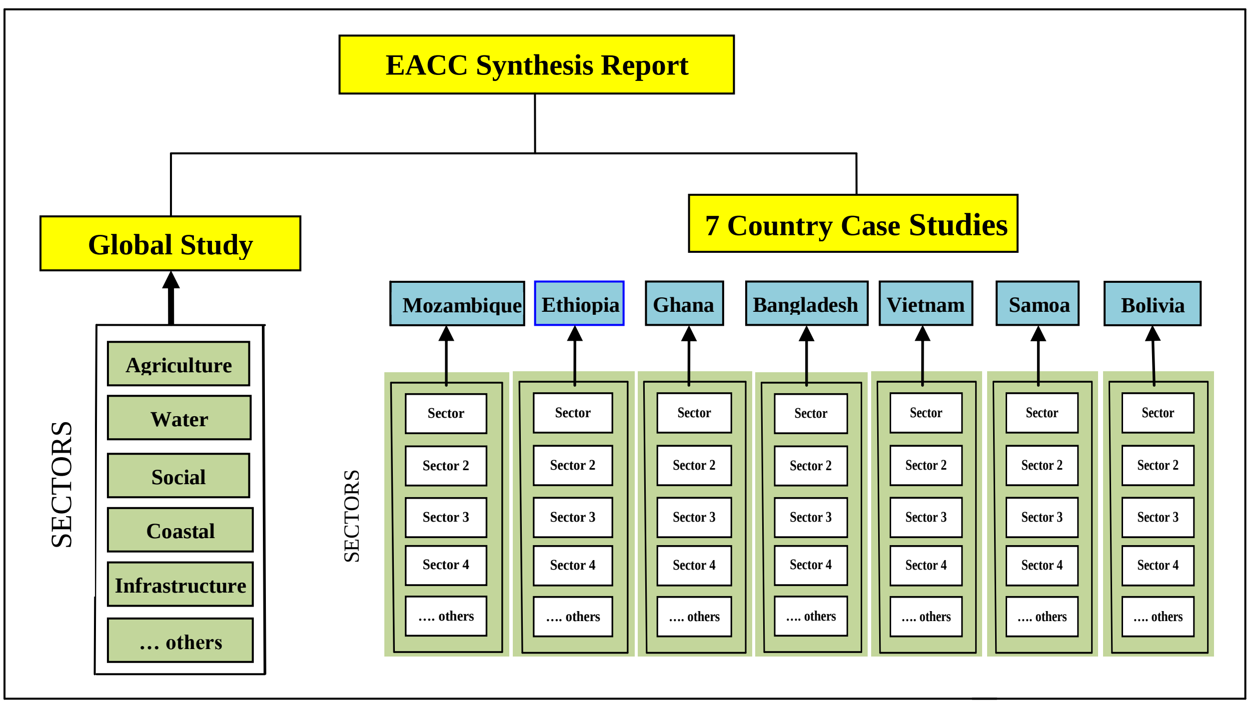
[2] Parry, M., N. Arnell, P. Berry,D. Dodman,S. Fankhauser, C. Hope,S. Kovats, R. Nicholls, D. Satterthwaite, R. Tiffin, and T. Wheeler. 2009. *Assessing the Costs of Adaptation to Climate Change: A review of the UNFCCC and Other Recent Estimates*. London: Internaional Institute for Environment and Development and the Grantham Institute for Climate Change, Imperial College.

I.3 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.

I.4 The Synthesis Report

This Synthesis Report sits at the apex of a *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. The Diagram below depicts graphically 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 Synthesis 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. At the same time, given the political importance of climate change, the findings of this and similar studies are highly relevant for policymaking in both developed and developing countries. This Report, therefore, is aimed at a very broad audience, although it is primarily written having policy-makers in developing countries in mind. Given their different objectives, related EACC reports may be of interest to a very diverse audience.

This Report presents a synthesis of the methodology developed and results derived from research conducted for the EACC global and country study tracks in Bolivia, Bangladesh, Ethiopia, Ghana, Mozambique, Vietnam and Samoa. The report intends to provide information on lessons learned and insights gained on adaptation to climate change from global, country and sector-level analyses. Recommendations are made to help guide prioritization of actions, as well as the development of a robust, integrated approach for increasing resilience to climate risks across scales of action.

The report comprises five main sections. Section II presents the concepts and methodology used for analyses in both the global and the country case studies. Section III introduces the results from the global analysis and Section IV focuses on results from the country analyses. Section V discusses the limitations of the EACC study and the final section presents lessons learned and recommendations for future work.

I.5 Main findings

Based on the global and the country track analyses, the EACC main findings are the following:

- *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% of the projected GDP of all developing countries in the current decade and at the same time to as much as 80% of total disbursement of ODA.*

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

- *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.*

- *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.*

- *Adaptation to climate change should start with the adoption of measures that tackle the weather risks that countries already face, e.g. 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.*

- *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.*

- *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.*

I.6 Recommendations for future work

Important shortcomings of this study relate to three broad categories: uncertainty, institutions, and modeling limitations. They are natural entry points for thinking about future work and knowledge needs.

EACC LIMITATION	RECOMMENDATION FOR FUTURE WORK
Use of mathematical models and no efficiency criterion	Include institutional, social, cultural and political perspectives to identify good policies. Find simpler rules for decision makers
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 range of adaptation	Include a broader range of strategies, including more local level
No environmental services	Pull better information and introduce more consistent estimates

II. CONCEPTS AND METHODOLOGY

II.1 Concepts

Adaptation costs. One of the biggest challenges of the study has been to operationalize the 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 hard to operationalize, however. A simple way of measuring the costs of adaptation involves first establishing a baseline development path (for a country or all countries) with no climate change. The uncertainties here are no different from standard economic forecasts, with the baseline established sector by sector assuming that countries grow along a "reasonable" development path.

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 exceed the costs. This leads to a portfolio of adaptation actions that either improve or deteriorate social welfare relative to a baseline without climate change.

Operationalizing the definition. 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 policymakers may choose an efficient level of adaptation instead. Adaptation costs would then be defined as the cost of actions attempting to restore pre-climate change welfare standards whose marginal benefits exceed marginal costs. Because welfare would not be fully restored, there would be residual damage from climate change after allowing for adaptation.

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. 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. While inextricably linked and reinforcing each other, 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.

Adaptation deficit. The separation of adaptation from development costs often refers to the concept of the adaptation deficit, which captures the notion that countries are underprepared 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*.[3]

II.2 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. (A successful water pricing example?)

- **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).

II.3 Dealing with uncertainty

Uncertainty about climate outcomes. 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. Exposure to extreme weather events; increased water insecurity; sea-level rise; reduced agricultural productivity; increased health risk and aggregate impacts are key factors that contribute to this prevailing uncertainty. In addition, large-scale singularities such as the melting of the Greenland and West Antarctic ice sheets, the collapse of the Atlantic thermohaline circulation, and the die-back of the Amazon—are hard to predict and can

[3]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. Unfortunately, except in the most abstract modeling exercises, the costs of closing the adaptation deficit cannot be made operational. This study therefore does not estimate the costs of closing the adaptation deficit and does not measure adaptation costs relative to a baseline under which the adaptation deficit has been closed, a notable exception being coastal adaptation in Bangladesh.

trigger potentially irreversible and catastrophic processes. Such inherent uncertainties in climate projections suggest that a range of adaptation options and costs should be estimated for a range of climate scenarios.

Hedging. Total adaptation costs for a specific climate projection assume that policymakers know with certainty that a particular climate projection will materialize. But national policymakers do not have such certainty. The current disparities in precipitation projections mean, for example, that ministers of agriculture have to consider the risks of both the wettest and the driest scenarios and thus whether to invest in irrigation to cope with droughts or in drainage to minimize flood damage. Urban planners in flood-prone areas have to decide whether to build dikes (and how high) without knowing whether the future will be wetter or drier.

Both the country analyses and the global analysis have calculated the range of adaptation costs over wet and dry scenarios to bracket adaptation costs between two or three extreme scenarios. This provides a range of estimates for a world in which decisionmakers have perfect foresight. In the real world, where decisionmakers must hedge against a range of outcomes, actual expenditures are potentially much higher than these estimates. This calls for hedging mechanisms across sectors and across countries.

Hierarchy of uncertainty and timing (adapt to what exactly, and when). Rational resource allocation must take account of the degree of uncertainty and timing of climate outcomes. When will it be optimal to start building sea walls in coastal areas? Balancing the uncertainty of the event (including its potential impacts) and the need to mobilize resources that could be used in other priority social programs leads to choices about the timing of adaptation actions and their scale. This may imply that the priorities and sequencing of existing strategic development plans need to be revised. A model is needed that allows governments to prioritize and sequence adaptation strategies in a financially constrained environment and based not only on economic criteria but also on social, institutional, and cultural factors.[4] A pilot exercise was carried out at a sub-basin water level in Bolivia.

Economic forecasts and future technologies. As in similar kind of studies, projections about the future rates of economic growth are subject to great uncertainty. Factors such as population growth, labor productivity, energy availability and prices, and so many others are very difficult to project, particularly at such dilated time horizons as 50 years and beyond. Apart from the intrinsic behavior of such factors, the economic models themselves present numerous limitations which introduce another significant level of uncertainty into projections. Lastly, technology development is an additional factor bringing more uncertainty to projections about the future, especially energy technologies, which will so directly influence the ability of countries to grow while restricting their carbon emissions.

[4] Kellerer, Hans, Ulrich Pferschy, and D. Pisinger. *Knapsack Problems*. Berlin: Springer, 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.

II.4 Methodology

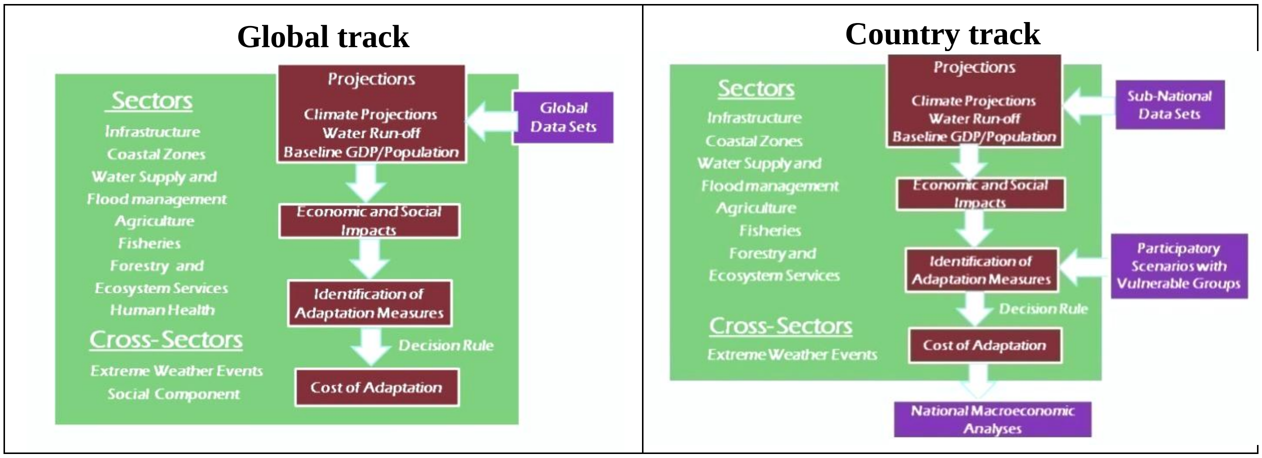
The baseline. To estimate the impacts of climate change and then the costs of adaption, it is necessary to compare, for each time period, the difference between the world with climate change and the world without climate change. To do this, we first have to project what the world will look like between 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 timeframe of 2050, development baselines are first developed for each sector using a common set of GDP and population forecasts for 2010–50. [5] 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 as large as possible a range of model predictions. Although model predictions do not diverge much in projected temperatures 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.

Predicting impacts. The changes in climate are used to predict what the world would look like under the new climate conditions. 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 1. EACC study methodology: global and country tracks



Simplifying assumptions. Given the complexity of climate change and the number of variables and actors involved, simplifying assumptions have been made to facilitate the modeling. First, it is assumed that policymakers 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

[5] 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.

options (early warning systems, community preparedness programs, watershed management, urban and rural zoning). This approach was deliberately chosen because the former options can be concretely valued and costed, not because the latter options are less important. 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. 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. The only case where technical change is considered is in the agricultural sector, where growth in total factor productivity is built into the model, and explicit investment in research is included in the costs. We return to these points in the limitations discussion.

Few differences between the global and country tracks. The steps identified apply to both the global and country tracks. But given their different objectives, the methodologies differ on two steps. 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.[6]

Social analysis and participatory scenario development. 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 workshops focused on participatory scenario development (PSD) 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 support 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, collective action, NGOs, and the private sector to inform future adaptation planning. This approach was not viable in the global track.

[6] As a companion piece to the EACC Synthesis Report, an EACC-Social Synthesis Report has been produced, which presents the findings of the social component conducted in all case study countries except Samoa.

III. RESULTS FROM THE GLOBAL ANALYSES

III.1 Putting a price tag on adaptation

Overall, the study estimates that the cost between 2010 and 2050 of adapting to an approximately 2^{o}C warmer world by 2050 is in the range of $70 billion[7] to $100 billion a year (Table 1). 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%) of the wealth of countries (measured by their GDP, which was roughly $60 trillion in 2009).

Table 1. Total annual costs of adaptation for all sectors, by region, 2010–50 (U$ billions at 2005 prices, 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	14.1	71.2
Net sum	17.7	6.5	14.5	2.4	14.6	13.8	69.6

Note: 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 net positive and negative items within countries but not across countries and include 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.
Source: Economics of Adaptation to Climate Change study team.

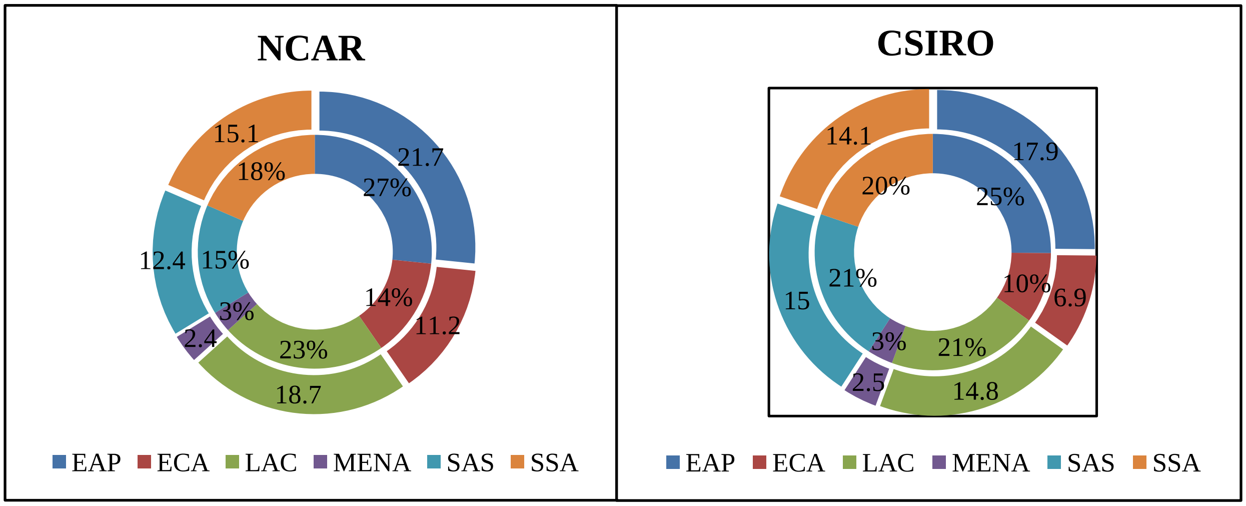
Total adaptation costs calculated by the gross sum method average roughly $10-15 billion a year more than the other two methods (the insignificant difference between the X-sum and net sum figures is largely a coincidence). The difference is driven by countries that appear to benefit from climate change 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, and coastal zones costs are highest for the drier scenario.

