Economics of Adaptation to Climate Change

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Economics of Adaptation to Climate Change

MOZAMBIQUE


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Acronyms

ANE	National Roads Agency
CGE	Computable general equilibrium
CRU	Climate Research Unit
CV	Coefficient of variation
DIVA	Dynamic interactive vulnerability assessment
DNA	Department of Water Affairs
EACC	Economics of Adaptation to Climate Change
FAO	Food and Agriculture Organization of the United Nations
FEMA	Federal Emergency Management Unit
GCM	Global circulation model
GDP	Gross domestic product
GFFDR	Global Facility for Disaster Reduction and Recovery
GRDC	Global Runoff Data Center
GTZ	German Development Cooperation (Gesellschaft für Technische Zusammenarbeit)
HDI	Human Development Index
IMPEND	Investment Model for Planning Ethiopian Nile Development
INGC	National Institute for Disaster Management
IPCC	Intergovernmental Panel on Climate Change
JTWC	Joint Typhoon Warning Center
MPD	Ministry of Planning and Development
NAPA	National Adaptation Programme of Action
NGO	Nongovernmental organization
PARPA	Action Plan for the Reduction of Absolute Poverty (Government of Mozambique)
PEDSA	Strategic Plan for the Development of Agricultural Sector
PPCR	Pilot Program for Climate Resolution
PQG	Programa Quinquenal do Governo (Government of Mozambique five-year plan)
PRA	Participatory rural appraisal
PSD	Participatory scenario development
SADC	Southern African Development Community
SCF	Strategic Climate Fund
SLOSH	Sea, lake, and overland surge from hurricanes (US National Weather Services Model)
SLR	Sea level rise
TFESSD	Trust Fund for Environmentally and Socially Sustainable Development
TIA	Trabalho de Inquerito Agricola
TPC	Tropical Prediction Center
UNDP	United Nations Development Programme
WEAP	Water Evaluation and Planning System

UNITS OF MEASURE

Agl	Above ground level
AMWS	Annual mean wind speed
gW	gigawatt
ha	hectares
km	kilometers
km^2	square kilometers
kW	kilowatt
m	meters
mW	megawatt

USD/US$ United States Dollar

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


OAKITE

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Executive Summary

This report is part of a broader global study, the Economics of Adaptation to Climate Change (EACC), which has two principal objectives: (a) to develop a global estimate of adaptation costs for informing international climate negotiations; and (b) to help decision makers in developing countries assess the risks posed by climate change and design national strategies for adapting to it.

The first part of the study—the "global track"—was aimed to meet the first objective. Using several climate and macroeconomic models, the global track (World Bank 2009) concludes that by 2020, the annual costs of adaptation for developing countries will range from $75 billion to $100 billion per year; of this amount, the average annual costs for Africa would be about $18 billion per year.

In order to meet the second objective, the study also commissioned a "country track" consisting of seven country-specific case studies. Mozambique was one of three African countries selected for the "country-track" study, along with Ghana and Ethiopia. The objective of the country track was both "ground-truthing" the global study and helping decision makers in developing countries understand climate risks and design effective adaptation strategies.

Approach

The three studies in Africa use similar methodologies. In accordance with the broader EACC methodology, climate change impacts and adaptation strategies were defined with regard to a baseline (without-climate change) development trajectory, designed as a plausible representation of how Mozambique's economy might evolve in the period 2010–50 on the basis of historical trends and current government plans. The baseline is not a forecast, but instead it provides a counterfactual—a reasonable trajectory for growth and structural change of the economy in the absence of climate change that can be used as a basis for comparison with various climate change scenarios.

Impacts are thus evaluated as the deviation of the variables of interest (economic welfare, sector development objectives, etc.) from the baseline trajectory in priority sectors. Adaptation is defined as a set of actions intended to reduce or eliminate the deviation from the baseline development path caused by climate change.

The impacts of climate change, and the merits of adaptation strategies, depend on future climate outcomes, which are typically derived from global circulation models (GCMs) and are uncertain, both because the processes are inherently

stochastic and because the GCM models differ in how they represent those processes. Since scientists are more certain of likely patterns of temperature increase than of changes in precipitation, the work describes for Mozambique a "wet" and a "dry" scenario. In order to enable comparison with other countries, this report utilizes the two "extreme" GCMs used in the global track of the EACC (labeled "global wet" and "global dry"). However, a globally wet scenario is not necessarily wet in Mozambique. In fact, the global wet scenario projects a slight drying and the global dry is in fact somewhat wetter in Mozambique. Hence, two additional models—labeled "Mozambique wet" and "Mozambique dry"—were selected in order to represent the range of possible outcomes for Mozambique.

The Mozambique EACC study selected four sectors that are believed to be vulnerable to climate change: (1) agriculture, which employs over 70 percent of the population; (2) energy, particularly hydropower generation, which is dependent on water runoff; (3) transport infrastructure, notably roads; and (4) coastal areas, which do not conform to a "sector" but characterize specific geographical areas vulnerable to floods and storm surges directly and indirectly related to sea level rise.

The analysis developed growth paths "with climate change" incorporating climate shocks on priority sectors under alternative climate projections. The economic impact of climate change was assessed by comparing with a baseline trajectory labeled "without climate change." Finally, costs of adaptation measures required to offset the negative impacts of climate change were calculated both at the sectoral and economy level. The study also considered the social dimensions of climate change.

While this study is one of the most comprehensive studies looking into the implications of climate change for a low-income country to date, some impact channels were not considered. For example, the assessment did not include climate change impacts on ecosystem services or on the prevalence of malaria. The EACC study also did not consider a number of key adaptation strategies. Excluded were improved public awareness and communications; insurance mechanisms; wider access to weather information (that is, not related to the sectors mentioned), improved land use planning and management, such as improved building codes, not building on flood plains; regional watershed management; forest and woodland conservation; and mangrove and wetland conservation. These options have potentially very high returns. Nevertheless, the study does provide interesting results.

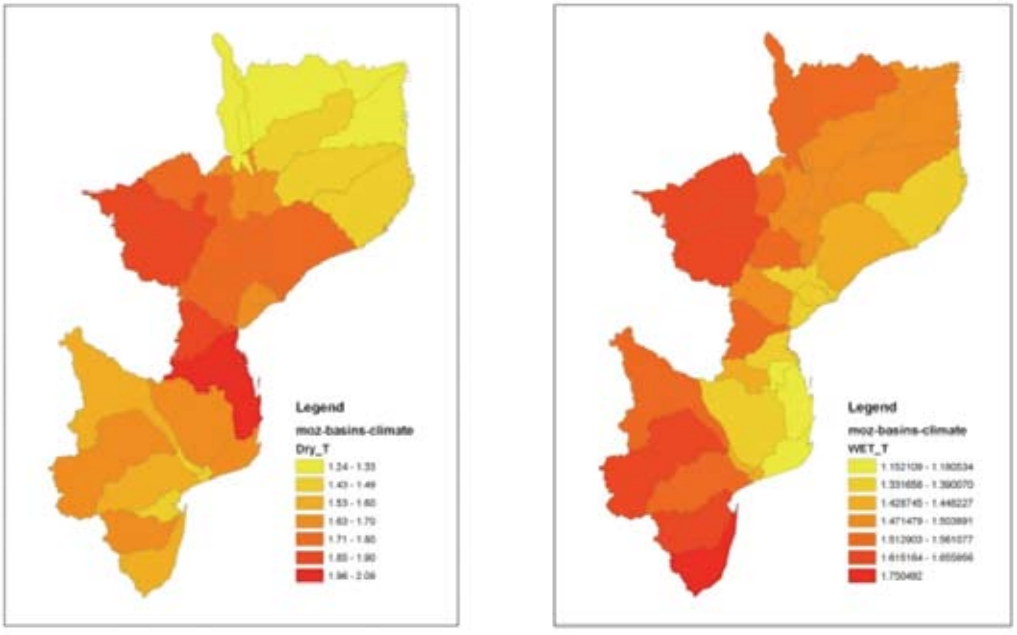
When identifying potential resilience measures to adopt, both "hard" infrastructure—such as sea walls, irrigation systems, and power generation and distribution—and "soft" policy options were considered. For example, road redesign proved to be one of the most powerful adaptation options considered. The study makes the point that, in the long run, adaptation strategies should not be limited to the sectors studied. The results of the study have to be qualified because of these limitations.

CLIMATE CHANGE IMPACTS

Changes in precipitation and temperature from the four GCMs (the two global scenarios plus two extreme scenarios for Mozambique) were used to estimate (a) the changes in yield each year for both irrigated and rain-fed crops, as well as irrigation demand for six cash crops and eight food crops; (b) flow into the hydropower generation facilities and the consequent changes in generation capacity; and (c) the impact on transport infrastructure and the increased demand and costs of road maintenance. Simulations of sea level rise were constructed independently of the climate scenarios.[1] Two approaches were undertaken.

1 The study of sea level rise in Mozambique considers three sea level rise scenarios—termed low, medium, and high, ranging between 40cm and 126cm by 2100—following the approach used in the global study.

FIGURE ES.1 **MOZAMBIQUE WET AND DRY TEMPERATURE IN 2050**



First, an integrated model of coastal systems was used to assess the risk and costs of sea level rise in Mozambique. Second, focused analyses of the interactions between cyclone risk and sea level rise were undertaken for Beira and Maputo, the two largest cities in Mozambique.

As illustrated in Figure ES.1, by 2050, Mozambique will see an increase in temperature of 1–2 degrees Celsius no matter what the scenario; more precisely, temperatures will increase by 1.15 to 2.09 degrees Celsius, though with regional variations.