[7] See footnote to Table 2 below. This number is slightly smaller than the original (US$ 75 Billion) reported in the EACC Global Report ((The Cost to Developing Countries of Adapting to Climate Change: New Methods and Estimates, WB 2010), reflecting our revised estimates in the agricultural sector.

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 2). 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.

Figure 2. Total annual cost of adaptation and share of costs, NCAR and CSIRO scenarios, by region ($ billions at 2005 prices, no discounting)



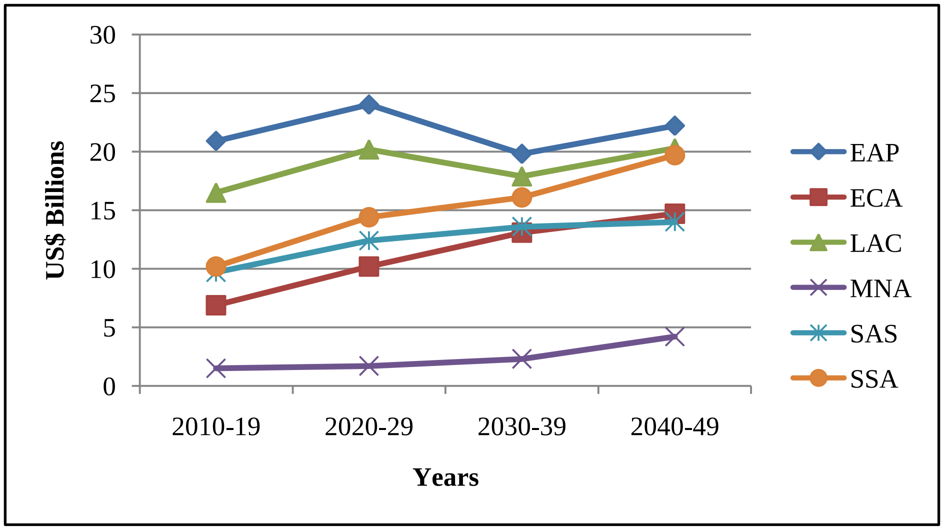
Note: EAP is East Asia and Pacific, ECA is Europe and Central Asia, LAC is Latin America and Caribbean, MNA is Middle East and North Africa, SAS is South Asia, and SSA is Sub-Saharan Africa.
Source: Economics of Adaptation to Climate Change study team.

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 3 and 4). 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 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 policymakers who must make tough choices in the face of great uncertainty.

Infrastructure. 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 roads (mainly paved) at 23 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.

Figure 3. Total annual cost of adaptation for The National Centre for Atmospheric Research (NCAR) scenario, by region and decade ($ billions at 2005 prices, no discounting)



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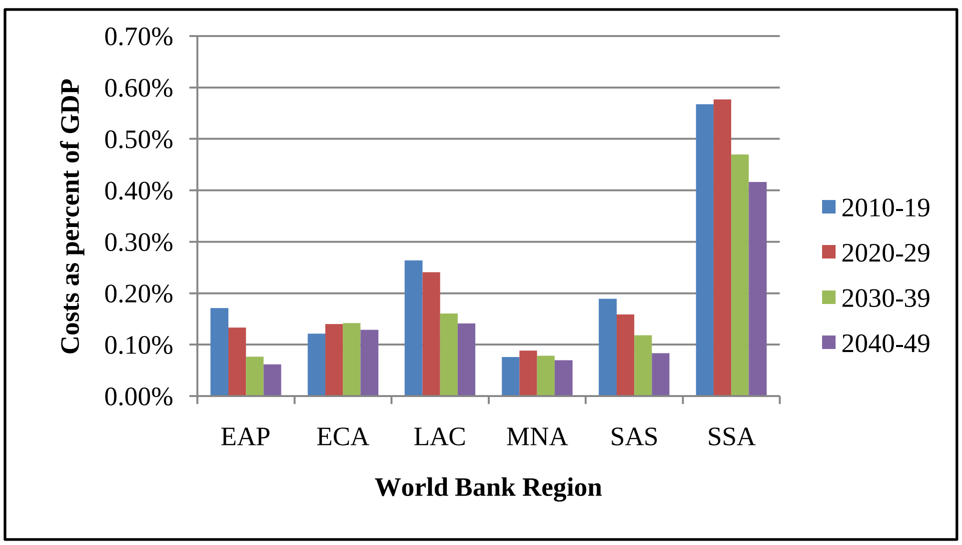
Source: Economics of Adaptation to Climate Change study team.

Figure 4. Total annual costs of adaptation for the NCAR scenario as share of GDP, by decade and region (percent, at 2005 prices, no discounting)



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Source: Economics of Adaptation to Climate Change study team.

Coastal zones. 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. 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. 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. The key human health impacts of climate change include increases in the incidence of vector-borne disease (malaria), water-borne 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 the health sector adaption costs will be shouldered by Sub-Saharan Africa.

Extreme weather events. 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.

III.2 Putting the 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.[8]

Table 2. Comparison of adaptation cost estimates by the UNFCCC and the EACC, US$ Billions

Sector	UNFCCC (2007)	EACC Study Scenario	
		NCAR (wettest)	CSIRO (driest)
Infrastructure	2-41	27.5	13
Coastal zones	5	28.5	27.6
Water supply and flood protection	9	14.4	19.7
Agriculture, forestry, fisheries	7	2.6*	2.5*
Human health	5	2	1.5
Extreme weather events	—	6.7	6.4
Total	28-67	81.5	71.2

*Note that the costs of adaptation in the agriculture, forestry and fisheries sector have changed as compared to the estimates presented in the EACC Global Report (The Cost to Developing Countries of Adapting to Climate Change: New Methods and Estimates, WB 2010) in which these costs stood at $7.6Billion for the NCAR and $7.3Billion for the CSIRO scenarios. The current costs are estimated as the difference in public spending in the scenario with climate change and adaptation as compared to the no climate change scenario, and use the same methodology as has been applied to the other sectors. In WB 2010, the costs were incorrectly reported as reflecting the difference in public spending in the scenario with climate change and adaptation as compared to the scenario with climate change but no adaptation. The difference lowers the EACC lower bound estimate of the global cost of adaptation from US$ 75 billion reported in WB 2010 to US$ 71.2 billion per year, rounded to US$ 70 billion per year.
Note: NCAR is The National Centre for Atmospheric Research, and CSIRO is the Commonwealth Scientific and Industrial Research Climate.
Source: UNFCCC (2007) and Economics of Adaptation to Climate Change study team.

Another reason for the higher estimates is the higher costs of adaptation for water supply and flood protection under the EACC study, particularly for the drier climate scenario, CSIRO. 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.

[8] 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.

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 costs 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. The limitations section summarizes and discusses these and other assumptions and simplifications in this study.

III.3 Lessons

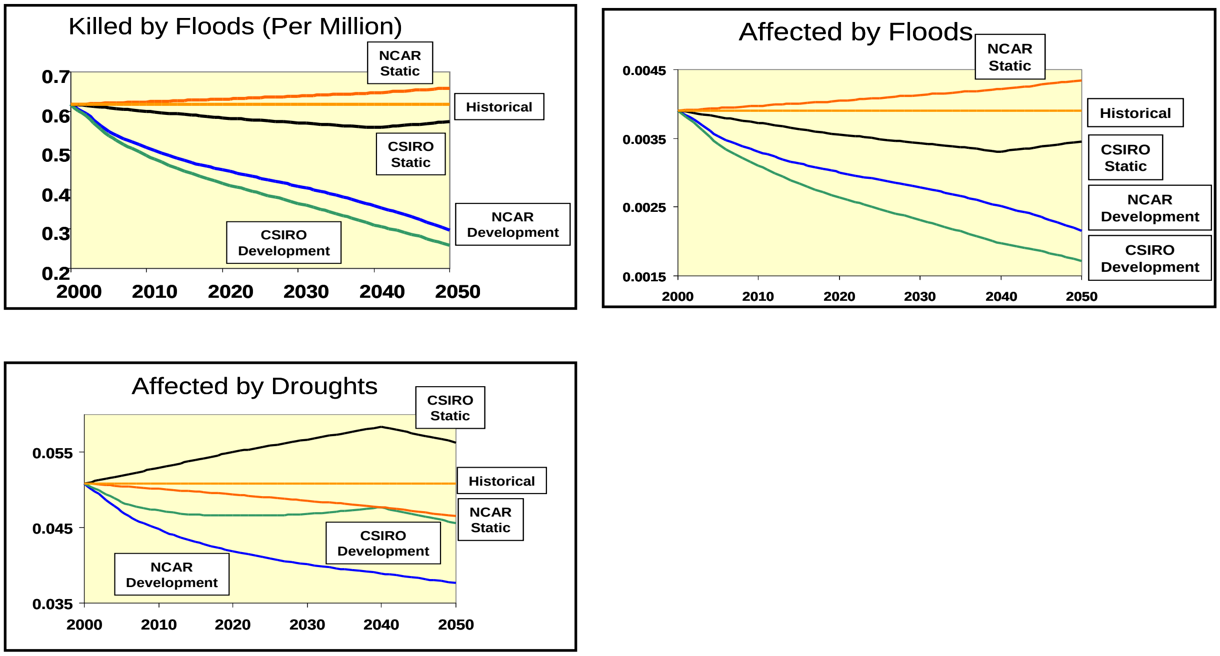
The sector estimates of adaptation costs presented in the global track report point to a few important lessons.

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 5). If development is held constant at 2000 levels, the number of people killed by floods increases over time under the NCAR (wettest) scenario and decrease 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 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.

Figure 5. Development lowers the number of people killed by floods and affected by floods and droughts, 2000–50



Source: EACC study team

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 the economic impacts and adaptation responses make 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.

IV. RESULTS FROM THE COUNTRY ANALYSES

The purpose of the country case studies is to help the governments to 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 (i) a brief description of the nature and degree of vulnerability of the country to climate change, (ii) the EACC study approach and main results from the modeling exercises as well as local level perspectives on adaptation – i.e., findings derived from local participatory scenario development workshops with community and government stakeholders, as well as fieldwork, and (iii) a summary of country specific lessons and recommendations.

IV.1 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. Country interest and buy-in at high government level was also fundamental to select the countries. Although it was difficult to *ex ante* identify the best set of candidates, 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 agro-ecosystems—from small-scale family agriculture on the Altiplano (largely composed by 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 to sea level rise and storm surge – see Table 3.

Table 3. Sector analyses carried out in each country case study

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

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

IV.2 Methodology in African countries

The overall methodology adopted in the three African countries closely follows the one used in the global track. Using a timeframe 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 Ghanaian economy over a period of 40 years that can be used as a basis of 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 (described in Box 1), incorporating comparable approaches to incorporating climate change shocks 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.

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 economy-wide 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 economy-wide 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 2003–2050 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.

To complement the economic modeling component, the social component developed vulnerability assessments in socio-geographic hotspots in order to understand the socially differentiated nature of vulnerability. Part of this methodology included conducting numerous participatory scenario development workshops in the three case countries in order to characterize various future adaptation pathways possible for different livelihood groups, given their identified vulnerabilities and assets.

IV.3 Mozambique

A. 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, and has contributed to an estimated 4,000 deaths between 1980 and 2000. Floods in Mozambique are characterized by a number of geographical factors. More than 60% 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, twenty major flood events were recorded, affecting more than nine million people (RMSI[9] 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 forty 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 80% 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 a "sector" but characterize specific geographical areas vulnerable to floods and storm surges

[9] "Regional Maritime Security Initiative" (RMSI). 2009

directly and indirectly related to sea level rise – Figure 6. Other sectors or issues of importance – such as health and urban infrastructure – were not included in the EACC analyses.

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, and 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.

B. 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 (i) 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; (ii) flow into the hydropower generation facilities and the consequent changes in generation capacity; and (iii) the impact on roads infrastructure and the increased demand and costs of road maintenance. Simulations of sea level rise were constructed independently of the climate scenarios, with an integrated model of coastal systems being used to assess the risk and costs of sea level rise in Mozambique.

Analysis made at the sector level suggest, for example, net negative changes in crop productivity over all of Mozambique in all scenarios (Figure 7), with central Mozambique being hit hardest. The average percent yield drop in the crops analyzed was only 2%, varying from -5% to +2%. Also, the potential energy deficit due to climate change relative to the base generation potential (2005–2050) is -109,716 GWh.

Figure 6. Population density and land vulnerable to the 2100 highest sea level (1 m) and flood-prone areas

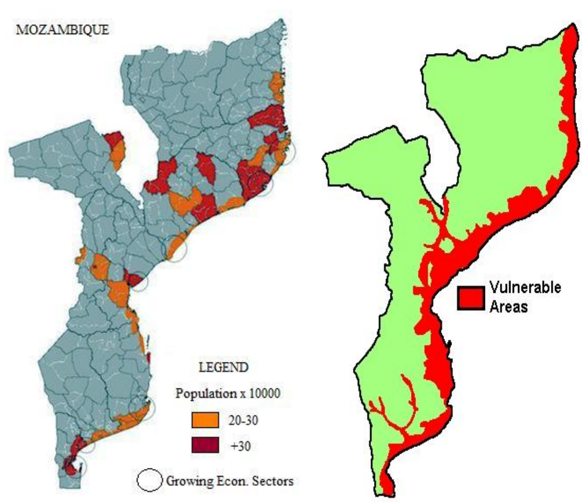
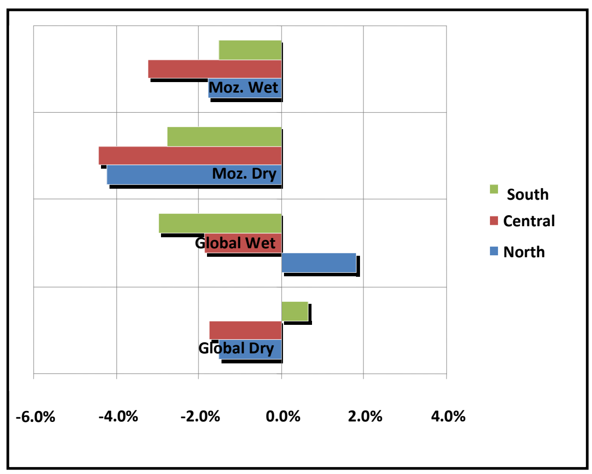


Figure 7. Agriculture: Effects on yield in 2050 compared to historic averages

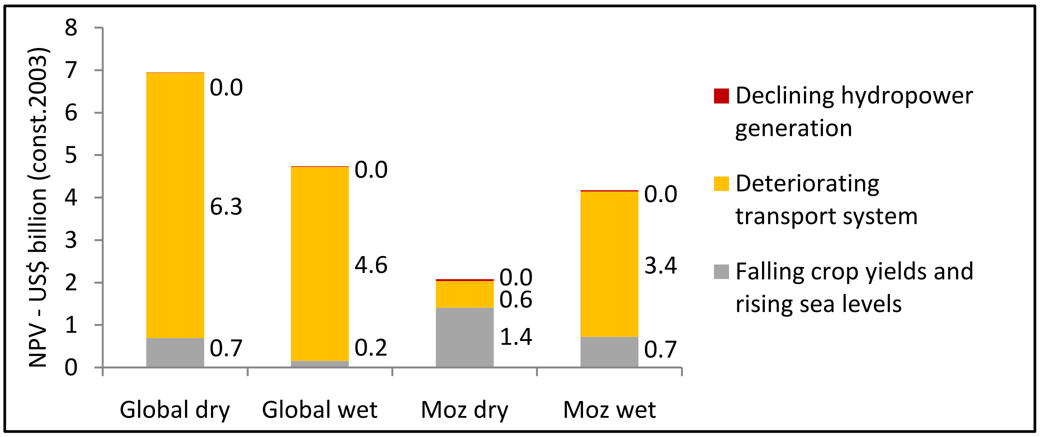


Bars represent the average change in overall crop productivity. Regional averages are weighted by historic crop yield rates per crop in the region

The estimated impacts on agriculture, roads, hydropower and coastal infrastructure fed a macroeconomic model – a dynamic Computable General Equilibrium (CGE) model – which 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 the graph below, there are significant declines in national welfare by 2050. Impacts are varied across climate change scenarios.