Comparing Figure ES.1 with Figure ES.2, it becomes clear that regional variation in temperature is not as significant as variation in precipitation. As shown in the maps below, regional variation in precipitation continues to be significant between northern and southern Mozambique—no matter what the climate scenario. However, depending on the scenario, precipitation in the southern region is projected to either decrease relatively little (in the dry scenario) or increase dramatically (in the wet scenario).

Precipitation will either increase or decrease depending on the models, again with regional differences. The main message here is that climate will become increasingly variable and uncertain, and that people and decision makers need to plan for this uncertainty.

AGRICULTURE

Agriculture in Mozambique accounts for 24 percent of GDP and 70 percent of employment. In all scenarios, the net average crop yield for the entire country is lower relative to baseline yield without climate change. The impact of climate change over the next 40 years would lead to a 2–4 percent decrease in yields of the major crops, especially in the central region, as shown in Figure ES.3. This, combined with the effects of more frequent flooding on rural roads, would result in an agricultural GDP loss of 4.5 percent (conservative) and 9.8 percent (most pessimistic).

Mozambican agriculture is primarily rain-fed, with only 3 percent of farmers using fertilizer.

FIGURE ES.2 MOZAMBIQUE WET AND DRY PRECIPITATION IN 2050

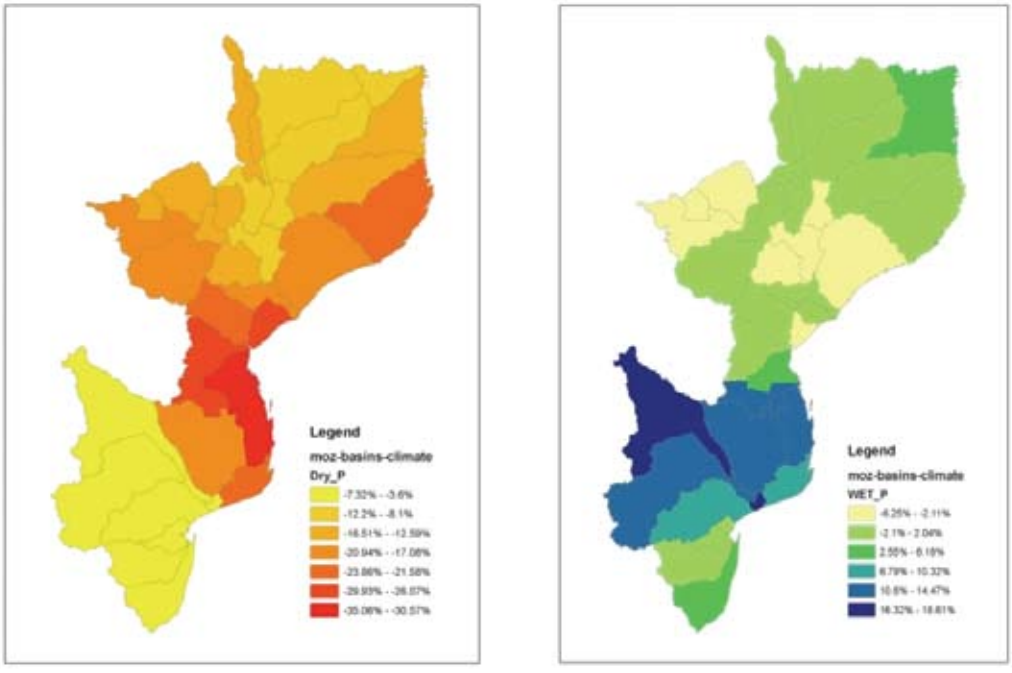
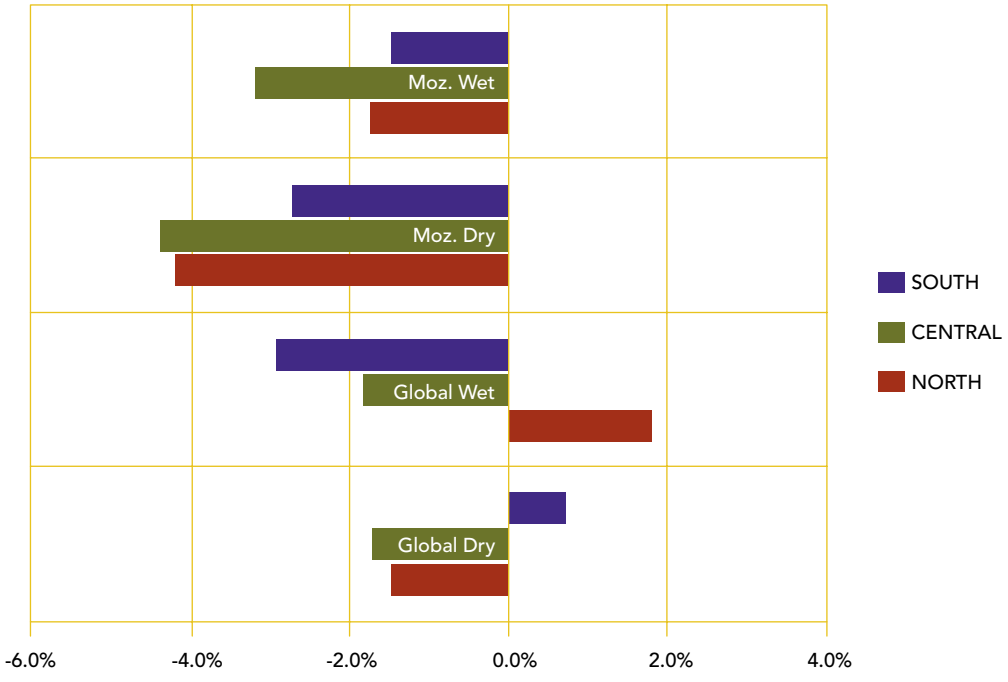


FIGURE ES.3 CLIMATE CHANGE EFFECTS ON YIELD FOR ALL MAJOR CROPS



Note: The crops modeled are cassava, sorghum, soybeans, sweet potatoes and yams, wheat, groundnuts, maize, millet, and potatoes.

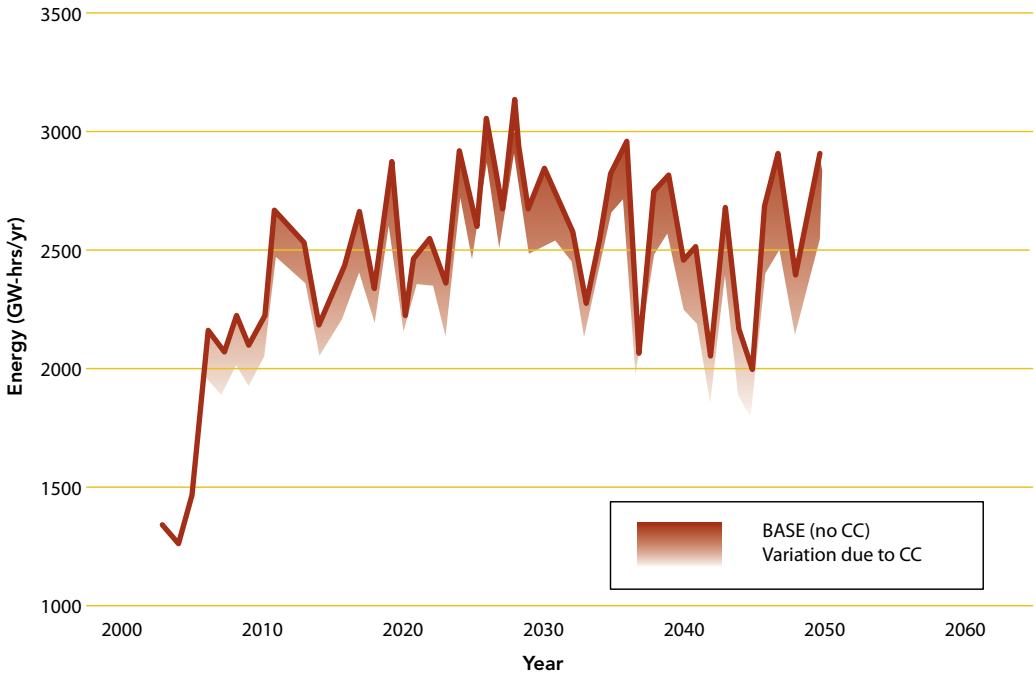
"Slash and burn" techniques are widely used, and these methods, combined with uncontrolled fires, result in soils that are poor in vegetative cover and vulnerable to erosion—and hence to further losses in productivity from floods and droughts.

ENERGY

Only 7 percent of Mozambicans have access to electricity. The primary source is hydropower from barrages in the Zambezi Basin. There are plans to develop hydropower further, both for export to Southern Africa and to increase supplies for the population. Given the economic potential of hydropower, the EACC study undertook an analysis of the potential impacts of climate change on hydropower generation. The potential energy deficit due to climate change relative to the baseline's generation potential, from 2005–50, is of approximately 110,000 GWh.

The graph in Figure ES.4 illustrates that under all scenarios except the most pessimistic, the impact of climate change on energy supplies would be only modestly negative (1.4 percent less electricity generated than "without" climate change). This is because the plans for new energy generation plants have largely already taken into account changing patterns of temperature and precipitation. The most significant impact would be from increased evapotranspiration (and hence less water available for electricity) from the reservoirs. Although the EACC study did not model this, the operators of the hydropower generation plants will need to pay particular attention to the timing of water releases to ensure sufficient downstream flow at times of low water availability and to avoid interference with port activities. The EACC study did not consider other forms of energy (fuelwood, coal).