Figure 8 below suggests that (i) without public policy changes, the worst scenario results in a net present value of damages of nearly US$7 billion – equivalent to an annual payment of US$390 million (5% discount rate); (ii) the transport system damages are the main impact channel and are due to major flooding within the trans-boundary water basin; (iii) crop yield damages are more severe in the Mozambique dry scenario; and (iv) hydropower reduces surplus energy exports, but not welfare.

Figure 8. Decomposition of impact channels from a macroeconomic perspective



Adaptation. After calculating the impacts, the CGE then considers potential adaptation measures in the same four sectors (hydropower, agriculture, transportation, and coastal infrastructure). Four adaptation strategies are then introduced in the model to minimize the damages: (i) transport policy change[10], and then the same change plus (ii) increased agricultural research and extension, (iii) enhanced irrigation, and (iv) enhanced investment in human capital accumulation (education).

The results are shown in Figure 9 below. Sealing unpaved roads reduces the worst case climate change damages substantially, restoring approximately 1/3 of lost absorption, and with little additional costs (i.e., it is a no-regret action advisable even under the baseline). Remaining welfare losses could be regained with improved agricultural productivity or human capital accumulation. Irrigation investments appear to be a poor alternative: 1 million hectares of new irrigation land would only slightly reduce CC damages. Lastly, in terms of softer adaptation measures, raising agricultural productivity by 1% each year over baseline productivity trends offsets remaining damages to agriculture (e.g., further 50% maize yield increase by 2050); providing primary education to 10% of the 2050 workforce also offsets damages. Lastly, investment costs required to restore welfare losses are subject to debate, but are reasonably less than US$390 million per year over 40 years – see Figure 10.

[10] Options include both hard and soft infrastructural components (e.g., changes in transportation operation and maintenance, new design standards, transfer of relevant technology to stakeholders, and safety measures).

Figure 9. Reduction in CC damages, 2003-2050 (5% discount rate)

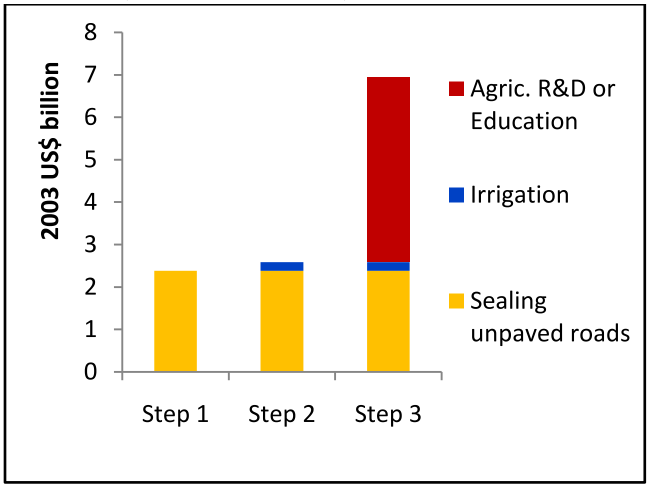
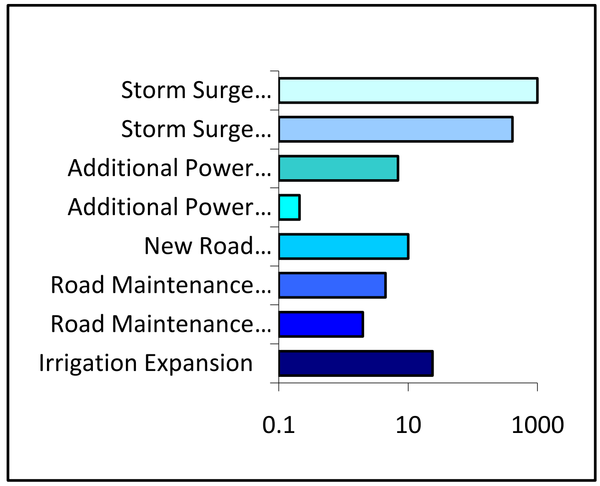


Figure 10. Adaptation costs in last decade (2041-2050), US$ millions



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 the Table 4 below:

Table 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*

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.

All of the planned options in the left hand column represent potential government interventions. The right hand 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 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, however there are few opportunities to do so.

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. See Box 2 for a description of the social component in Mozambique.

BOX 2 – Methodology and field work of social component in Mozambique

In all case countries, the EACC- Social Component was designed to explore vulnerability in the country context in order to identify implications for pro-poor climate adaptation planning. Innovative methods were used to conduct vulnerability assessments at the local level and to identify pro-poor adaptation investment options.

In Mozambique, the vulnerability assessment included a literature review, the identification of six socio-geographic "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, NGOS and traditional leaders. Household interviews were also undertaken: 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 at national level 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 trade-offs 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 trainings on workshop design and implementation.

C. Lessons and recommendations

Several important lessons emerge from the Mozambique work.

- **In Mozambique, investing in large scale coastal protection schemes (sea walls, and other "hard adaptation" options) to reduce the costs of cyclones or floods on the coast will not be economically efficient.**

  – The results from the DIVA model all point to developing "soft" strategies, which focuses more on the people affected than the land lost and is economically smarter.

- **Immediate adaptation should occur where vulnerabilities are well known and adaptation measures are beneficial no matter the climate future**

  – Protection of the port of Beira, possibly within the framework of the PPCR to speed up process. Lessons from the process can be used to aid future adaptation measures

- **Adaptation entails pursuing development but at a higher cost (i.e., increase the climate resilience of current development plans), particularly transport infrastructure and inland flood protection.**

  – Planned roads and infrastructure need to be built to higher design standards to withstand higher frequency of floods. Coastal protection will have to be built to protect the more vulnerable populations and infrastructure.

- **"Soft" adaptation measures must complement "hard" adaptation measures**

  – Install dikes where absolutely necessary to protect current, immobile, vital infrastructure (e.g., the port of Beira), but avoid the development of new infrastructure in the shadow of the dike.

- **Higher priority needs to be provided to adaptation options that are robust to uncertainty**

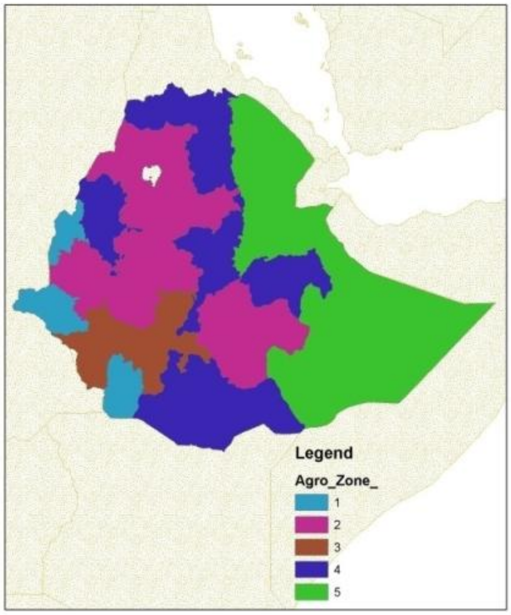
  – Adaptation investments that provide benefits across a broad array of scenarios need to be accelerated (e.g., improved water resources management) while adaptation options needed under a limited set of climate futures should be delayed.

IV.4 Ethiopia

A. Vulnerability to climate change

Ethiopia is divided into five agro-ecological zones as illustrated in Figure 11. Around 45 percent of the country 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 (1500m above sea level). Within the highlands, zones 2 and 3 generally have sufficient moisture for, respectively, the cultivation of cereals and *enset* (a root crop), whereas zone 4 is prone to droughts. The arid lowlands in the east of the country – zone 5 – are mostly populated by pastoralists.

Figure 11. Agro-ecological zones in Ethiopia



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 – 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.

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 women and children left behind as male adults migrate for employment during drought-related production failures. Other vulnerable groups identified included communities living on already-degraded lands, and pastoral communities who regularly experience conflict over natural resources (especially access to land for herd mobility) with agriculturalists and the state.

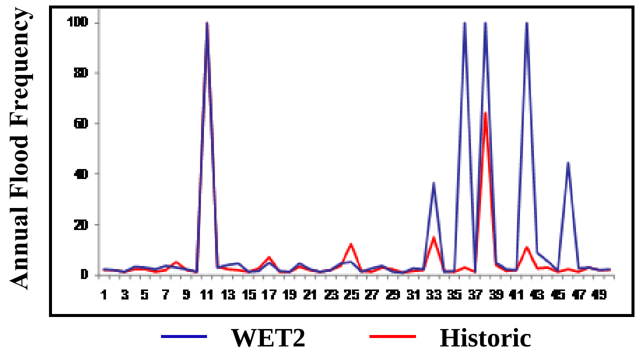
The EACC study has examined four climate scenarios – the Global Wet and Dry scenarios referred to as Wet1 and Dry1, together with country-specific wet and dry scenarios – Wet2 and Dry2, which highlight the consequences of more extreme changes in moisture. The models suggest an increase in rainfall variability with a rising frequency of both severe flooding and droughts due to global warming. The Dry2 scenario shows reductions in average annual rainfall of (a) 10-25% in the central highlands, (b) 0-10% in the south, and (c) more than 25% in the north of the country. The Wet2 scenario shows increases in average annual rainfall of (a) 10-25% in the south and central highlands, and (b) more than 25% in most of the rest of the country. If this scenario is accompanied by an increase in the variability of rainfall intensity, then there will be severe episodes of flooding caused by storm run-off in highland areas.

B. EACC approach and results

Impacts. Climate change affects the Ethiopian economy through three major channels: (1) agriculture, which accounted for 47% of Ethiopian GDP in 2006, is highly sensitive to seasonal variations in temperature and moisture; (2) roads, which are the backbone of the country's transport system, are often hit by large floods, which cause serious infrastructure damage and disruptions to supply chains; and (3) dams, that provide hydropower and irrigation, are affected by large precipitation swings. For the baseline, the model uses historical weather data and projects the historical pattern into the future. For the climate change scenarios, stochastic representations of weather variability in each global circulation model 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.

Figure 12 shows the incidence of severe floods in zone 3 for the baseline (in red) and for the Wet2 scenario (in blue). The Y axis measures frequency of a severe flood, with a 100 year flood being the most extreme. In the baseline, such a flood is expected to occur only once in a century, but under the Wet2 scenario it occurs three times in the final decade of the 40 years period under consideration.

Figure 12. Damage caused by flooding, Region 3, two climate scenarios



Changes in precipitation and temperature from the four GCMs were used to estimate (i) changes in yields for major crops, (ii) flow into hydro-power generation facilities and the consequent changes in power generation; and (ii) the impact of flooding on roads. Figure 13 below shows deviations in GDP from the no-climate-change baseline growth path for the two climate change scenarios that capture the widest range of possible variability in Ethiopia: “Dry2” (the ipsl_cm4 model); and Wet2 (the ncar_pcm1 model).

CGE modeling suggests that the loss of GDP is very substantial in the 2040-49 decade for the Wet2 scenario, because of the costs of coping with damage caused by extreme weather events, especially floods, from the 2030 decade onwards. The 10-year average GDP for the final decade is 9% lower than in the Baseline. While this is not a forecast of future climate impacts, it highlights the extreme degree of vulnerability of Ethiopian agriculture and infrastructure to flooding. In contrast, the costs of droughts under the Dry2 scenario are smaller, but are spread across the entire period. Comparing welfare losses under the two scenarios, the discounted present value of welfare losses is larger under the Dry2 scenario (3.6% of discounted GDP, compared to 3.2% for the Wet2 scenario), given that there are significant losses in the early periods as well as later periods, while the negative impact is much larger in the later period under the Wet2 scenario.

Climate change brings about increased weather variability which translates into large swings of the year-to-year growth rates of agriculture GDP, illustrated in Figure 14 by the increase in standard deviation of year-to-year growth rates compared to the baseline. While the simple means of year-to-year growth rates are similar across the scenarios (not shown), high variability leads to significant welfare losses. A priority for adaptation investment is therefore to reduce income variation and the related welfare losses.

Finally, as shown by Figure 15 below for the Wet2 scenario, climate change impacts are likely to vary significantly across regions.

Figure 13. Percent deviations of GDP from Baseline

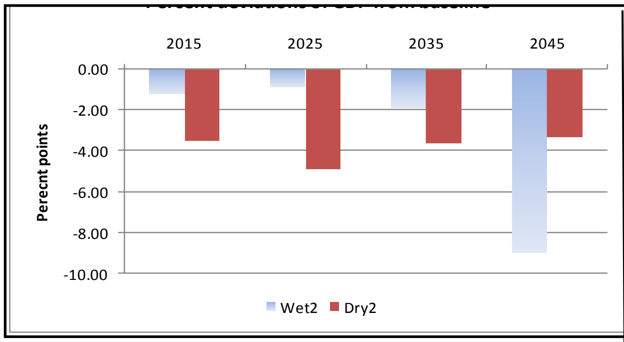


Figure 14. Standard deviation of Agriculture GDP (2010-2050)

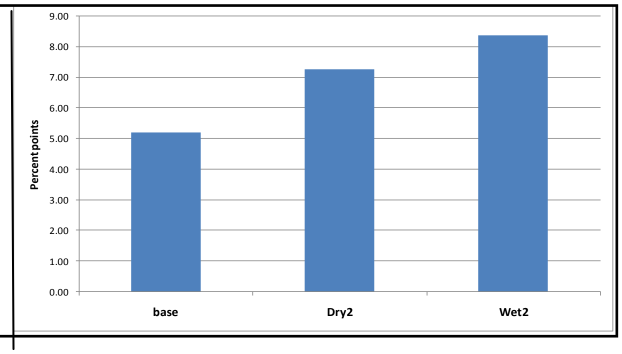
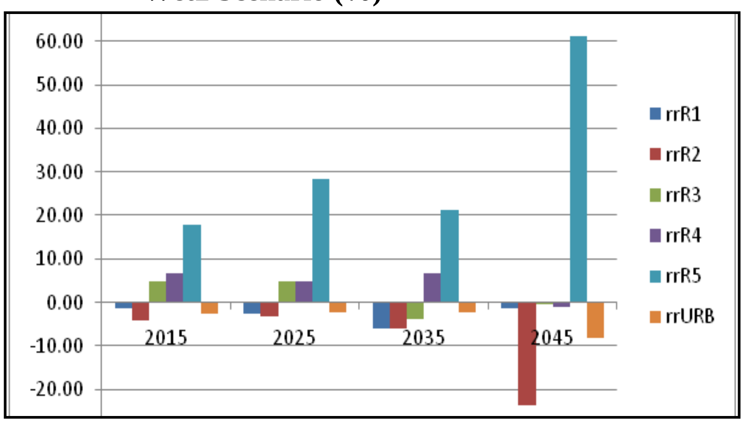


Figure 15. Regional GDP deviation from Base Run, Wet2 Scenario (%)



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.

Adaptation. The Baseline scenario includes an ambitious investment program in dams, hydropower development, irrigation, water management, and road building, reflecting government programs and priorities, which were discussed at a workshop with government counterparts in November 2009.

While pursuing such an investment program is likely to enhance Ethiopia's resilience to climate change, 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 cropland that is irrigated and investing in agricultural research and development. In the transport sector adaptation options included increasing the share of paved and hardened roads, and also "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 downstream flow and irrigation flow.

These strategies were first assessed on a sector-by sector basis, resulting in an estimated total cost of $40 to $150 million on annual average. However, once the full set of economy-wide linkages is taken into account, direct and indirect adaptation costs are significantly greater, as indicated in Table 5 below.

Table 5. General equilibrium costs of the adaptation strategy ($ billions)

	Sum (a)	NPV (b)	Average (c)
Wet2	10.67	3.32	0.260
Wet1	13.05	3.58	0.318
Dry1	17.75	4.65	0.433
Dry2	25.18	6.90	0.614

(a) Sum: Total, 2010-2050
(b) NPV: Net Present Value of adaptation costs, 2010-2050
(c) Average: Average annual adaptation costs.

The annual adaptation costs are significant, ranging from 2 to 5 percent of annual gross fixed capital formation. From another perspective, annual adaptation costs represent about 10% of the annual current account deficit of Ethiopia, which is largely financed of aid flows. That is, an increase of annual foreign aid by about 10% would be required to finance Ethiopia's adaptation investment.

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 a scenario reflecting adaptation investments. The main findings are that adaptation a) lowers income variability and that b) it reduces, but does not eliminate, welfare losses – Figures 16 and 17. Adaptation reduces by 40-50% variability of agriculture GD growth compared to the no adaptation scenario; and similarly, cuts in half the welfare loss due to climate change (measured here by the difference from the baseline of total absorption – output plus imports minus exports, discounted over the 40 years time horizon). In the base scenario, decadal average annual growth rates of aggregate GDP range from 6% to 6.5%, with climate change shocks lowering mean growth rates slightly and increasing annual variability, especially in agriculture.

Figure 16. Discounted differences in absorption baseline, 2010-2050 (share of discounted GDP)

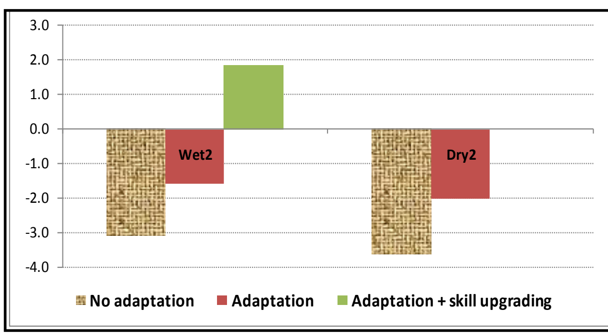
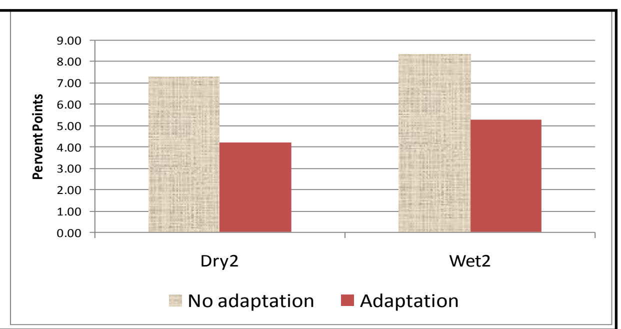


Figure 17. Standard deviation of from agriculture GDP growth (2010-2050)



While the benefits of adaptation investments are significant, they do not fully offset the negative impact of the climate change scenarios. To explore the potential of other investment programs to offset these negative impacts, an additional labor-upgrading program is included in the adaptation strategy. In this scenario, 0.1% 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 (Figure 15). This result confirms the significant potential benefits of accelerating the diversification of the economy away from highly climate sensitive sectors, such as agriculture.

Local level perspectives on adaptation. Key conclusions from modeling exercises echo some of the main concerns raised by local stakeholders in three local participatory scenario development workshops (in highland, midland and lowland areas), and one national workshop. These include the importance of investments in: (i) road connectivity to reduce regional disparities and isolation and to improve market integration; (ii) improved agricultural productivity including soft measures such as agricultural extension, and hard measures such as improved on-farm technology; improved seeds and flood control measures; and better weather forecasting; and (iii) non-farm diversification.

While these preferences are largely in line with the NAPA and related national climate strategy priorities, findings from the PSD workshops also revealed strong stakeholder preferences for investments in governance, social protection, training and education, and land tenure. Establishing or clarifying land use rights for particularly vulnerable groups such as pastoralists was considered especially important.

C. Lessons and recommendations

The key lessons from the Ethiopia country study are:

a) Extreme weather variability associated with some climate scenarios can lead to very large costs for predominantly agricultural economies. Droughts are damaging, but in the case of Ethiopia the greatest damage is caused in the later periods by more frequent large floods which damage agricultural output and infrastructure (particularly roads).

b) Robust growth based on infrastructure investment is the first line of defense against climate change impacts. If Ethiopia does not meet its ambitious development plans, climate change impacts will be greater as the core investment strategy helps to climate proof the economy. Relatively small deviations from the ambitious investment targets envisaged in the baseline for roads, dams, hydropower, water management, and irrigation, would significantly increase vulnerability to climate change and thus make adaptation costlier.

c) Climate uncertainty has important implications for the design and cost of adaptation strategies. In general economic equilibrium terms, the cost of adaptation varies by a factor of 3, depending on the climate scenario considered; and so 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.**

- **At the same time, it seems plausible that a range of investments and policies are likely to be "low regret" (i.e. sensible under a wide range of climate outcomes). For example:**

  - **Enhancing the climate resilience of the road network** (through adopting higher design standards) can avoid costly disruptions of communications links and supply chains that increased flood frequency might bring about;
  - **Investments in improved agricultural productivity –** such as watershed management, on-farm technology, access to extension service, 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;
  - **Accelerated diversification of income and employment sources away from climate-sensitive sectors such as agriculture** is likely to become increasingly important under an increasingly erratic climate; and it should be explored in closer detail.

On the other hand, the optimal timing of dams and other investments in water infrastructure is likely to be quite sensitive to climate outcomes, and it should be subject –on account of the large capital outlays involved – to careful climate-robustness tests.

IV.5 Ghana

A. Vulnerability to climate change

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

The gendered nature of 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 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 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 6). 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.

Table 6. GCM scenarios for the Ghana case study

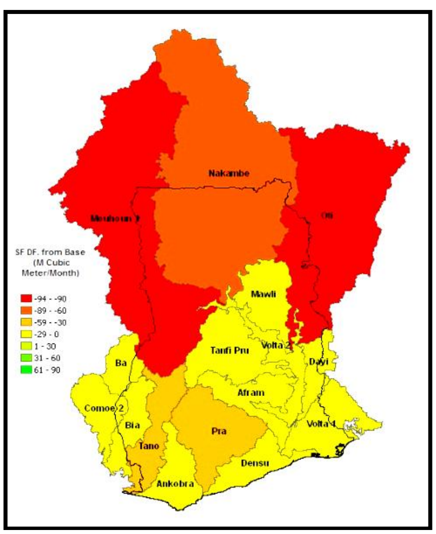
Scenario	GCM	SRES	CMI Deviation
Global Wet	ncar_ccsm3_0	A2	-17%
Global Dry	csiro_mk3_0	A2	9%
Ghana Wet	ncar_pcm1	A1b	49%
Ghana Dry	ipsl_cm4	B1	-66%

The projections indicate fairly wide fluctuations in annual temperatures in all four Ghana agro-ecological regions (Northern Savannah, Southern Savannah, Forest, and Coastal) for all the four scenarios. However, the trend over the period 2010-2050 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 agro-ecological regions show significant precipitation variability compared to the baseline scenario. The coefficient of variation of annual precipitation in Ghana varies between -9% (global wet scenario) to -14% (Ghana dry scenario).

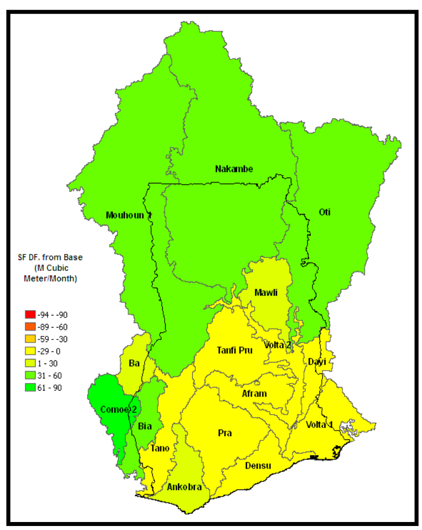
There is indication that there would be wide variations in stream flows and runoff changes. The southwestern part of Ghana is expected to experience increases in runoff under both Ghana specific scenarios, with the opposite occurring with the Black Volta basin. The fluctuations in stream flows and runoffs, 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 need for sub-regional co-operation in the management of water resources.

Figure 18. Surface flow average difference from the no-climate change scenario, 2010-2050 (million cubic meter per month)

Ghana Dry Scenario (ipsl_cm4-B1)



Ghana Wet Scenario (ncar_pcm1 A1b)

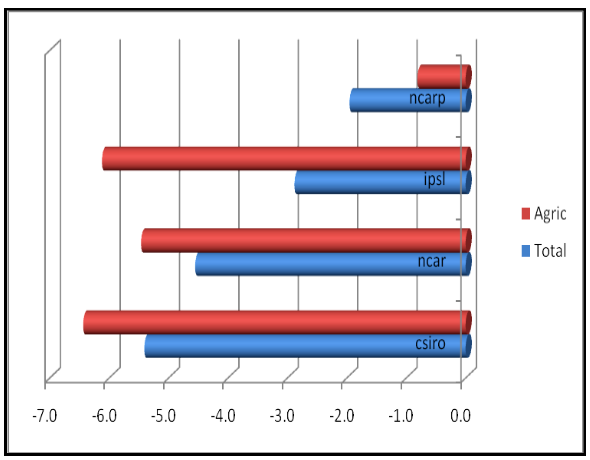


EACC approach and results

Impacts. All four GCM scenarios suggest significant adverse economy-wide effects, which become stronger towards 2050. Although there is considerable variation in real GDP growth over the simulation period, the overall trend relative to the baseline is clearly downward. The projected decline in real GDP ranges from 5.4 percent per annum (Global Dry) to 2.1 percent per annum (Ghana Wet) by 2050 (projection was based on historical climate parameters). There is a relative decline in real household consumption levels of 5-10% in 2050, with rural households suffering greater reductions compared to urban households.

Still in comparison to the baseline growth path without climate change, the output of the agricultural sector is estimated to decline by between 6.4% (Global Dry) and 0.8% (Ghana Wet) by 2050 – Figure 19. Productivity of the cocoa sub-sector could be reduced significantly, with output falling by 26-39 percent relative to base for the Global Wet and Dry scenarios and Ghana Dry scenarios. However, in the Ghana Wet scenario, annual cocoa output is projected to increase by about 18 percent relative to base by the 2020s, slowing to about 7 percent by the 2050s due to the offsetting effect of increased warming. The projections for cocoa pose serious socio-economic implications in view of its significant contribution to national income and farmers' livelihoods.

Figure 19. Deviation of real total and agricultural GDP from base, terminal year (%)



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 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). Like for most coastal cities around the world, the coastal areas in Ghana 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 fresh water resources in deltas and estuaries.

The total cost of damage from flooding, land loss and forced migration is estimated to reach $4.8 million/yr by the 2020s, rising to $5.7 million/yr by the 2030s, before a slight fall to $5 million/yr in the 2040s using the high sea level rise scenarios. The total costs of the damage is estimated to be $0.4 million/yr, $7 million/yr, and $3 million/yr for 2020s, 2030s, and 2040s respectively using the low seal level rise scenario.

Ghana's water and energy sectors have also already shown signs of vulnerability to climate change, particularly the effect of highly variable precipitation patterns on hydropower production. The drought of the early eighties (1980 to 1983) 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. Annual average output of the water and energy sector is expected to decline to within a range of $20.3 billion to $21.0 billion from a baseline output of $21.4 billion. This represents a decline of between1.7 and 5.2% per annum on average.

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. As in the Mozambique study, the economy-wide simulation analysis assumes that the same road infrastructure adaptation strategy is adopted in all adaption 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 Global Wet scenario, the share of irrigated land rises gradually from less than 0.4 to 15 percent of the current total cultivated area. The resulting average annual factor productivity increase for crop agriculture as a whole is an additional 0.36 percentage point 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 US$859 million, which reduces the amount available for agricultural investment. For example under Global Wet scenario, 10 percent of the resource envelope goes to power and the rest to agriculture.

Coastal Zone. Coastal adaption 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 $82 million per year under a high sea level rise scenario, and $3-12 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 $8 million in the 2010s, rising to $32 million by the 2040s. Total annual adaptation costs for the coastal zone are estimated to be between $12 – 143 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 (e.g. fishery industry protection) and so should be taken in light of these limitations. Compared to 1990, the 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 7.1 cm and 37.8 cm using the high sea level rise scenario, respectively).

Macroeconomic/integrated analysis. In the dynamic CGE analysis, it is assumed that the maximum resource envelope available for adaptation measures over the simulation period (2010-2050) is equal to the present value of the aggregate welfare loss due to climate change in the absence of adaptation measures (Table 7). From an economy-wide perspective, these figures represent the lump-sum income transfers Ghana would have to mobilize in order to be fully compensated for the economic impacts of climate change.[11] 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 7 below shows that in the absence of adaptation, aggregate real welfare losses up to 2050 will range (in present value terms) from US$1.9 billion (Ghana Wet) to US$25.7 billion (Global Wet). In annualized values, these estimates range from US$112 million (Ghana Wet) to US$1.5 billion per annum. On a per capita basis, they amount to US$4.80 and 64.08 for Ghana Wet and Global Wet, respectively.