FIGURE ES.4 IMPACT ON HYDROPOWER—ANNUAL GENERATION 2005–50



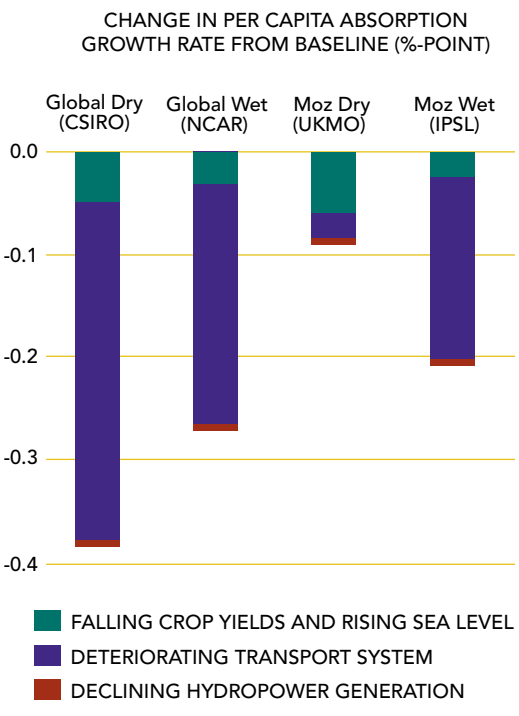
TRANSPORT

Mozambique already has one of the lowest road densities per person of any African country. The EACC study modeled the impact of severe rainfall events on roads. The economic impact would result from loss of access from damage to roads, culverts, and bridges. The overall losses would be substantial, in part because of the importance of current and required investments in the sector.

TABLE ES.1 PERCENTAGE CHANGE IN THE STOCK OF ROADS (MEASURED IN KILOMETERS) RELATIVE TO BASE

Scenario	*No Adaptation (%)*	*Adaptation (%)*
Baseline	0	1
Global dry	-22	-19
Global wet	-16	-14
Moz dry	-2	-2
Moz wet	-12	-9

FIGURE ES.5 DECOMPOSITION OF IMPACT CHANNELS FROM A MACROECONOMIC PERSPECTIVE



COASTAL ZONES

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

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

ECONOMY

The estimated impacts on agriculture, transport, hydropower, and coastal infrastructure[2] were fed into a macroeconomic model—a dynamic computable general equilibrium (CGE) model—that complements the sector models by providing a complete picture of economic impacts across all sectors within a coherent analytical framework. The CGE model looks at the impact of climate change on aggregate economic performance. As indicated in Figure ES.5 below, climate change

2 The CGE model takes into account the full transportation sector, including coastal infrastructure. Coastal adaptation options are studied and presented separately.

has potential implications on rates of economic growth. These growth effects accumulate into significant declines in national welfare by 2050. In the worst case scenario, the net present value of damages (discounted at 5 percent) reaches about $7.6 billion dollars, which is equivalent to an annual payment of a bit more than $400 million. GDP falls between 4 percent and 14 percent relative to baseline growth in the 2040–50 decade if adaptation strategies are not implemented.

Figure ES.5 decomposes the climate change shocks into three groups: (1) crop yields, including land loss from sea level rise, (2) the transportation system, and (3) hydropower. The graph illustrates the dominant role played by transport system disruption, principally as a result of flooding. The global dry scenario is in fact a very wet scenario for the Zambezi water basin as a whole, and thus causes significant damage to roads. By contrast, the local dry scenario is a very dry scenario for Mozambique and causes greater damages for agriculture.

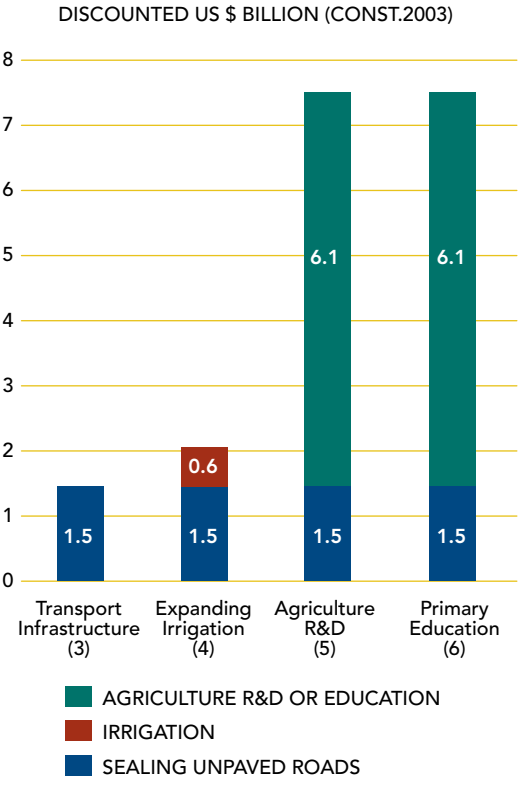
Adaptation Options

After calculating the impacts, the CGE then considers potential adaptation measures in three sectors—hydropower, agriculture, and transportation.[3] Four adaptation strategies are introduced in the model to minimize the damages: (1) transport policy change,[4] and then the transport policy change plus (2) increased agricultural research and extension, (3) enhanced irrigation, and (4) enhanced investment in human capital accumulation (education). Figure ES.6 shows the present value of the reduction in climate change damages over the 2030–50 time period (using a 5 percent discount rate).

3 The CGE model takes into account the full transportation sector, including coastal infrastructure. Coastal adaptation options are studied and presented separately.

4 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 ES.6 PRESENT VALUE OF REDUCTION IN CLIMATE CHANGE DAMAGES, 2030-2050



Sealing unpaved roads reduces the worst-case climate change damages substantially, restoring approximately a fifth of lost absorption, and with little additional cost (i.e., it is a no-regret action advisable even under the baseline). The study considered a number of options for "climate-proofing" roads, given resource constraints and the trade-offs between improving "basic access" and having "fewer but stronger" roads. The conclusion is that Mozambique would be advised to focus investments on climate-proofing highly targeted areas, such as culverts, to ensure that designs minimize broader erosion risks, and to set aside some funds from the investment budget for additional maintenance so that "basic access" roads can be quickly repaired following heavy rainfall.

Remaining welfare losses could be regained with improved agricultural productivity or human capital accumulation. Currently, only 125,000 hectares

are developed for irrigation in Mozambique, though only 40,000 ha of this area are actually operational due to operational and maintenance problems. However, the model results suggest that irrigation investments are a poor alternative: 1 million ha of new irrigation land would only slightly reduce climate change damages. Given the poverty of most farmers and the fact that the vast majority of Mozambique's cultivated area (22 million ha) is rainfed, less costly approaches such as water harvesting, soil/moisture conservation, and agroforestry and farm forestry must play a key role in climate resilience. Improved woodland and forest management will also have broad impacts on the resilience of land and on water absorption capacity. Other, "softer" strategies include support for improved access to markets and inputs, support to increased value addition, and reduction of postharvest losses. Improved livestock and fisheries productivity and value addition are as important as cropped agriculture in this strategy.

In terms of these softer adaptation measures, raising agricultural productivity by an additional 1 percent each year over baseline productivity trends offsets remaining damages to agriculture; for example, a further 50 percent maize yield increase by 2050. Providing primary education to 10 percent of the 2050 workforce also offsets damages. Lastly, investment costs required to restore welfare losses are subject to debate, but are reasonably less than $400 million per year over 40 years.

With respect to specific coastal adaptation measures, the integrated coastal system analysis examined two protection measures:[5] beach/shore nourishment and sea and river dike building and upgrading (including port infrastructure). When these are applied, the physical impacts are significantly reduced. For instance, the total land area lost could be reduced by a factor of more than 80 to 61km^2, and the number of people forced to migrate could be reduced by a factor of 140 to 7,000 people. Hence, the total annual residual damage cost is reduced by a factor of four to $24 million per year. However, the total investment required to achieve these adaptation options is estimated at $890 million per year in the 2040s for the high sea level rise scenario, which appears much higher than the benefits of the adaptation in terms of damages avoided. At the same time, more targeted investments in high value and more vulnerable locations can provide positive returns. The range of costs of more economically viable adaptation options in the 2040s varies from $190 million to $470 million per year depending on the sea level rise scenario. Note that the adaptation strategy we evaluated, a large-scale sea dike system for Mozambique focused on urban areas, would be more costly than the estimated benefits of $103 milllion that accrue through 2050, but as long-term capital assets this dike system would also yield long-term benefits in the form of avoided land-loss protection and avoided population displacement well beyond the 2050 scope of this analysis, and in fact through 2100, as SLR and storm surge risks accelerate. Those long-term benefits of adaptation, while outside the scope of the current study, are considered in the modeling of the choice of coastal adaptive strategies, and could reasonably be far in excess of the reported benefits through 2050.

The superior resilience option is likely to include a phased approach to protection of key coastal economic assets (e.g. ports and cities) combined with improved land use planning and "soft" infrastructure. Dikes should be installed where absolutely necessary to protect current, immobile, vital infrastructure (like the port of Beira), but new infrastructure located behind the dike should be avoided to prevent catastrophic costs if the dikes are breached. The rule of thumb is simple: to the extent possible, install valuable new capital in safer locations. "Hard" adaptation options, particularly expensive ones, should be subjected

5 The study did not examine tradeoffs between "hard" and "soft" infrastructure options, nor did it explicitly consider indirect impacts such as saline intrusion into groundwater and low-lying agricultural areas; these are limitations. It also did not consider the impact of climate change on fisheries (fish spawning grounds, migration patterns, safety of fishermen) or on tourism.

to serious scrutiny before being undertaken, as the associated costs are potentially large.