Table 7. Real welfare impacts with no adaptation investments

Climate Scenario	Present value of lost welfare (US$ Billion)	Equivalent annual value (US$ Million)	Annual equivalent per capita
Global Dry	-16.017	- 933.4	-39.89
Global Wet	-25.731	-1,499.6	-64.08
Ghana Dry	- 4.825	- 281.2	-12.02
Ghana Wet	- 1.926	- 112.2	-4.80

(i) Discount rate = 5%. Welfare is measures 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.
(ii) Second column: constant annual flow with same present value. Third column: second column / 2010 population (UN medium projection: 23.4 Million).

Table 8 reports deviations of the present value of real absorption from 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 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.

[11] 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.

Table 8. Deviations of real welfare from baseline under alternative adaptation strategies (present value, in US$ billions)

No Adaptation scenario		Road Design	Adaptation Investment in		
			Agriculture	Hydro /Agric.	Education
Global Dry	-16.017	-13.171	0.461	0.299	-4.774
Global Wet	-25.731	-21.561	-0.988	-1.071	-8.264
Ghana Dry	-4.825	-5.130	-0.867	-0.426	-2.552
Ghana Wet	-1.926	1.456	3.376	3.081	2.506

Key assumption: Resource envelope is externally financed and does not reduce Ghana's baseline investment path.

The simulated adaptation investments in agriculture in combination with road design slightly over-compensate the climate change damages in a macroeconomic sense under Global Dry and Ghana Wet scenarios. This means that the total cost of returning aggregate welfare to the baseline is slightly lower than the assumed adaptation investment expenditure, e.g. slightly lower than $ 16 billion in the Global Dry climate scenario. In the other two scenarios the agriculture-focused strategy restores aggregate real absorption close to the baseline level, but the negative signs in Table 6 indicate some residual damage remains. 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 Ghana Dry climate scenario it is preferable ex post 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 even under the very moderate assumptions about returns to broad-based education investments used in the simulation analysis, such measures can be quite effective in countering the macroeconomic growth impacts of climate change across all climate scenarios.

The message that emerges from these simulation results is that planned adaptation can be effective in compensating the adverse impacts of climate change. The adaptation strategies under consideration aim to restore aggregate absorption to the baseline, rather than to restore each "sector" to the baseline, as the latter approach is unlikely to lead to an efficient allocation of a limited adaptation budget. To the extent that the adaptation interventions under consideration succeed in returning the growth path of the economy close to the baseline growth path across all climate change scenarios, they can be seen as robust low-regret measures in the presence of considerable uncertainty about actual future climate outcomes. However, it is important to draw attention to the fact that the macro level at which the foregoing welfare analysis was conducted masks the residual damage that can occur at the micro or sector level. There will be a need for the design of compensation mechanisms that involve redistribution from "net adaptation winners" to adversely affected population groups.

Local level perspectives on adaptation. While the economic analyses prioritized improved road infrastructure, energy and regional integration (including trans-boundary 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 PSD stakeholders and respondents in fieldwork. In addition, adaptation preferences expressed in the PSD workshops largely coincided with priority action areas in the NAPA as well as related climate strategy priorities in-country. Notably, discussions also focused on the need for improved governance, social protection, land tenure, and training and education in order to accelerate development and in particular, 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 co-benefits with sustainable development yet preferred adaptation measures that were often more expensive and left little room for integration of inputs of local communities.

B. 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*:* Investments 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; 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 of where there is economically important urban and port infrastructure; upgrade of peri-urban slums and controlled development of new ones; protection, management, and sustainable use of coastal wetlands; review of Ghana coastal development plans to take into consideration climate change adaptations including coast line and ports protection, flood protection, and coastal communities and fishery industry protection.

Social: Safety nets improvements, community-based resource management systems, and disaster preparedness. It is also necessary to accelerate 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.

IV.6 Bangladesh

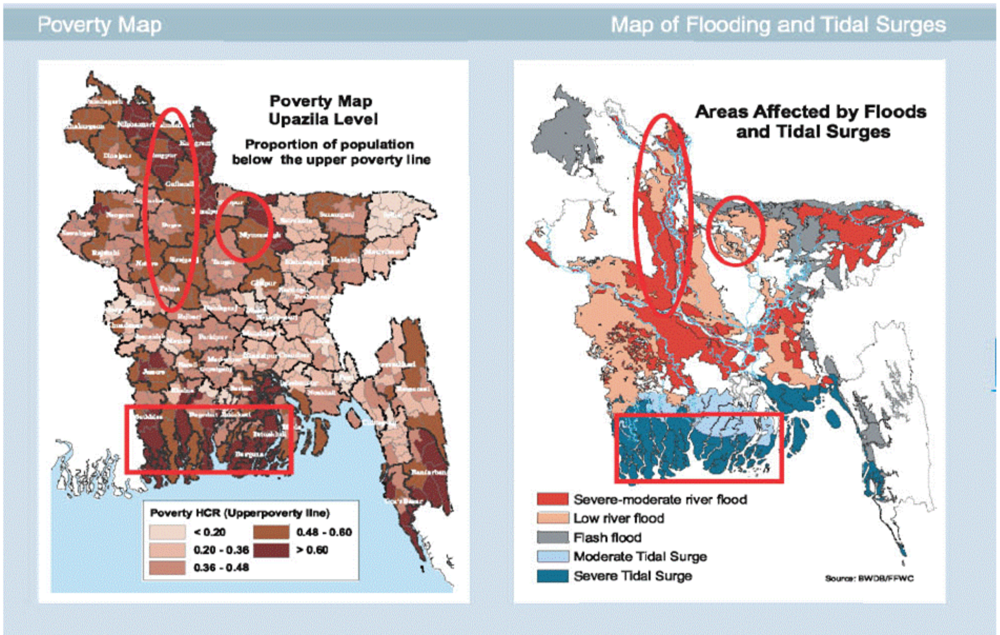
A. Vulnerability to climate change

Bangladesh is one of the most vulnerable countries to climate risks, being the most vulnerable to tropical cyclones. Between 1877 and 1995 Bangladesh was hit by 154 cyclones (including 43 severe cyclonic storms and 68 tropical depressions) – one severe cyclone every three to five years. The largest damages from a cyclone result from the induced-storm surges, and Bangladesh is on the receiving end of about 40% of the impact of total storm surges in the world. Bangladesh also experiences severe monsoon flooding, on average also once every three years, resulting in significant damage to crops and properties. The performance of the agriculture sector is in turn heavily dependent on the characteristics of the annual floods. Nearly two-thirds of the country is less than 5 meters above sea levels and is susceptible to flooding. In a typical year approximately one quarter of the country is inundated. Farmers have adapted to these "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 impacts of tropical cyclones, storm surges, floods, and other climatic hazards are geographically concentrated in specific regions of the country which also have a higher concentration of the poor, who are most vulnerable and have the lowest capacity to address the impacts, hence are also affected disproportionately. The importance of adapting to these climate risks to maintain economic growth and reduce poverty is thus very clear – see Figure 20.

Bangladesh has put in place an extensive set of risk reduction measures – both structural and non-structural, and enhanced its disaster preparedness system (Box 3). Households have also needed to adapt to reduce exposure to these risks and to maintain their livelihoods. While these measures have significantly reduced damages and losses from extreme events over time, especially in terms of deaths and injuries, the cost of strengthening and expanding these measures to further reduce the risks from existing climate-related hazards is less than the avoided damages.

Figure 20. Maps of poverty, flooding and tidal surges



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 which make them lie above the highest flood levels with a return period of 50 years while feeder roads are designed to lie above the normal flood level, and agriculture 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 the hazards, as evidenced by the decline in the number of fatalities and the share o GDP lost as a result of these events.

Coastal embankments. In the early sixties and seventies, 123 polders, of which 49 are sea facing, 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 dykes. 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 the 1991 cyclone, Sidr (2007) and Aila (2009) have been partially attributed to the foreshore afforestation. Government Officials have recommended that the existing forest belt includes at least a 500 meter wide of mangrove forest. Currently 60 km of forest belts exist on the 49 sea facing polders that span a total combined length of 957 km, leaving over 90% 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 mega-cyclone Sidr of 2007, 15% of the affected population took refuge in cyclone shelters, saving thousands of lives. Focus group interviews with the area residents revealed that the use and effectiveness of shelters have been limited 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 dykes is not cost effective (e.g., 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 command and delayed effective relief. Recent efforts to decentralize operations have proven quite successful. They included 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 emergency communication system. Pre-positioning of emergency relief materials and life saving drugs and medical supplies is playing increasingly important role in quickly initiating relief and rehabilitation activities.

A warmer and wetter future Bangladesh predicted by the General Circulation Models further increases the existing climatic risks, particularly when the climate state goes beyond historical variations. The median predictions from these models are for warming of 1.55^0C and increase in precipitation of 4% by 2050. Current trends for water levels in coastal areas suggest rise in sea levels of over 27 cm by 2050. Further, increased severity of cyclones in the Bay of Bengal is expected to increase risks of inundation in coastal areas by 2050.

B. EACC approach and results

The Bangladesh case study builds on a parallel study on the impacts of climate change and food security[12] 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.

[12] Yu, W.H., et al. (2010), *Climate Change Risks and Food Security in Bangladesh*, Earthscan Publishers, London, pp. 133, 2010.

Impacts. Both damage and adaptation costs are presented for tropical cyclone induced storm surges and inland flooding. The impacts in the agricultural sector are also analyzed.

Tropical cyclone induced storm surges. The potential damages and the adaptation cost necessary to avoid these damages are estimated separately for two scenarios – a baseline scenario without climate change and another with climate change. Both assume an economy with "normal" development patterns including population projections that reach replacement fertility by 2021, and a continuation of the current annual GDP growth projections of 6 to 8%. The baseline scenario is developed from all 19 major historical cyclones making landfall in Bangladesh between 1960 and 2009, and represents the current and future risk in 2050 in the absence of climate change. Climate change is expected to increase the severity of cyclones by 2050. Three main anticipated effects: a) sea level rise of 27cm, b) increase in the observed wind speed by 10%, and c) landfall during high tide are used to simulate storm surge conditions in 2050 under the climate change scenario.

Damages from cyclones and induced storm surges are computed for each of the two scenarios. They are based on a detailed inventory of population and assets that are potentially at risk. Cyclone-induced storm surges due to climate change are expected to inundate an additional 15% of the coastal area and also increase the inundation depth in these areas (Figures 21 and 22). 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 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 22). As a result, if additional public adaption measures 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% of GDP, with the burden likely falling disproportionately on the poorest households.

Figure 21. Inundation risk from storm surges in coastal areas with and without climate change in relation to current population density

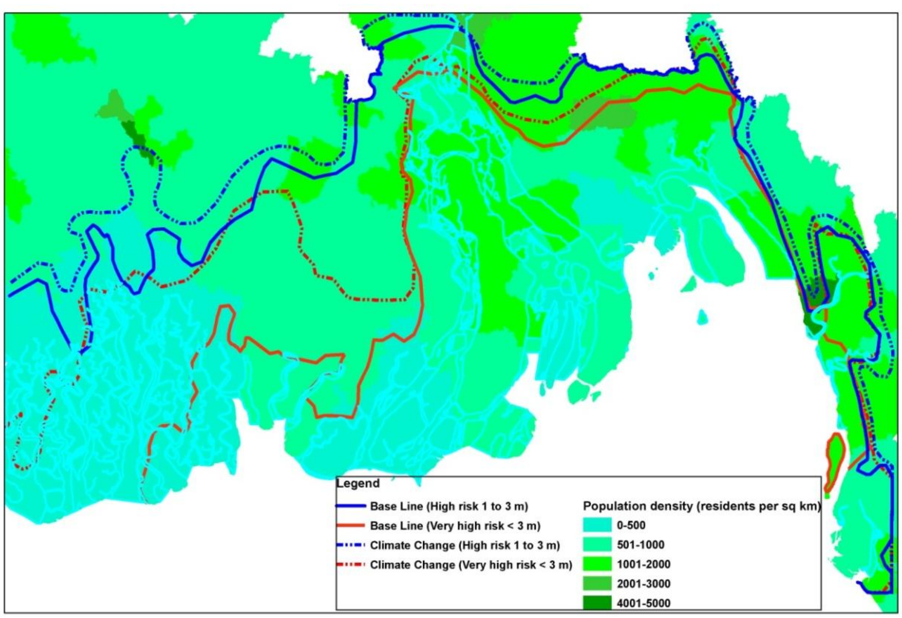
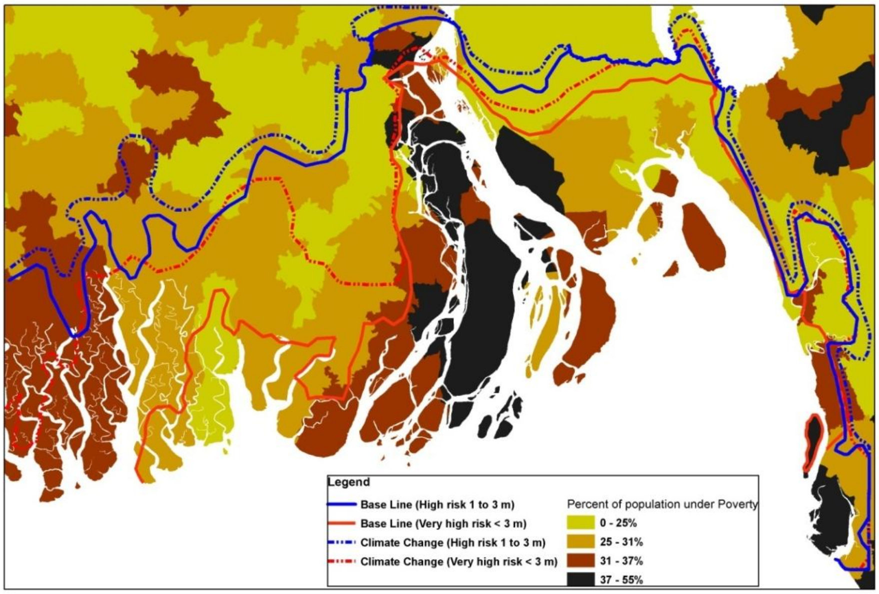


Figure 22. Inundation risk from storm surges in coastal areas with and without climate change in relation to current poverty rates

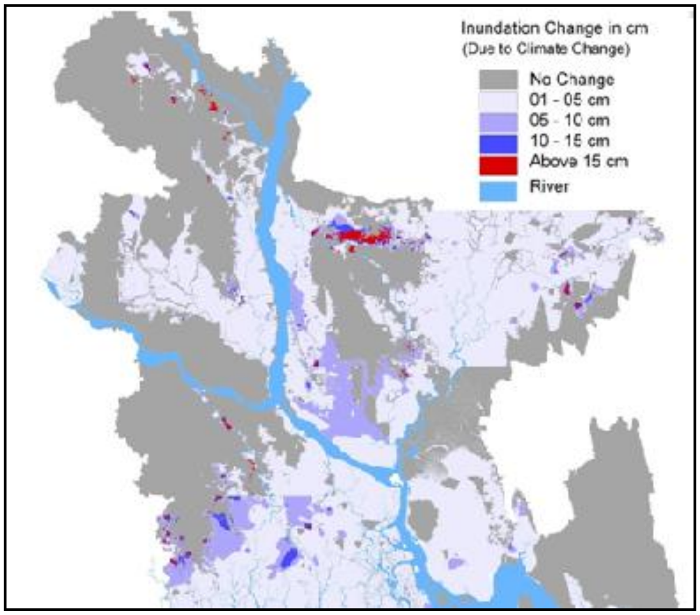


Inland flooding. Rural households have adapted their farming systems to the "normal floods" that typically inundates about a quarter of the country every year by switching to high-yielding rice crops instead of low-yielding deepwater rice. As a result agricultural production has actually risen over the 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 or 4.8% of GDP, approximately equally split between infrastructure, agriculture and industry/commerce.

The depth and extent of inundation is expected to increase with climate change due to the warmer and wetter climate and rising sea levels. The total inundated area increases by 4% exposing more assets and activities to risk. While the inundation depth increases in about half of the county, compared to the baseline scenario the increases are greater than 15cm in only 544 km^2, or less than 0.5% of the country (Figure 23).[13] The rural population exposed to flooding, however, declines from current levels due to rural-urban migration that is projected to occur by 2050. These risks are in addition to the substantial baseline risks that currently exist from inland flooding. Damage estimates from the agriculture component indicates that climate change increases the existing damages about a third, suggesting that actions to manage current severe floods is a good no-regret strategy for adapting to future climate change. Similar comparisons were not completed for other sectors.

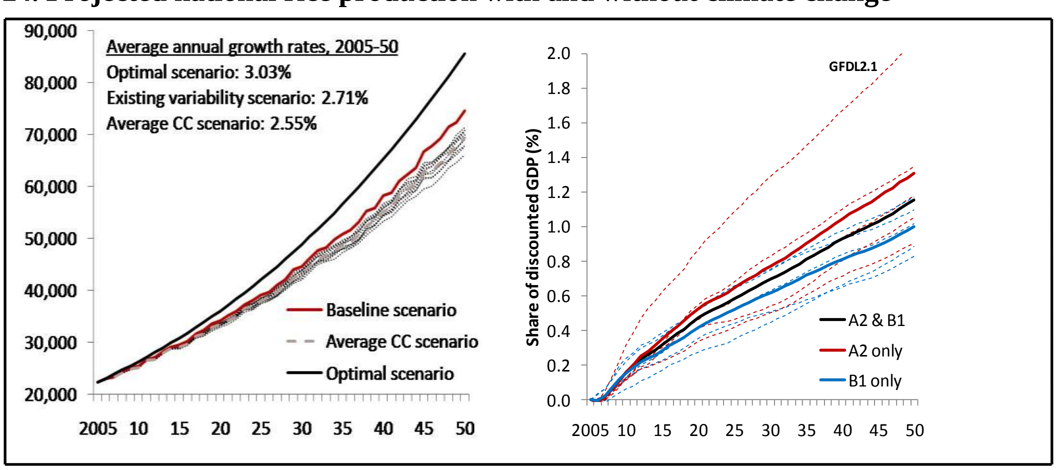
[13] The inundation depths and potential vulnerable zones are estimated based on a hydrodynamic modeling system of the Bay of Bengal combined with historical data of inundation depths of all 19 cyclones for the base case, and 5 potential cyclone tracks consisting of the 4 large cyclones of 1974, 1988, 1991, and 2007 for the second scenario.

Figure 23. Change in inundation depth (cm) from monsoon flooding (with and without CC)



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 global circulation models for 3 emission scenarios. In addition, the impacts of severe flooding on agricultural production are assessed using 5 GCMs and 2 emission scenarios. The models predict that higher yields of the main rice crops *aman* and *aus* resulting from higher concentrations of $C0_2$, rising temperature and precipitation will be more than offset by declines in the yield of the *boro* crop, crop damages from severe flooding and loss in 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% each year) over 2005-50, driven primarily by reduced *boro* crop production (Figure 24). Agricultural GDP is projected to be 3.1% lower each year (US$36 billion in lost value-added) and total GDP US$129 billion lower due to climate change over the 45-year period 2005-2050.

Figure 24. Projected national rice production with and without climate change



<u>Adaptation</u>. 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.

<u>Tropical cyclone induced storm surges</u>. Since the sixties, Bangladesh has made significant investments in embankments, cyclone shelters, coast 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 (i) embankments, (ii) afforestation, (iii) cyclone shelters, and (iv) early warning systems. The total cost of adaptation due to climate change to address storm surge risk is $2.4 billion in initial investment and $50 million in annual recurrent costs – Table 9.

Table 9. Cost of adapting to tropical cyclones and storm surges by 2050 (US$ millions)

Adaptation Option	Baseline Scenario IC	Baseline Scenario ARC	CC Scenario IC	CC Scenario ARC	Additional Cost due to CC IC	Additional Cost due to CC ARC
Polders	2,462	49	3,355	67	893	18
Afforestation			75		75	
Cyclone shelters	628	13	1,847	37	1,219	24
Resistant housing			200		200	
Early warning system			39	8+	39	8+
Total	3,090	62	5,516	112+	2,426	50+

CC = climate change; IC = investment cost; ARC = annual recurrent cost

<u>Inland flooding</u>. The analysis focuses on adaptation measures to avoid further damage from additional inundation has been 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 10. 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.

Table 10: Total adaption cost for inland flooding by 2050 (US$ 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

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 some of which has been 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.

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% of surveyed households). Storage of food and drinking water before extreme events is also common, and 25% of surveyed households also reported building livestock platforms to guard animals during such events. Adaptive capacity among all field sites was low, though poor urban dwellers in particular 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; waste management); water resource management (drainage, rain water harvesting, drinking water provisions, and flood control); infrastructure (roads; 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 urban poor) and gender-responsive disaster management (separate rooms for women in cyclone shelters; mini-shelters closer to villages; and use of female voices in early warning announcements; mobile medical teams in Char areas).

C. 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. Deficiency of costal protective measures weakens 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 the 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%. 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% 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.

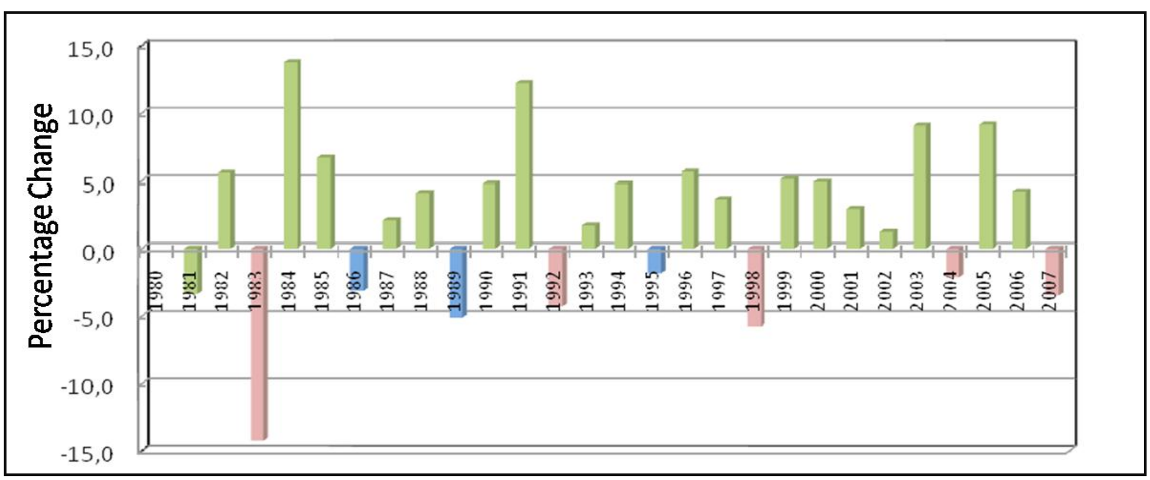
IV.7 Bolivia

A. 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 2006-2007 in Bolivia cost approximately US$ 443.3 million in damages, half of which were direct damage to property and the remaining 45 percent were 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.

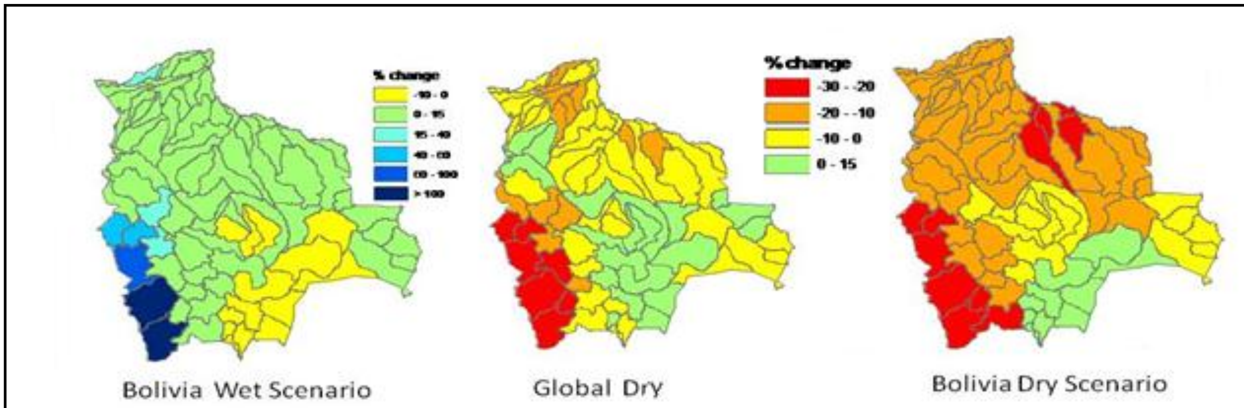
Figure 25 below shows the influence of accumulating extreme events on agricultural GDP. The negative impact of strong El Niño events (red) is clear in the years 1982-1983, 1991-1992, and 2005-2006. Also visible is the slight improvement of agriculture management in 2003-2004. The less severe effects from the phenomenon La Niña (blue) also show through in the years 1985-1986, 1988-1989 and 1994-1995.

Figure 25: Annual percent change of agricultural GDP from El Niño and La Niña effects



Most of the climate models do not agree with regards to rainfall projections in terms of sign of the change, intensity and geographical distribution in Bolivia (Figure 26), showing a range of plausible wet and dry scenarios. The economic and the population welfare impacts 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 south-west of the country, 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.

Figure 26. Projected precipitation changes to 2050 under different climate scenarios



The extreme importance of hydrocarbons and minerals extraction on Bolivia's economy make the country largely protected from more intense (economic) impacts from climate change. Yet, a large portion of the country's population is extremely vulnerable to the effects of climate change, as it relies on subsistence rain-fed agriculture, small-scale livestock farming, and seasonal labor agriculture. Approximately 30 percent of Bolivia's rural population resides in the valleys and high plateau areas where water availability is problematic. In addition, a high proportion lives in extreme conditions without the necessary resources to adapt to climate change.

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 exposed to decreasing trends of rainfall, to unexpected changes in seasonality and to prolonged droughts.

B. 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 considers 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%, whereas the dry scenario shows a temperature increase of 2.4 ˚C and a decrease in precipitation of -19% 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 these events within shorter time frames, can easily threaten the development as usual patterns in Bolivia given the serious public sector financial limitations.

Impacts

Water. Water resources are abundant in Bolivia. Average rainfall is about 1200 mm[14], and despite high evaporation rates, averaged water allocation is high at approximately 45.000 m^3 per capita per year[15]. However, natural water supply presents both a marked geographical and seasonal variability: 45 % of the rainfall falls within 3 months (December-February), with values from 600 to 100 mm in the cold Altiplano and less cold Central-Southern Valley Regions, and values up to 2000 mm in the warm Low lands with maximum values of 5000 mm in certain areas of the transition from the Valley to the low lands.

- 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, the rapid melting of glaciers is expected to 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, like 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[16].

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%, while that for potatoes and quinoa by 60%-90%. 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 in the order of 25% for maize and 10-15% for soybeans, potatoes

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[14] 1146 mm reported by Aquastat, 1459 mm from PNCC (2007), 1189 mm own estimations from CRU data.
[15] Ministry of Environment and Water, 2008.
[16] 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.

and quinoa. They suggest 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 investment 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 the 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, development of systems for flood warnings and disaster prevention can all reduce the economic and social costs of flooding in lowland areas. More expensive forms of flood prevention such as dykes 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, the application of deficit irrigation and changes in the sowing dates and crop varieties are viable options for quinoa; 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.

Measures indicated in the consultations by local populations include better information and capacity building initiatives geared towards 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.

Economic analysis of adaptation investment options

Three different economic assessments were made regarding the costs, benefits and sequencing of alternative adaptation measures at different levels. The first assessed the costs and benefits of

Government selected adaptation measures under the National Adaptation Plan for Bolivia areas. Projects were selected primarily based on the availability of data. Water projects included water supply and water management, and the agricultural consisted primarily of irrigation projects. 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 change climate scenarios. The objective was not to evaluate the projects themselves, but rather their economic feasibility as appropriate adaptation measures to climate variability in Bolivia – Table 11.

Table 11: Cost-benefit analysis of adaptation measures in the agriculture and water sectors

Project	Investment Costs (000)	Beneficiaries	NPV[1] (000)	IRR (%)	NPV[1] (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

1. NPV = Net present value

Note: parenthesis values indicate a negative NPV, suggesting that dam restoration is not economically feasible in this location.

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 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 extreme conditions. Thus, adaptation measures in Bolivia represent primarily good development strategies under climate variability.

This cost benefit analysis illustrates the use of an economic tool for the evaluation, prioritization and sequencing of investment projects under a changing climate. However, the selection of projects is limited to rural areas due to data availability at the time of this analysis. It excludes the larger infrastructure projects in urban areas as these projects are usually excluded from national budgets and mostly financed by international cooperation.

The other two exercises aimed at exploring the possible effects of climate change on a long-term irrigation program (National Watershed Program – PNC by its Spanish acronym) at the watershed level –

Mizque Watershed. This is a watershed which has been identified as being particularly susceptible to climate effects by impact analysis.

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 additional water storage relative to no-climate change irrigation demands would be on the order of total US$ 12 million under the wet climate scenario, and US$ 60 million under the dry climate scenario up to 2050.

The second exercise explored the effect of climate change on PNC's planned investment program for the Mizque watershed. Incorporating the effects of climate change appears to modify the original development plan only slightly. Most of the potential irrigation investments in the Mizque watershed are strongly robust to climate outcomes. 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. The effect of the "dry scenario is to reduce potential social benefits by only 1-3%. The effect of the wet scenario is to increase benefits by 1-3%. These results vary with varying assumptions regarding the amount of money available to invest each year and the degree of budgetary decentralization and management.

In general the effect of budgetary decentralized management[17] at the sub-watershed level overwhelms the effect of climate change, regardless 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 in fact reduces social benefits and/or number of families directly benefitting from the projects by between 2% and over 30%. The effect is least where the budget constraint is loose and where authorities impose a cost-benefit test[18]. It grows when no cost-benefit criterion is imposed and the budget constraint is tight.

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 permits a detailed comparison of investment alternatives and the potential effect of climate change upon them. The approach facilitates investigation of the sequencing and prioritization of actions in a certain timeframe, as well as robustness of alternative investment and policy strategies to possible climate outcomes.

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

[17] 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.

[18] To the extent that budgetary decentralization rule take resources from good projects in some sub-basins to invest in poor projects in other sub-basins budgetary decentralization will inevitably reduce basin-wide benefits. This effect must be balanced against the well-known benefits of increased local knowledge that comes from decentralization. Additional criteria can be imposed—such as the cost-benefit test described above—to get the benefits of decentralization of budgets without undo sacrifice of overall benefits. This model is ideal for experimenting with the relative benefits of various optimization constraints and conditions.