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

Adaptation Priorities: Local-level Perspective

Climate change poses the greatest risk to livelihoods based on agriculture. Rainfed agriculture takes the hardest hit from climate hazards, and subsistence farmers, as well as economically and socially marginalized individuals (elderly, orphans, widows, female heads of households, and the physically handicapped), are the most vulnerable. Education and overall knowledge about climate events are needed so that these groups can expect disasters to be a recurrent 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 their adaptive capacity.

The most frequently mentioned approach for reducing climate impacts was the construction of irrigation systems, and the most frequently listed barrier to this was lack of finance. In terms of strategies, local populations prioritized improved access to credit, better health care and social services, as well as programs that enhance the capacity of community associations to manage local resources effectively and support livelihood diversification. Integrating rural areas into markets—including a great deal of attention to improving transportation infrastructure and diversification away from agriculture— will be important activities, even if costly and difficult to achieve in rural areas.

Lessons and Recommendations

Rather than climate change eclipsing development, it is important to think of socioeconomic development as overcoming climate change. The best adaptation to climate change is rapid development that leads to a more flexible and resilient society. In this sense, the adaptation agenda largely reinforces the existing development agenda.

The following lessons emerge from the EACC Mozambique country case study:

- Adaptation entails increasing the climate resilience of current development plans, with particular attention to transport systems and agriculture and coastal development.
- Changes in design standards, such as sealing unpaved roads, can substantially reduce the impacts of climate change even without additional resources.
- The imperative of increasing agricultural productivity and the substantial uncertainties of climate change argue strongly for enhanced investments in agricultural research.
- Investments to protect the vast majority of coastal regions of Mozambique from sea level rise may not be cost effective; however, high value and vulnerable locations, such as cities and ports, merit specific consideration, especially those at risk for severe storm surge events.
- "Soft" adaptation measures are potentially powerful. Because the majority of the capital stock in 2050 remains to be installed, land use planning that channels investment into lower risk locations can substantially reduce risk at low cost.
- Viewed more broadly, flexible and more resilient societies will be better prepared to confront the challenges posed by climate change. Hence, investments in human capital contribute both to the adaptation agenda and to the development agenda.

ONE

Introduction

Background

The *Economics of Adaptation to Climate Change* (EACC) study has two specific objectives. The first is to develop a "global" estimate of adaptation costs to inform the international community's efforts to help those developing countries most vulnerable to climate change to meet adaptation costs. The second objective is to help decision makers in developing countries to better understand and assess the risks posed by climate change and to better design strategies to adapt to climate change.

The EACC study comprises a 'global track' to meet the first study objective and a country specific case study track to meet the second objective. The 'country track' comprises of seven countries: Ethiopia, Mozambique, Ghana, Bangladesh, Vietnam, Bolivia and Samoa.

Under the global track, adaptation costs for all developing countries are estimated by major economic sectors using country-level datasets that have global coverage. Sectors covered are agriculture, forestry, fisheries, infrastructure, water resources, coastal zones, health, and eco-system services. Cost implications of changes in the frequency of extreme weather events are also considered, including the implications for social protection programs.

Under the country track, impacts of climate change and adaptation costs are established by sector, but only for the major economic sectors in each case study country. In contrast with the global analysis, however, vulnerability assessments and participatory scenario workshops are being used to highlight the impact of climate change on vulnerable groups and to identify adaptation strategies that can benefit these groups. Furthermore, macroeconomic analyses using Computable General Equilibrium (CGE) modeling are being used to integrate the sector level analyses and to identify cross-sector effects, such as relative price changes.

Scope of the Report and Collaboration

The purpose of this study is to assist the Government of Mozambique in its efforts to understand the potential economic impacts of climate change and to support its efforts to develop sound policies and investments in response to these potential impacts. Adaptation options and their costs were estimated in four economic sectors: agriculture, transport infrastructure, hydropower, and coastal impacts; and compared with costs of inaction.

To facilitate this study, collaboration was established in April 2009 with the Institute for Calamities Management (INGC) on the biophysical modeling and with the Ministry of Planning and Development (MPD) on the adaptation options. This collaboration facilitated information sharing, understanding of critical issues and ownership of the study.

This study complements three other important studies on climate change. The first of these is the Impact of Climate Change on Disaster Risk study that was financed by Denmark, UNDP and GTZ and executed by INGC. It downscaled climate models to provide information on cyclone activity and sea level rise, river hydrology and agriculture land use resulting from further climate change. The INGC modeling is a world-class biophysical study about the possible impact of climate change (especially extreme events). However, it did not produce precise recommendations about possible adaptation options or any costs of climate change impacts and adaptation options. INGC and MPD agree that the EACC could well complement the INGC study by costing the impacts and some adaptation options.

The second study, the Disaster Vulnerability and Risk Reduction Assessment (World Bank 2009a), which is funded by the Global Facility for Disaster Reduction and Recovery (GFFDR) and executed by the World Bank, calculated the historical economic impacts of climate shocks, droughts and floods. Specifically, the study made two new methodological contributions: one related to cyclone analysis (river flooding and storm surge flooding are taken into account), and one on flood plains modeling (digital elevation model with a resolution of 90X90 meters). The EACC used the study results on extreme events as a baseline scenario to compare with the impacts of climate change on extreme events.

The third study (World Bank 2009b), Making Transport Climate Resilient for Mozambique, which is funded by the TFESSD and executed by

the World Bank, is part a Sub-Saharan Africa initiative to respond to the impact of climate changes on road transport. Using the same four scenarios than the EACC Mozambique country case study, the third study is a detailed engineer assessment of the impact of climate change on roads infrastructure and of different adaptation options.

The results of the EACC Study should also provide some guidance for the investment plan of the Pilot Program for Climate Resilience (PPCR). The PPCR is the first program under the Strategic Climate Fund (SCF) of the Climate Investment Funds (comprised of the Clean Technology Fund and the SCF). In early 2009, the PPCR Sub-Committee agreed, on the basis of the recommendations presented by the PPCR Expert Group, to invite Mozambique (as well as Niger, Zambia, Tajikistan, Bolivia, Cambodia, Bangladesh and Nepal) to participate in the program as pilots. These programs are designed to pilot and demonstrate ways to integrate climate risk and resilience into core development planning and support a range of investments to scale-up climate resilience. The investments are expected to be:

- Climate resilient budgeting and planning at central and local level, including adjustment of investment programs and capacity building;
- Climate resilient investments in agriculture, water and transport infrastructure in the two rural areas, including erosion and wildfire control, soil conservation, small scale irrigation, water resources management, roads, road maintenance planning and hydromet, with related capacity building;
- Climate resilient investments in one coastal city including coastal erosion control, storm water drainage and local capacity building in development planning

TWO

Overview of the Mozambican Economy

Background

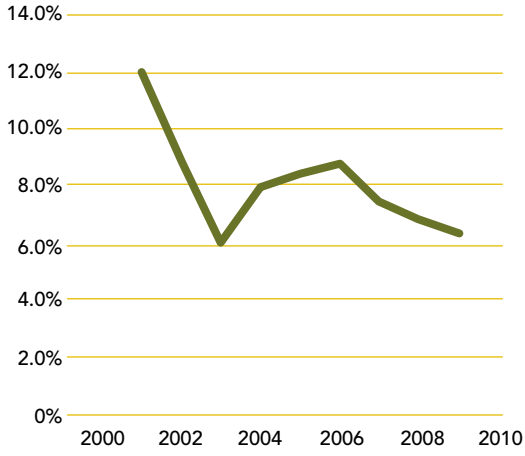
Mozambique is widely considered to be a successful example of post-conflict economic recovery in Sub-Saharan Africa. The country's 16-year civil war, which ended in 1992, cost over a million lives, stunted economic growth, and destroyed much of its infrastructure. Starting from this admittedly very low base, Mozambique has seen average annual growth rates of 8 percent between 1993 and 2009. Mozambique's high growth rates were accompanied by a decrease in poverty levels, which, according to household survey data, declined from 69 percent in 1997 to 54 percent in 2003.[6] In particular, extensive agricultural growth in the last two decades, achieved primarily through expansion in the area farmed and increases in labor input, drove this reduction in poverty levels. Mozambique's Human Development Index (HDI), a measure of development and poverty, has increased steadily over the years since the end of the civil war.

However, Mozambique remains extremely poor, with HDI levels still well below the average Sub-Saharan African level, much less than the rest of the world. Life expectancy remains dismally low at 47.8 years—166th out of 172 ranked countries—and Mozambique places 169th for per capita GDP, with purchasing power parity of $802/year (UNDP 2009). Poverty is relatively higher in rural areas, and rural households are exceptionally vulnerable to natural disasters, notably droughts and floods, which Mozambicans have acutely suffered from in the past. In particular, the southern region of the country is the poorest—in large part a result of its drier climate, less productive soils, and proneness to natural disasters. Factors contributing to these high poverty rates are a lack of infrastructure (especially road access to goods and services), distant markets to sell agricultural products, low-yielding agricultural techniques, and lack of basic services (such as health care and low education rates), among many others.