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.

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 benefitted 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.

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.

C. Lessons and recommendations

There is little practical difference between Bolivia's development agenda and the adaptation agenda. 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 which will work well under both wet and dry conditions are called for. A combination of improved water resources management and building water storage and irrigation infrastructure are needed, and these are no-regret strategies which should be pursued irrespective of climate change.

IV.8 Vietnam

A. Vulnerability to climate change

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, significant losses to the agriculture and fisheries sectors, and resulted in a large number of fatalities. In the course of the 20th century, approximately 25,000 lives have been lost in Vietnam as a direct result of climate related events (MARD, 2007[19]). Between 1991 and 2000 more than 8,000 people were killed by natural disasters (storms, floods, flash floods, landslides). In addition, an estimated 9,000 boats were sunk and 6 million houses were destroyed. The total economic value of losses for this period alone was estimated at USD 2.8 billion (CCFSC, 2001[20]).

Vietnam is divided into 8 agro-ecological zones from roughly north to south. Figure 27 illustrates vulnerability to storms and flooding, which is the primary source of economic losses caused by extreme weather conditions. Figure 28 shows that poverty is concentrated in highlands districts, especially in the NW, NE and North Central Coastal zones. Incidence of poverty is much lower in the Red River Delta, SE, and Mekong River Delta. However, both of the major river deltas and parts of the coastline are vulnerable to a combination of sea level rise and storm surges.

[19] Ministry of Agriculture and Rural Development (MARD). 2007. *National Strategy for Natural Disaster Prevention, Response and Mitigation to* 2020, Hanoi.
[20] Central Committee for Flood and Storm Control (CCFSC). 2001. Second National Strategy and Action Plan for Disaster Mitigation and Management in Viet Nam-2001 to 2020. MARD, Hanoi.

Figure 27. Vulnerability to weather losses

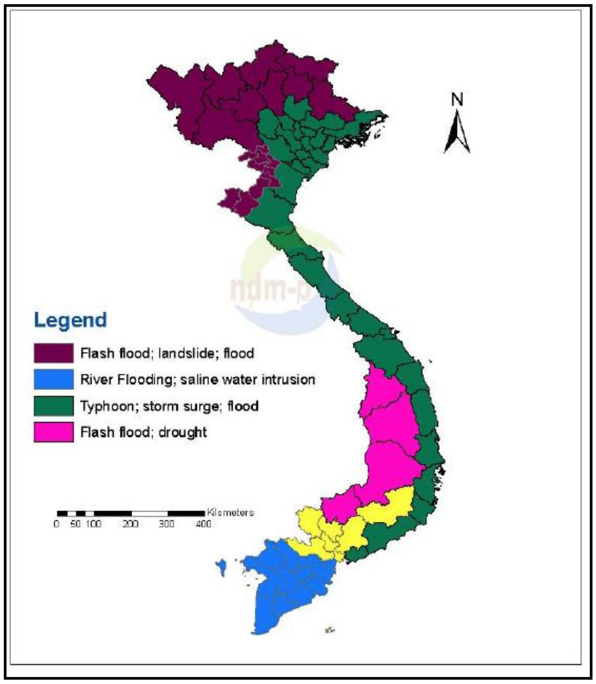
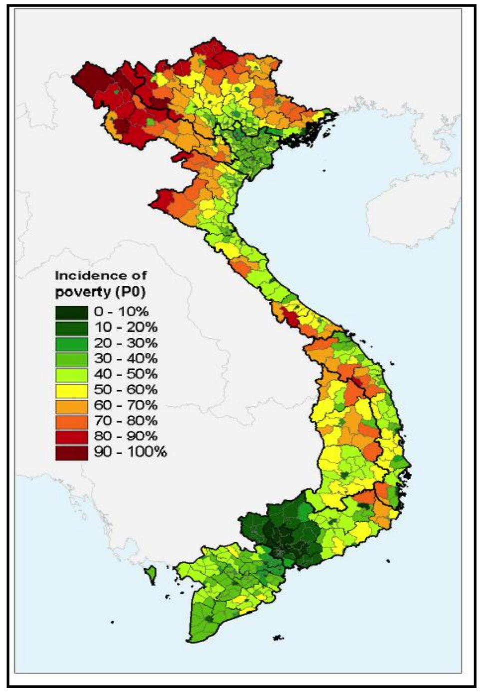


Figure 28. Poverty mapping



The social component identified key socio-economic and biophysical zones of vulnerability and concluded that the regions are quite distinct in terms of exposure and vulnerability – Table 12.

Table 12. Exposure and Sensitivity of Regions

Region	Exposure	Sensitivity
Mekong Delta Region	H	M
Northern Mountais	L	H
Central Highlands	M	H
Central Coast	H	M
Red River Delta	M	L
Southeast Region	L	L

H: High; M: Moderate; L: Low

In June 2009, the Ministry of Natural Resources and Environment (MoNRE) published Vietnam's official climate change scenario, using the medium emission scenario B2 for purpose of impact assessment and adaptation planning. The official scenario includes projected changes in temperature, rainfall, and sea level over the 2020 – 2100. In addition to the MoNRE scenario, the EACC study has examined two other climate scenarios – country-specific Dry (IPSL-CM4) and Wet (GISS-ER). The MoNRE scenario falls in the middle of distribution of climate moisture indices for Vietnam.

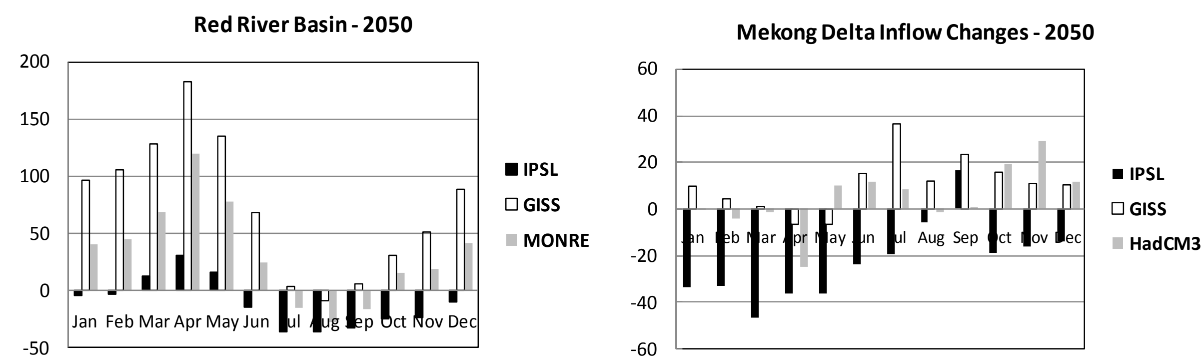
Rainfall projections across seasons are of particular interest. The dry seasons are projected to get drier, with the March – May rainfall reductions being higher in the southern part; the wet seasons are projected to get wetter, with the June – August rainfall increases being higher in the northern part. 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 rise is also projected to rise at an increasing rate over the period 2020 – 2100, leading to an increase of approximately 30 cm by 2050 and up to 75 cm by 2100 under the medium scenario. As pointed in MoNRE's official scenario, it is generally believed that IPCC projected changes in sea levels have been under-estimated.

B. EACC approach and results

Impacts. Figure 29 shows striking differences between the effects of climate change on river run-off in the Red River and Mekong River basins – note that the Hadley CM3 model is used as a proxy for MoNRE which does generate projections outside Vietnam. There are large increases in run-off in the Red River basin for the Wet (GISS) and MoNRE scenarios, whereas the equivalent increases are much smaller in the Mekong River basin. The Dry (IPSL) scenario has a particularly severe impact on run-off in the Mekong River basin.

Figure 29. Percent changes in average monthly run-off by climate scenario



Agriculture. The impact of the alternative climate scenarios on crop production has been examined using hydrological models of run-off for major river basins, which affects the availability of irrigation water, plus agronomic models which take account of temperature and rainfall patterns, water availability for rainfed and irrigated crops, and other factors to estimate the impact of alternative climate scenarios on crop productivity. The analysis allows for variations in space using data from a network of weather stations and the climate projections by grid square. The effects of CO_2 fertilization have been examined, but the results reported below assume no fertilization.

Productivity impacts are summarized in Table 13. Yield reductions vary widely across crops and agro-ecological zones under climate change. For rice, the worst yield reductions (e.g. IPSL without CO_2 fertilization effects) are about 12% in the Mekong River Delta, while about 24% in the Red River Delta. Across zones, Central Highlands tends to have the highest crop yield decline under both the dry and the wet climate change scenarios. Country-wide, rice yield decreases between 10% and 20% in 2050 without CO_2 fertilization; with CO_2 fertilization, rice yield decreases are less than 12%. It is also of interest to observe that the MoNRE scenario results in rice production increases when CO_2 fertilization is considered, and that it is the scenario leading to the smallest rice yield reductions across all regions.

Table 13. Potential impacts of climate change on agricultural productivity in Vietnam

Agro-ecological Zone/River Basin	Potential rice yield impacts of CC
North West	Declines by 11.1% to 28.2%; other crops decline by 5.9% to 23.5%. Generally, the dry scenario results in more yield reduction than the wet scenario.
North East	Declines by 4.4% to 39.6%; yields of other crops decline by 2.7% to 38.3%. The largest yield reduction can be with either the dry or wet scenarios, depending on crops.
North Central Coast	Declines by 7.2% to 32.6%; yields of other crops decline by 4.1% to 32.9%. The largest yield reduction can be with either the dry or wet scenarios, depending on crop.
South Central Coast	Rice yield declines by 8.4% to 27.0%; yields of other crops decline by 4.0% to 20.9%. Generally, the dry scenario results in more yield reduction than the wet scenario.
Central Highland	Declines by 11.1% to 42.0%; yields of other crops decline by 7.5% to 45.8%. The largest reduction can be with either the dry or wet scenarios, depending on crop.
South East	Yield increase by 4.3% in the dry scenario, the same in the wet scenario, and declines by 8.8% in the MONRE scenario. Yields of other crops decline by 3.0% to 22.7%.
Mekong River Delta	Declines by 6.3% to 12.0%; yields of other crops decline by 3.4% to 26.5%. The largest yield reduction can take place under any of the three scenarios, depending on crops.

By 2050, climate change may reduce rice production by 2 to nearly 7 million metric ton per year, without CO_2 fertilization; with CO_2 fertilization, rice production decrease is less than 3.6 million metric ton. We found production reduction in 2030 may be larger than that in 2050 with CO_2 fertilization.

Sea level rise. Increased inundation of crop land in the rainy season and increased salinity intrusion in the dry season will both impact crop production. For the Mekong River Delta, expected sea level rise of 30 cm by 2050 will result in increased inundation of 193 thousand ha rice area during rainy season and increased salinity intrusion-affected rice area of 294 thousand ha during dry season. The loss of rice area will lead to a rice production decline of about 2.6 million metric ton per year. This accounts for more than 13% of today's rice production in the Mekong River Delta. The estimate assumes rice yield remains unchanged in the future. Considering yield increase due to varietal and farming technology improvement over time, production loss due to sea level rise can be significantly higher.

Compared to Mekong River Delta, rice area loss is much less in the lower Dong Nai river basin. With increased rice area inundation of 4,300 ha in 2030 and 10,700 ha in 2050, production losses are about 18,000 ton and 47,000 ton in 2030 and 2050, respectively.

Macro-economic impacts. As in other country studies, a CGE model has been used to examine the macro-economic impacts of climate change on the economic growth and GDP in 2030 and 2050. A broad picture of the results may be obtained by examining changes in aggregate GDP and other variables under the climate scenarios in 2050 relative to a baseline with no climate change. The impacts are largely driven by the effect of climate on value-added in agriculture together with consequential effects on processing, distribution, trade and retail prices. The model does not attempt to take account of damage to roads and other infrastructure caused by storms and flooding.

Table 14 below suggests that with no adaptation real GDP in 2050 is 2.4-2.3% lower than the baseline under the Dry/Wet scenarios but only 0.7% lower under the MoNRE scenario. Value-added in agriculture is 13.9-13.5% lower in the Dry/Wet scenarios, marginally offset by small increases in value-added in industry and services. Although not shown in the Table, regional GDP is severely affected in the Central Highlands with losses of nearly 25% for the Dry/Wet scenarios and 19% for the MoNRE scenario. The impact on household incomes is also heavily skewed with much greater losses for those in the lowest quintile than for the top quintile.

Table 14. % changes in GDP, regional and household incomes without and with adaptation

	(1) No adaptation			(2) With adaptation			(3) Adaptation benefits		
	DRY	WET	MoNRE	DRY	WET	MoNRE	DRY	WET	MoNRE
Real GDP	-2.4	-2.3	-0.7	-1.1	-0.7	0.7	1.3	1.6	1.3
Real consumption	-2.5	-2.5	-0.7	-1.4	-0.8	0.6	1.1	1.7	1.3
Rural household income									
Quintile 1 (RQ1)	-6.5	-6.3	-2.6	-1.9	-1.4	2.4	4.7	4.9	5.0
Quintile 2 (RQ2)	-5.2	-5.0	-1.9	-1.6	-1.1	1.9	3.6	3.9	3.8
Quintile 3 (RQ3)	-4.2	-4.0	-1.5	-1.5	-1.0	1.4	2.7	3.1	2.9
Quintile 4 (RQ4)	-2.9	-2.9	-0.9	-1.4	-0.8	0.8	1.6	2.1	1.8
Quintile 5 (RQ5)	-1.6	-1.7	-0.4	-1.5	-1.0	0.0	0.1	0.7	0.4

Without adaptation, climate change causes all households to be worse off, relative to the no climate change baseline. The largest adverse effects are experienced by the poorest urban (not shown) and rural households. These households are the most vulnerable on both income and expenditure sides to the losses in agricultural income.

Adaptation. A portfolio of adaptation options has been considered for each of the climate scenarios. These include relatively low cost changes in agricultural practices such as 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. In addition, the analysis assumes that (a) average crop yields increase by 13.5% relative to the baseline by spending more on agricultural research and extension, and (b) the area of land under irrigation increases by about 688,000 ha, roughly half for rice and the remainder mainly for maize and coffee. The undiscounted total cost of these measures is estimated at about $210 million per year at 2005 prices over the period 2010-50.

The macro-economic impacts of these adaptation measures were assessed by comparing future economic development with and without adaptation. The reduction in real GDP and real consumption is much less severe 'with adaptation'. When measured in dollar terms (Table 15), the net benefits of adaptation appear clearly positive.

Table 15. Real aggregate consumption ($US billion)

Consumption		Climate change scenario		
		Dry	Wet	Monre
Annual average 2010-2050				
(1)	No adaptation	-4.1	-3.4	-1.3
(2)	With adaptation	-1.5	-2.0	0.7
Present value				
(3)	No adaptation	-47.9	-37.8	-16.3
(4)	With adaptation	-15.6	-24.7	7.8
(5)	Net benefit of adaptation = (4) – (3)	32.3	13.1	24.2

A major benefit of the adaptation measures considered is that they offset most of the disproportionate impact of climate change on poorer households. The "With adaptation" results show that the lowest quintiles of urban and rural households are slightly worse affected under the Dry & Wet scenarios, but they gain most under the MoNRE scenarios. Overall, the gains from adaptation are substantially skewed in favor of lower income households.