The reforms credited for spurring this poverty reduction began in 1987 when the government of Mozambique initiated pro-growth economic policies such as measures to decrease inflation and the costs of doing business, a value-added tax, removal of price controls and import restrictions, and the privatization of many state-owned-entities. Due to the country's tight monetary and fiscal policy during this time, inflation was reduced to single-digit levels (from 70 percent at the end of the civil war), providing a stable environment for rapid

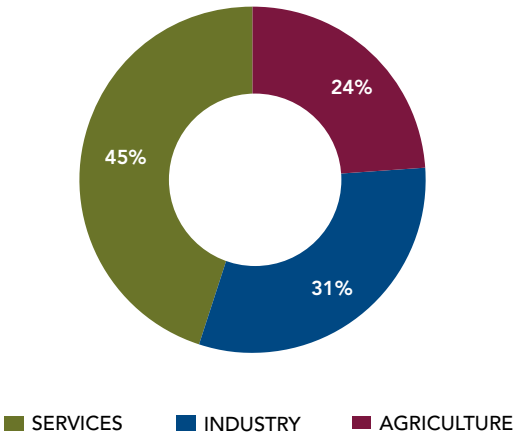
6 World Bank. Available at <http://data.worldbank.org/country/mozambique>

FIGURE 1 GDP GROWTH IN MOZAMBIQUE, 2001–09



Source: World DataBANK, 2009

FIGURE 2 GDP COMPOSITION IN MOZAMBIQUE



Source: CIA World Factbook, 2009

economic growth. This growth was bolstered by a significant influx of foreign investment into the country and high levels of donor support—approximately equivalent to 12 percent of GDP, relative to the African average of 4 percent.

Mozambique's economy is largely dominated by the agricultural sector, at least as far as employment is concerned, with at least 70 percent of the labor force employed in this sector.[7] However, the sector only represents 24 percent of GDP, as illustrated below in Figure 2.

The industrial sector accounts for such industries as aluminum, petroleum products, chemicals, food, and beverages. Agricultural exports include cotton, cassava, cashew nuts, sugarcane, citrus fruits, corn, coffee, beef, and poultry, among others; fisheries (shrimp and prawn) are also an important source of exports.

Mozambique also boasts abundant resources of fossil fuels, including natural gas, thermal and coking coal, and significant reserves of non-fuel minerals. Most of these natural resources are (and will continue to be) exported, as is the electricity generated by the country's enormous and to-be-expanded hydropower dam, Cahora Bassa. Mozambique has four major hydropower stations, of which Cahora Bassa is the largest; however, there is significant scope to further develop Mozambique's hydropower potential, with Electricidade de Mozambique estimating feasible capacity at 13,000 MW (World Bank 2007).

Current Growth Policies

PARPA II is the government's second Action Plan for the Reduction of Absolute Poverty (2006–09), which describes the social and economic policies to reduce poverty and achieve economic growth. PARPA II aims to reduce absolute poverty and promote growth through three "pillars": (1) promoting good governance, (2) investing in human capital, and (3) stimulating economic growth by promoting rural development and improving the investment environment. A key focus of this last pillar is the agricultural sector, with the broad aims

7 The CIA World Factbook sets this number at 81 percent in 2007. Available at: <https://www.cia.gov/library/publications/the-world-factbook/geos/mz.html>

of increasing productivity and access to world markets, notably with emphasis on agriculture, optimal natural resource use, and local economic development. However, poor infrastructure and limited access to markets are a major impediment to growth in this sector.

AGRICULTURE

The government's second phase of the National Agricultural Programme (ProAgri II) ran from 2005 to 2009. During this time, the government approved a Green Revolution Strategy for Mozambique, directly targeting smallholders, as well as larger-scale farmers, and is credited with having increased crop production and infrastructure development. Following this, a Food Production Action Plan for 2008–11 was approved. Now, a ten-year Strategic Plan for the Development of the Agricultural Sector (PEDSA) is under preparation to define what the Ministry of Agriculture should do over the coming decade to increase agricultural production (so as to reverse the country's agricultural deficit and improve food security). PEDSA implementation will occur in two phases: the first phase, from 2009–11, would involve immediate anti-hunger actions (focusing on halting the increase in food prices), while the second phase (2011–18) would be more of a long-term focus on achieving the Millennium Development Goals (MDGs). To support this plan, a National Irrigation Programme is currently being prepared with the aims of maintaining existing irrigation schemes, rehabilitating formerly operational irrigation equipment, and supporting private sector irrigation projects.

MEGAPROJECTS

Mozambique is on the cusp of intense natural resource development underpinned by an unprecedented scale of mega-project investment, especially energy mega-projects: about five or six are completed or in various stages of construction, while about 13 more are planned. These include further expansion of the Mozal smelter and the Cahora Bassa hydropower plant. In particular, due to the increasing demand for electricity in Mozambique and in the Southern African Development Community (SADC) region in general, the development of water resources along the Zambezi River is a government priority. This "boom" in mega-projects, provided it is accompanied by further infrastructure development, could potentially generate huge economic growth, though social and environmental considerations must be taken into account.

TOURISM

Mozambique's tourism industry plummeted during the civil war. However, this fact means that Mozambique's natural assets—for instance, its 2,700 km coastline—are mostly undeveloped. These pristine beaches are thus potentially highly attractive to tourists. Yet the current contribution of tourism to GDP is relatively low—data from 2003 establish tourism as responsible for 1.2 percent of national GDP (Republic of Mozambique 2004). The government of Mozambique, recognizing the sector's potential value, established a separate Ministry for Tourism in 2000 and developed a Strategic Plan for the Development of Tourism in 2004. The government's current tourism strategy is to promote areas of high value, low-volume ecotourism based on the country's wildlife parks and beach resorts. Its stated vision for 2020, however, is to host 40 million annual visitors.

Vulnerability to Climate

Mozambique is subject to extreme weather events that can ultimately take the form of drought, flooding, and tropical cyclones, and ranks third among the African countries most exposed to risks from multiple weather-related hazards (UNISDR 2009). During the past 50 years, the country has suffered from 68 natural disasters, which have killed more than 100,000 people and

affected up to 28 million. As much as 25 percent of the population is at risk from natural hazards. The country's economic performance is already highly affected by frequent droughts, floods, and rainfall variability.

Drought is the most frequent disaster. Droughts contributed to an estimated 4,000 deaths between 1980 and 2000. Droughts occur primarily in the southern and central regions, with a frequency of 7 in 10 and 4 in 10 years, respectively. There are areas in these regions classified as semi-arid and arid (Gaza, Inhambane, and Maputo), where rain—even when above average—is inadequate and results in critical water shortages and limited agriculture productivity. An estimated 35 percent of the population is now thought to be chronically food insecure. Disaster costs to the national economy have been estimated at $1.74 billion during 1980–2003, but this largely underestimates losses and impacts on the poor. Economic impacts of drought seem to be most significant in Zambezi Province, where production losses could range between $12 and $170 million for maize alone, depending on the severity of the drought.

Floods in Mozambique are caused by a number of geographical factors and can prevail for several months, occurring most frequently in the southern and central regions, along river basins, in low-lying regions, and in areas with poor drainage systems. They are linked not only to heavy rainfall but also to water drainage from rivers in upstream neighboring countries. Water from nine major river systems—from vast areas of southeastern Africa—finds its way to the Indian Ocean through Mozambique. In fact, 50 percent of the water in Mozambique's rivers originates from outside the country. In 2000, Mozambique experienced its worst floods in 50 years, killing about

800 people and displacing 540,000. Mozambique is also subject to three or four cyclones every year, which travel up the Mozambique Channel due to monsoonal activity in the Indian Ocean, particularly from January to March.

More than 60 percent of Mozambique's population of 22 million live in coastal areas, and is therefore highly vulnerable to seawater inundation along its 2,700 km coastline. Seawater inundation includes saline intrusion of coastal aquifers and estuaries, beach erosion, and short extreme rises in sea level due to tropical storms and cyclones. Saline intrusion of the coastal aquifers and estuaries holds serious implications for coastal agriculture and fishery production.

The issue of beach erosion is very serious, threatening coastal infrastructure such as roads and housing. In some portions of Beira, 30 to 40 meters of beach have been eroded in the past 15 to 20 years, destroying natural mangroves and encroaching on homes and roads. Storm surges pose a huge threat to coastal infrastructure as they can temporarily raise sea level as much as 5 meters. While many of the major coastal cities of Mozambique have infrastructure in place to stem the effects of such an extreme event, many are in need of serious maintenance. Furthermore, Mozambique is subject to three or four cyclones every year. In addition to the extreme wind and rainfall caused by these cyclones, they can exacerbate seawater inundation threats, especially that of storm surge.

A regression analysis over the period 1981–2004 suggests that Mozambique's GDP growth is cut by an average of 5.5 percent when a major water shock occurs. Assuming a major disaster occurs every five years, an average 1 percent of GDP is lost every year due to the impacts of water shocks World Bank 2007). In regional projections, climate change is expected to only increase the frequency and magnitude of shocks and rainfall variability. As a result, droughts, floods, and cyclones are likely to pose large threats to Mozambique's growth.

THREE

Climate Forecasts Using Four Different General Circulation Model Outputs

Mozambique's climatic characteristics are region-specific, with major differences between its northern and southern regions. In the northern and central regions, the climate can be classified as tropical and subtropical; in contrast, steppe and dry arid desert conditions exist in the south. There is also a strong coastal-to-inland orographic, or elevation gradient, effect on weather patterns in Mozambique. Weather patterns change as they move west from the southeastern, low-elevation, coastal belt into the central and north-central plateau regions of the country.

Mozambique has a distinct rainy season lasting from October to April, with an annual average precipitation for the whole country of around 1,032 mm. Along the coast, annual rainfall is generally between 800 to 1,000 mm and decreases to 400 mm at the border with South Africa and Zimbabwe. In the southern mountains, rainfall averages between 500 and 600 mm. Inland central and northern regions experience annual rainfall typically ranging from 1,000 to 2,000 mm, resulting from a combination of the northeast monsoon and high mountains. Average annual evapotranspiration ranges from 800 mm along the Zimbabwean border to more than 1,600 mm in the middle of the Mozambican portion of the Zambezi basin. Coastal evapotranspiration is consistently high, ranging between 1,200 and 1,500 mm annually.

Both historic and future climate inputs specific to Mozambique and its international river basins (such as monthly temperature and precipitation) will be used to drive the river basin and water resource model. Historic inputs will be gathered using the Climate Research Unit's (CRU) global monthly precipitation and temperature data, while future inputs will be taken from five general circulation models (GCMs) forced with different CO_2 emission scenarios.

The five GCM/emission scenario pairings have been chosen to represent the total possible variability in precipitation. The NCAR-CCSM sres_a1b represents a "global wet" scenario; CSIRO-MK3.0 sres_a2 represents the "global dry" scenario; ukmo_hadgem1 sres_a1b represents the "Mozambique dry" scenario; cnrm_cm3 sres_a1b represents the "Mozambique medium" scenario; and ipsl_cm4 sres_a2 represents the "Mozambique wet" scenario. Precipitation and temperature data acquired from these simulations will be used to estimate the availability of water at a sub-basin scale.

Historical climate data for each basin will be gathered using precipitation and temperature data when available along with the Climate Research Unit's 0.5° by 0.5° global historical precipitation and temperature database.

TABLE 1 GCM/EMISSION SCENARIOS FOR EACC

Scenario	*Characteristics*	*Used in Global Track?*	*Used in INGC Study?*
NCAR-CCSM sres_a1b	Global Wet	Yes	
CSIRO-MK3.0 sres_a2	Global Dry	Yes	Yes
ukmo_hadgem1 sres_a1b	Mozambique Dry		
cnrm_cm3 sres_a1b	Mozambique Medium		
ipsl_cm4 sres_a2	Mozambique Wet		Yes

The flow of information through the integrated river basin and water resource model is generally linear, as shown in Figure 3. Climate data are entered into CLI_RUN and CLI_CROP in order to produce stream-flow runoff estimates and crop irrigation demand estimates, respectively.

CLI_RUN is a two-layer, one-dimensional infiltration and runoff estimation tool that uses historic runoff as a means to estimate soil characteristics. The 0.5° by 0.5° historic global runoff database generated by the Global Runoff Data Center (GRDC) will be used to calibrate CLI_RUN. CLI_CROP is a generic crop model explained in the next chapter.

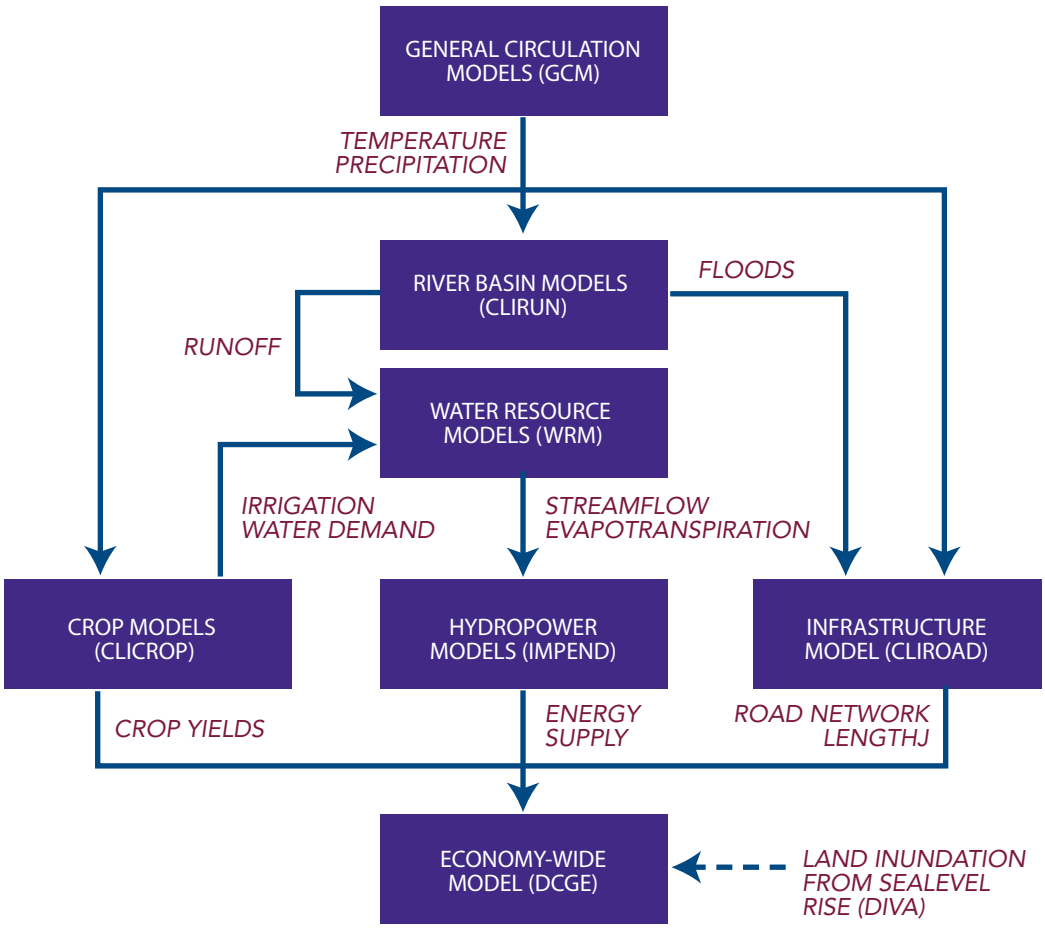
Inflows calculated using CLI_RUN are passed to IMPEND (Investment Model for Planning Ethiopian Nile Development), where storage capacity and irrigation flows are optimized to maximize net benefits. The outputs from IMPEND, along with the irrigation demands estimated from CLI_CROP, are then passed to the Water Evaluation and Planning System (WEAP), where water storage and hydropower potential are modeled based on their interaction with the climate and the demands in the river basins being modeled.

Finally, this information is passed to the CGE model, where the economic implications of the modeled data are assessed. Within the river basin model there is, however, one interaction with the potential for nonlinearity. The interaction between IMPEND and WEAP will be an iterative process depending on the scenario. Reservoir flow calculated in WEAP may change what was previously put into IMPEND, thus requiring the net benefits to be recalculated and their implications re-modeled in WEAP.

Figure 3 shows all data flowing to the CGE, which implies that all useful outputs will be a product of the CGE. This is misleading. Every process leading up to the CGE provides important outputs that are relevant to ongoing studies in the region. Outputs from the GCMs, such as precipitation and temperature, are important to any process or study involving climate change. Runoff outputs from CLI_RUN will provide information about runoff changes related to changes in precipitation and temperature caused by climate change. Moreover, IMPEND can estimate the monetary tradeoffs between using water for agriculture or water for hydropower at a given time.

These findings will be very important to ongoing studies in Mozambique, most notably the INGC study on the "Impacts of Climate Change on Disaster Risk in Mozambique: Main Report Phase II." Previous work by INGC during Phase I of the report suggests areas of Mozambique where climate has the potential to impact the country's water resources. The data accrued in all the steps leading up to the CGE can be used to quantitatively estimate these potential impacts, thereby providing very valuable information that can be used by INGC. In addition, a crop model specific to Mozambique will be developed in CLI_CROP using over 50 soil compositions as well as climate data consistent with Phase I of the

FIGURE 3 **FLOW CHART OF PROJECT MODEL SEQUENCING**



report. The final model will provide INGC with a more robust estimate for irrigation demand and crop yield potential in Mozambique as temperature, water stress, and CO_2 load change with the future climate.

The following chapters examine four key sectors in the Mozambican economy, notably agriculture (chapter 4), roads/transportation (chapter 5), hydropower (chapter 6), and the coastal zones (chapter 7). Chapter 8 looks into cyclone assessment. Each chapter presents an overview of the potential climate change impacts these sectors will be subjected to, the techniques used to model them, and potential adaptation options.

FOUR

Agriculture

Background

Mozambique's major cash crops are sugar cane, cotton, coconuts, sesame, tobacco, and cashews; its major food crops are maize, sorghum, millet, rice, beans, groundnuts, vegetables, and cassava.

Table 2[8] shows the distribution (by yield in tons) of these eight food crops and six cash crops from the 2002 inventory, which will be modeled by CliCrop.

Table 3 shows the distribution of irrigation by crop for the three regions of Mozambique in 2002. The amount of irrigated cropland is estimated to be less than 0.5 percent of the total cropland, almost all of which is used for sugar cane production; however, a portion is used to grow rice and vegetables.

The Ministry of Agriculture plans to focus in the near future on increasing the productivity of food crops in order to increase both the volume of food within the country and the commercial and export values of these crops. The Ministry of Agriculture is also interested in the production of biofuels from excess food production.

8 These data are drawn from surveys implemented by the agriculture offices in each province and are available for at least ten consecutive years; the latest available are from the 2006–07 season.