Investments in flood and coastal protection were not incorporated in the macro-economic analysis. Separate studies have indicated that the costs of building/upgrading sea dikes and flood defences to protect urban infrastructure and the most valuable agricultural land would be substantially less than 0.1% of GDP for the MoNRE scenario – in the range $20-50 million per year at 2005 prices.

Local level perspectives. Up to now government policies have focused on sector-wide assessments for the whole country and on 'hard' adaptation measures – sea dykes, reinforced infrastructure, 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 etc – 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 confirms 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, sub-national and community levels.

C. Lessons and recommendations

The Vietnam study focused on the impact of climate change scenarios on water resources and agriculture together with consequential effects on the rest of the economy. One striking result is that the extreme Dry and Wet climate scenarios are almost equally bad in terms of the aggregate reduction in agricultural value-added and GDP. In contrast, the intermediate MoNRE scenario leads to much smaller impacts. Nonetheless, adaptation measures including spending on agricultural R&D and irrigation are justified under all three climate scenarios and would increase agricultural output and GDP under the intermediate MoNRE scenario. The key lessons are:

- The crop simulations indicate that temperature is the main factor causing a decline in crop yields under the climate scenarios for Vietnam, since it seems that some crops already grow near or above their optimal thermal ranges. As a consequence, yield reductions vary widely across crop and agro-ecological zones under different scenarios.

- Sea level rise may have a serious effect on rice production in the Mekong River Delta with a loss of about 14% of the Mekong Delta's present rice production. Adaptation will require investments in coastal and flood defense to minimize saline intrusion and flooding.

- The impact of climate change is particularly serious for households in the lowest quintiles of the rural and urban income distribution. Adaptation through agricultural improvement and expansion of irrigation largely offset this impact and reduces inequality in the MoNRE scenario.

- Climate change will always hide beneath climate variability. Systems that can effectively cope with existing climate variability will be more successful in adapting to future climate change than those that cannot. Hence, it is important to enhance the capacities of agricultural and water systems in Vietnam to cope with current climate variability and build resilience into such systems from now on.

IV.9 Samoa

A. 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 either the strength and/or 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 – see IWTC(2006). Nonetheless, many climate 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 very heavy rainfall and drought.

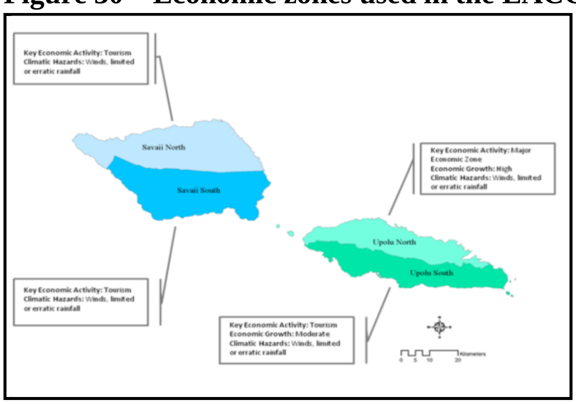
Approximately 70% of the population of Samoa lives in low-lying coastal areas which would be vulnerable to inundation as a consequence of the combined effects of sea level rise, more severe storm surges and. As an illustration of the risks, two major cyclones (Ofa & Val) hit or passed near to one of the two main islands in 1990-1991, damaging a majority of buildings and causing a total economic loss of about US$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.

B. 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 which 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 30. North Upolu has a population of about 110,000 while the populations of the other regions fall between 17,000 and 28,000. Table 16 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 0.8 to 1°C for the two climate scenarios. However, total precipitation declines marginally in 3 out of 4 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. On this basis, the shift in the probability distribution of storms has been assumed to be associated with the relative increase in total precipitation during the rainy season. This is significant for Upolu South in the NCAR scenario and for all regions in the CSIRO scenario.

Figure 30 – Economic zones used in the EACC



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 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%) of consumption over the period 2010-40 relative to the no climate change (NoCC) baseline.

Table 16 - Deviations in precipitation and temperature in 2050 by climate scenario

Scenario	Region	Baseline values for NoCC	Deviations in 2050 relative to NoCC

		Total precipit.	Precipitat. Dec-Feb	Precipitat. Nov-Apr	Mean temperat.	Total precipitat.	Precipitat. Dec-Feb	Precipitat. 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

Impacts. The gross economic losses when there is climate change without adaptation are shown in Columns (1) and (2) of Table 17. The impact of climate change is much larger for the CSIRO scenario and amounts to US$128 million at 2005 prices in present value terms. On an annualized basis this amounts to US$7.3 million at 2005 prices per year or 0.9% of total GDP in the baseline scenario.

Table 17 – 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	9.3	127.9	3.9	38.9	5.5	89.0
Annualized equivalent, $ million/year	0.5	7.3	0.2	2.2	0.3	5.1
Loss/benefit as % of baseline GDP	0.1%	0.9%	0.0%	0.3%	0.0%	0.7%

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% 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).

For the EACC study adaptation has been assumed to involve the retention of the 1 in 10 year threshold for storm damage after taking account of the shift in the probability distribution of storms over a period of 50 years from the date of construction. This means that the design standards for buildings and other assets are (a) revised immediately to cope with a peak wind speed of 120 kph and (b) increased in subsequent decades to cope with a peak wind speed of 140 kph in 2050, which corresponds to the 1 in 10 year event projected for 2100.

Other adaptation measures, largely drawn from the 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 annualised 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 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) & (4) of Table 17 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) & (6). They amount to US$5.5 million at 2005 prices (58%) for the NCAR scenario and US$89 million (70%) for the CSIRO scenario. The net economic loss in the CSIRO scenario is about 0.3% of baseline GDP.

Adaptation measures involving the adoption of more stringent design standards is clearly justified, even in the NCAR scenario for which the gross losses due to climate change are relatively small. However, under the NCAR scenario the other adaptation measures outlined above do not reduce climate losses by sufficient to cover their costs, though they may be warranted for other reasons. Under the CSIRO 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, some of the adaptation measures – e.g. moving coastal infrastructure in Upolu South – may be justified for non-climate reasons such as protection against the impact of earthquake tsunamis.

The analysis reveals another important point about the management of weather risks. The adoption of stricter design standards would be justified even in the absence of climate change. As explained above, the adaptation measures allow for a peak wind speed of 140 kph in 2050 for the CSIRO scenario, corresponding to a 1 in 20 year event at that date but a 1 in 10 year event in 2100. The analysis shows that if all buildings in 2050 were constructed to a 1 in 20 year standard, then the expected value of storm losses would be 1.9% of GDP rather than 5.3% of GDP for the current 1 in 10 year standard. The present value of adopting the stricter design standard would be about US$ 76 million at 2005 prices after allowing for the additional costs of construction.

Clearly, raising the general level of design standards to cover 1 in 20 year storms would be justified without any consideration of climate change. Going further, the figures suggest that the marginal benefit adopting a design standard of 1 in 50 year storms - 165 kph in 2050 for the CSIRO scenario – instead of a 1 in 20 year standard would reduce the expected value of storm damage by about 1.5% of GDP at an annual cost of less than 0.5% of GDP. In both cases, the adoption of more stringent design standards today would reduce the impact of the climate change in future and the residual damage after adaptation.

Local level perspectives on adaptation. The EACC 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 consultations which include women and untitled 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.

C. 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 lead 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 key adaptation measure identified in the study is the adoption of forward-looking design standards that will enable buildings and other assets to cope with storms with higher peak wind speeds and associated precipitation under alternative climate scenarios. At present, peak wind speeds above 110 kph may cause significant damage. If the standard were raised to 140 kph by 2050 – equivalent to a 1 in 10 year storm in 2100 for the CSIRO scenario - the expected losses from climate change would be greatly reduced.

- The analysis also 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 without significant damage.

V. 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, how to improve the quality of education. The goal of this study was to focus on the economics of adaptation, but it is essential to bear in mind that it 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.[21] Where researchers, data, and models already existed, the EACC 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 three categories: uncertainty, institutions, and modeling limitations – discussed below.

V.1 Uncertainty

Uncertainty complicates the analysis of adaption 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. Consequently, decisions about investments in assets having a useful life of 20, 30, or even 40 years – such as dams, dykes, urban drainage, bridges and other infrastructure – have to be based upon 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 means that countries are 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. These issues are discussed below.

[21] 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.

Climate uncertainty. 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 investment 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 2 projections for the global track and for 2-4 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.[22]

Growth uncertainty. 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 2010-2019, 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% 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 for global GDP in 2050 using the medium fertility population projection. 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

[22] It should be noted that 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.

similar exercises. The very same uncertainties apply in the analyses of all economic sectors that have such extended time horizons.

Technological uncertainty. With the exception of one sector 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 estimates of the costs of adaptation. The exception is the agricultural sector. 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.

V.2 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, determining what is feasible as opposed to what might be desirable from an economic perspective. But there was a clear trade-off between extending the scope of the study and ensuring that the economics of adaptation could be examined in sufficient detail. [23]

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.[24] Good development policies to reduce

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[23] 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.

[24] See *Accommodating Migration to Promote Adaptation to Climate Change*, A policy brief prepared for the Secretariat of the Swedish Commission on Climate Change and Development and the World Bank World Development Report 2010 team, prepared by Jon Barnett and Michael Webber, Department of Resource Management and Geography, The University of Melbourne.

poverty and enhance social inclusion are essential without any consideration of climate changes, so that 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.

V.3 Modeling

The study has estimated the additional public sector (budgetary) costs which will be required for countries to adapt to climate change.[25] 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 on another sector, or whether cash transfers would maintain welfare at lower cost, was beyond the capacity of this exercise.[26] Several of the country studies CGE models calculated the economy-wide 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. The African case studies will widen the exploration of adaptation options, providing further insights into strategic thinking about adaptation.

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.

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[25] 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.

[26] There are a number of reasons why it has not been possible to optimize cross-sectorally and inter-temporally. Most importantly is the fact that 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.

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 which implement projects at differing points in the future. An alternative approach would be to look for robust rules of thumb which 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 on which models have to rely, 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 were not addressed. Additional work is also especially 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 (i) the level of effort required to obtain the necessary economic information, (ii) problem in scaling up very specific local and soft measures for incorporation in national models, and (iii) 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.

There are two final observations which are not really limitations of the study as such but reflect general lessons that apply in all areas of development policy. The first concerns uncertainty, which is pervasive when dealing with climate change. The key lesson is no different from any other area of economic policy – do not act on fixed assumptions about the future, build flexibility into both policies and hardware. No study, however careful and detailed, can remove this uncertainty.

The second point has to do with institutions. Any type of outside assistance in support of institutional reform must build on changes that have internal sources and support. There are no magic recipes for dealing with the institutional aspects of adaptation. As an illustration, certain countries manage to cope with extreme weather events better than others at similar levels of income. The mechanics of what they do can be identified, but the incentives and mechanisms to make this happen have to come from internal concerns and conviction.

VI. LESSONS AND FUTURE WORK

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 discussed in chapters III and IV. The recommendations for future work follow mostly from the limitations identified in chapter V.

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 is 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 to be on average $70 billion to $100 billion a year at 2005 prices between 2010 and 2050. While the nominal cost of adaptation is large, the cost of adaptation amounts to about 0.2% of the projected GDP of all developing countries in the current decade and falls to about 0.12% of projected GDP for 2040-49. On the other hand, the total cost is very large relative to current levels of development aid. The upper end of the range is more than 80% of 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% of GDP for the Sub-Saharan Africa region in 2010-19 falling to about 0.5% of GDP in 2040-49. In contrast, the equivalent figures for the East Asia and Pacific region are 0.13-0.19% in 2010-19 and about 0.07% in 2040-49. Apart from Sub-Saharan Africa the regions facing relative 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 US$70 billion to US$100 billion a year at 2005 prices. This amounts to about "only" 0.2% of the projected GDP of all developing countries in the current decade and at the same time to as much as 80% of total disbursement of ODA in 2008.

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 the weather variability. Economic development brings changes in economic activities which 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. Relatively small deviations from the ambitious investment targets envisaged in the baseline for roads, dams, hydropower, water management, and irrigation, would significantly increase vulnerability to climate change and thus make adaptation costlier.

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, substantial illiteracy, and 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 countries, 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 simply exacerbates them. 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 the 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 is particularly serious for households in the lowest quintiles of the rural and urban income distribution. Adaptation through agricultural improvement and expansion of irrigation largely offset this impact and reduces inequality.

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 to fall by 30%. 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 variances of weather indicators around climate average 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 all climate outcomes obviously raises the cost of adaptation prohibitively.

It also follows from this analysis that countries should want to delay adaptation decisions as much as possible and focus on low-regret actions, awaiting for greater certainty about climate and socioeconomic scenarios. These low-regret actions are 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. 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, access to extension service, 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.

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 towards delaying investments in large coastal protection schemes, and focusing more on the people affected rather than on the land lost. More vital infrastructure, such as the port of Beira, justifies the more expensive installation and construction of dykes. 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.

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.

Current climate vulnerabilities

Climate change will always hide beneath climate variability. Systems that can 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 increase 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 for example suggested that it is important to enhance the capacities of agricultural and water systems in order to cope with current climate variability and build resilience into such systems from now on.

Lesson 5: Adaptation to climate change should start with the adoption of measures that tackle the weather risks that countries already face, e.g. 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 protective infrastructure to great scrutiny to ensure robustness to different climate scenarios, appropriate incentives must be put in place, which discourage the accumulation of physical capital in the shadow of dykes considered to be "safe". As the tragedy of New Orleans dramatically illustrated, a sufficiently extreme event will breach a dyke. 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 made less disruptive and does not fall disproportionate upon the poor and the vulnerable.

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.

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, afforestation of mangroves ranked 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.

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 of devising and implementing soft measures are often under-estimated because these may involve changes in expectations or (quasi-) established property rights that are strongly resisted.

The analysis of the global costs of adaptation relies heavily upon 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 latter costs are zero or negative in the longer run, because the changes bring greater benefits than merely adaptation to climate change. But they are much harder to quantify.

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 safety nets improvements, community-based resource management systems, and disaster preparedness. It is also necessary to accelerate decentralization process to 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 R&D related to impacts of climate change on crops and livestock products and pest control, early-maturing varieties, improvement of the land tenure system, and improved entrepreneurial skills to generate off farm income. In the transport sector, the proper timing of road construction (for example, during dry season), routine and timely road maintenance, upgrade road design specifications including choice of materials.

In Ghana, a number of soft measures were given priority over hard measures: upgrade of peri-urban slums and controlled development of new ones; protection, management, and sustainable use of coastal wetlands; review of Ghana coastal development plans to take into consideration climate change adaptations including coast line and ports protection, flood protection, and coastal communities and fishery industry protection.

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 towards 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.

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. The table which follows identifies areas in which future work can contribute to this process of reducing uncertainty. It is fundamentally based on the study's limitations analyzed in Section V.

Table 11. Recommendations for future work

EACC LIMITATION	RECOMMENDATION FOR FUTURE WORK
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

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THE WORLD BANK

The World Bank
1818 H Street, NW
Washington, DC 20433 USA

www.worldbank.org/eacc
eaccinfo@worldbank.org

Ministry of Foreign Affairs

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