TABLE 2 TOTAL YIELD OF EACH CROP UNDER STUDY FOR MOZAMBIQUE (TONS)

Food Crops	Maize	1,326,513
	Sorghum	507,409
	Millet	108,217
	Rice	173,673
	Beans	416,750
	Groundnuts	285,910
	Cassava	1,024,324
	Horticulture	525,564
Cash crops	Sugar Cane	1,940,799
	Cotton	102,786
	Tobacco	42,568
	Sesame	13,855
	Cashews	13,119
	Coconut	44,285

In Mozambique, an estimated 3.3 million ha of land is available for irrigation. However, only about 50,000 ha is currently irrigated. In accordance with the Ministry of Agriculture's existing budget to increase irrigation and the progress made in recent years, the EACC study estimates that approximately 50,000 ha will be converted from rainfed to irrigated cropland. The team is also estimating an increase in maximum crop production (irrigated) by about 1–2 percent.

TABLE 3 **AREAS OF THE MAIN IRRIGATED CROPS ACCORDING TO THE INVENTORY FROM 2002**

Crops	*North*		*Center*		*South*		*Total*	
	(ha)	*(%)*	*(ha)*	*(%)*	*(ha)*	*(%)*	*(ha)*	*(%)*
Sugarcane	0	0	13,799	84.9	10,059	43.4	23,858	59.6
Horticulture	301	100	210	1.3	6,500	28.1	7,011	17.5
Rice	0	0	480	3.0	3,650	15.6	4,130	10.3
Tobacco	0	0	445	2.7	0	0	445	1.1
Citrus	0	0	370	2.3	0	0	370	0.9
Non-specified	0	0	953	5.9	3,036	13.1	4,249	10.6
Total	301	100	16,257	100	23,145	100	40,063	100

Modeling the Sectoral Economic Impacts

CROP MODEL DESCRIPTION

CliCrop is a generic crop model used to calculate the effect of changing daily precipitation patterns caused by increased CO_2 on crop yields and irrigation water demand. The model was developed in response to the available crop models, which use monthly average rainfall and temperature to produce crop outputs. These monthly models do not capture the effects of changes in precipitation patterns, which greatly impact crop production. For example, most of the International Panel for Climate Change (IPCC) GCMs predict that total annual precipitation will decrease in Africa, but rain will be more intense and therefore less frequent. In contrast to the existing models, CliCrop is able to produce predicted changes in crop yields due to climate change for both rainfed and irrigated agriculture, as well as changes in irrigation demand. Since CliCrop was developed to study the effects of agriculture on a global or continent scale, it is a generic crop model.

The Mozambique EACC study, with the help of MPD and INGC, developed a new model, CliCrop-Mozambique, which uses the CliCrop methodology but is specific to Mozambique. The model includes the effects of existing strategies, also specific to Mozambique. Some of these strategies may include expansion or reduction of rainfed or irrigated agriculture in order to supply water to the most efficient economic sectors, including nonagricultural sectors (i.e. power, municipal, industrial), as well as useful water management practices adapted to the Mozambican context. The following box provides an overview of INGC's *Study on the Impact of Climate Change on Disaster Risk in Mozambique*, its crop yield modeling methodology, and the collaborative effort between the World Bank and INGC to improve crop yield predictions using CliCrop.

CliCrop input. The inputs into CliCrop-Mozambique are weather (temperature and precipitation), soil parameters (field capacity, wilting point, saturated hydraulic conductivity, and saturation capacity), historic yields for each crop by province, crop distribution by province, and current irrigation distribution estimates by crop. The monthly weather input for the baseline come from the CRU of the University of East Anglia. The weather inputs into CliCrop for future scenarios are extracted directly from the five GCMs used in

BOX 1 IMPROVED CROP YIELD ESTIMATES: INGC AND WORLD BANK COLLABORATION

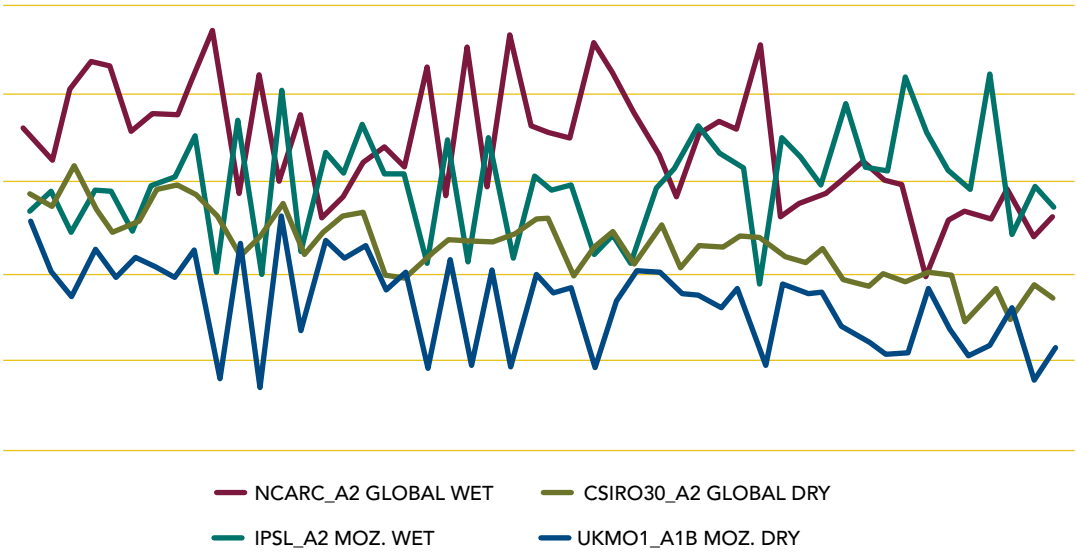
INGC's *Study on the Impact of Climate Change on Disaster Risk in Mozambique* examines Mozambique's crop yield vulnerability by directly modeling crop yield percentages and their sensitivity to climate variability. The study uses FAO's CropWat model to estimate crop yield as a percentage of the maximum potential crop yield possible for a given crop. The model takes into account basic soil and crop properties and applies a zero-dimensional water balance to simulate crop water availability. These values are then used to classify the country's current suitability for production of specific crops. Once crop suitability is established as a baseline for comparison, the model is run with future climate scenarios. Vulnerability is then assessed by examining the change in suitability for crop production and presented as a risk for increase or decrease in suitability. This analysis is done for three models (IPSL, ECHAM, and GFDL under the SRES A2 emissions scenario) and six crops (cassava, maize, soy, sorghum, cotton, and groundnut).

Conclusions from the analysis provide a detailed look into what areas of Mozambique are at significant risk for a reduction in suitable cropland; however, the analysis may be dramatically underestimating the risk posed by a changing climate. The CropWat model uses a very simple water balance that neglects the effects of excess water in the system. Excess water in the form of "ponding" and soil saturation can also reduce crop yields by drowning the crop and stunting its growth. The CropWat model does not take this into account and may predict high yields where there is excess water because the crop's water demand is fulfilled. Extreme rainfall events can cause excess water, and all three GCMs examined in the INGC study suggest that both average rainfall and rainfall variability are increasing in Mozambique. A new crop model must be used in order to account for the negative effects of excess water.

A collaborative effort between the World Bank and INGC is attempting to improve crop yield predictions and fix the "excess water" problem by using CliCrop. CliCrop's basic structure is essentially that of CropWat. It uses the same inputs and produces the same outputs as CropWat and, among many other improvements, CliCrop dramatically improves the water accounting. CliCrop uses a one-dimensional, dynamic soil profile where water can accumulate and can negatively affect crop yields if soil saturation occurs. CliCrop allows the full spectrum of the risk profile to be examined and provides a better estimate of land suitability changes in lieu of climate change (Fant 2008).

The INGC risk analysis will be repeated verbatim but with two significant improvements: improved water accounting and a more robust risk profile achieved by modeling a total of seven potential climate scenarios. Currently, the collaborative effort is concentrating on implementing a nationwide soil profile into CliCrop and adapting the local station data to a 1° by 1° grid resolution. All simulations with CliCrop will be done at this resolution.

FIGURE 4 **CHANGE IN CASSAVA YIELD FOR NORTHERN MOZAMBIQUE, 2001–50**



the other sectors.[9] The daily distributions of precipitation and temperature will be derived from the NASA POWER data set for both the baseline and the future scenarios. All required soil parameters come from the FAO Soils Database. The historic yields and crop distribution by province, as well as irrigation distribution by region, originated from Trabalho de Inquerito Agricola (TIA).

Clicrop output. The output of CliCrop-Mozambique (rainfed yield, irrigated yield, and irrigation demand) are then to be used as input to the CGE model as shocks/stressors caused by the predicted weather change from the GCMs. The CGE model includes details about Mozambique's agricultural crops and livestock commodities, as well as capital, land, and other infrastructural stocks. The CGE model is used to study and evaluate impacts of climate change adaptation strategies in the agricultural sector and consequently to the other sectors of the economy. The output of CliCrop-Mozambique is also used in the WEAP model, which calculates the changes in irrigation demand on the reservoir water supply.

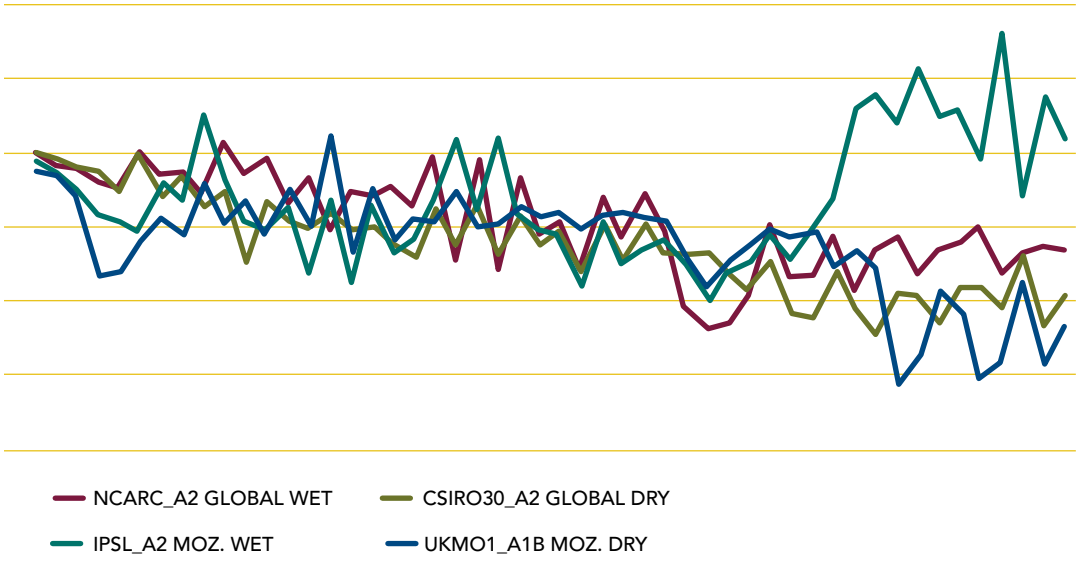
The results of this study complement the previous study on agriculture produced by INGC, published in June 2009. (See Box 1 on INGC's study and its models used.) The effects of the GCMs are reported as a percent of the area to have a certain category of risk (significant reduction, slight reduction, no change, slight increase, and significant increase in risk).

CLIMATE CHANGE IMPACT

The CliCrop and the changes in precipitation and temperature from the five GCMs were used to estimate the changes in yield each year for both irrigated and rainfed crops as well as irrigation demand (mm/ha) for six cash crops and eight food crops. The yields produced reflect the reductions in yield both due to the lack of available water and to the overabundance of water that causes waterlogging. These results for each crop, year, and scenario are presented in the Tables 4,

9 These consist of: NCAR-CCSM sres_a1b, Global Wet; CSIRO-MK3.0 sres_a2, Global Dry; ukmo_hadgem1 sres_a1b, Mozambique Dry; cnrm_cm3 sres_a1b, Mozambique Medium; and ipsl_cm4 sres_a2, Mozambique Wet.

FIGURE 5 CHANGE IN CASSAVA YIELD FOR CENTRAL MOZAMBIQUE, 2001–50



5, 6, and 7 showing the changes in irrigation and yield for each province in Mozambique. Maps have also been produced showing descriptive statistics of these changes at a 0.5° by 0.5° scale. The raw data output has been provided to the country for future study.

CONCLUSION

Since the climate projection changes from the four GCMs were applied directly to the 50-year daily weather sequence generated from the NASA POWER data set, a percent change in the yield of rainfed crops was calculated for the results presented below. In this case, the percent change in yield was calculated such that "10 percent" means a 10 percent increase of the baseline yield, and "-10 percent" means a decrease of 10 percent of the baseline yield. As an example, the yield changes for cassava are shown below as a time series for the northern, central, and southern regions of Mozambique. Figures 4 through 6 show how the cassava yield varies for each climate projection from year to year and region to region. These figures also show how each climate projection can represent a future that promises either good food production (resulting in export) or famine (resulting in import or starvation) for a specific crop. Table 5 provides the average percent change in yield, averaged over the 50-year run. Table 5 provides the 10th percentile, or the 1:10 year famine for each crop and each scenario. Table 6 provides the median (to get a sense of the skewness in comparison to the average), and Table 7 provides the 90th percentile, or the 1:10 year abundance. These percentile tables help illustrate the variability of crop production.

Adaptation Options

The primary adaptation strategy studied in this report is to increase or decrease the amount of cropland that is irrigated, based on the available water and crop demand. Two water management techniques are also modeled in CliCrop: zai holes (or planting holes) and organic mulching techniques. The CGE model optimizes an adaptation strategy that involves investing in agricultural research and development (see chapter 10).

FIGURE 6 **CHANGE IN CASSAVA YIELD FOR SOUTHERN MOZAMBIQUE, 2001–50**

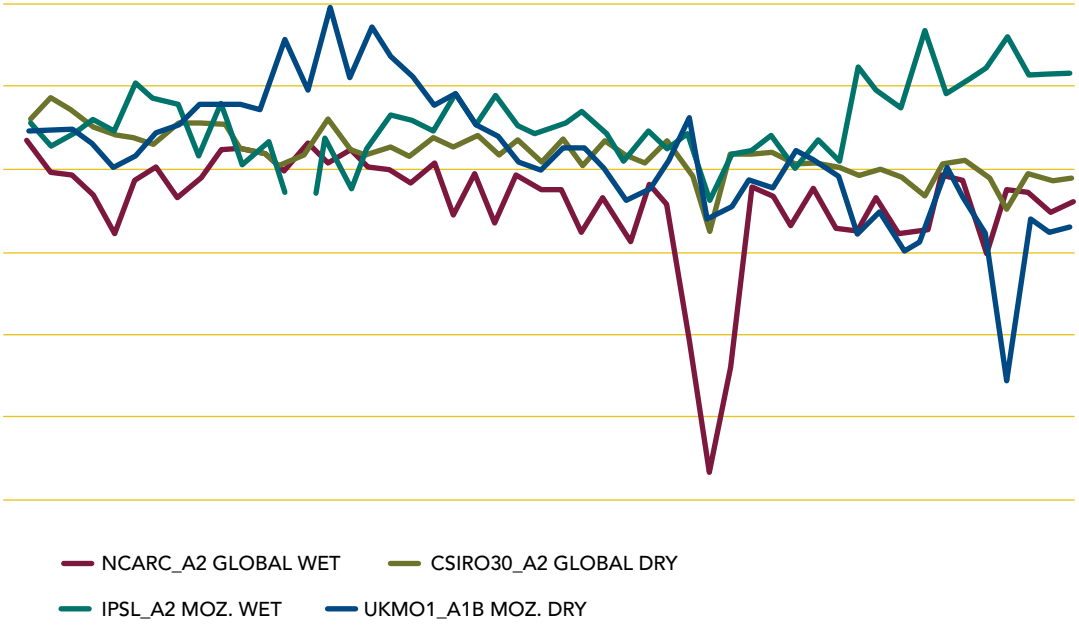


TABLE 4 AVERAGE OF THE PERCENT CHANGE IN YIELD FOR MOZAMBIQUE

	North				Central				South				
	csiro30_ a2	ncarc_ a2	ukmo1_ a1b	apsl_ a2	csiro30_ a2	ncarc_ a2	ukmo1_ a1b	apsl_ a2	csiro30_ a2	ncarc_ a2	ukmo1_ a1b	apsl_ a2	
Crop	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Average
Cassava	-3.44%	2.01%	-6.51%	-0.09%	-6.24%	-4.75%	-6.21%	-3.10%	-3.27%	-9.36%	-3.20%	0.36%	-3.65%
Sorghum	-0.99%	0.66%	-6.08%	-1.59%	0.25%	-0.74%	-0.66%	-1.97%	0.55%	-1.57%	1.33%	-0.68%	-0.51%
Soybeans	-0.40%	0.06%	-2.58%	-1.00%	-0.52%	-3.63%	-5.81%	-1.46%	-1.32%	-6.06%	5.91%	1.47%	-1.28%
Sweet Potatoes and Yams	0.29%	0.58%	-5.70%	-1.39%	-1.45%	-4.05%	-6.70%	-5.70%	-0.32%	-3.69%	-4.45%	-0.63%	-2.77%
Wheat	-2.18%	-2.31%	-5.11%	-3.20%	-0.93%	-4.33%	-3.03%	-2.93%	-1.64%	5.11%	2.48%	0.20%	-2.10%
Ground-nuts	0.71%	1.65%	-3.23%	-1.84%	1.17%	-0.08%	-4.73%	-3.66%	-1.66%	-2.90%	-3.72%	0.58%	-1.48%
Maize	-1.32%	1.27%	-1.87%	-2.92%	0.64%	0.34%	-2.59%	-3.04%	6.37%	3.49%	-3.95%	-4.36%	-0.66%
Millet	-6.82%	10.03%	-17.38%	-8.40%	-1.35%	-3.45%	-1.78%	-6.29%	-2.78%	-10.07%	7.85%	0.29%	-3.34%
Potato	-0.36%	4.15%	-5.87%	-1.10%	-3.20%	-1.15%	-8.05%	-1.46%	-4.09%	-6.78%	-3.10%	1.29%	-2.69%
Average	-1.61%	2.01%	-5.44%	-2.07%	-1.29%	-2.43%	-4.40%	-3.29%	-0.91%	-4.67%	-0.09	-0.45%	-2.05%

TABLE 5 10TH PERCENTILE OF THE PERCENT CHANGE IN YIELD FOR MOZAMBIQUE

	North				Central				South				
	csiro30_ a2	ncarc_ a2	ukmo1_ a1b	apsl_a2	csiro30_ a2	ncarc_ a2	ukmo1_ a1b	apsl_a2	csiro30_ a2	ncarc_ a2	ukmo1_ a1b	apsl_a2	
Crop	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Average
Cassava	-5.52%	-2.00%	-10.20%	-4.43%	-10.59%	-8.55%	-12.07%	-7.64%	-6.29%	-13.29%	-12.63%	-4.66%	-8.16%
Sorghum	-1.93%	-0.48%	-1.57%	-3.44%	-0.44%	-1.82%	-2.06%	-4.14%	-0.49%	-3.97%	-2.38%	-2.05%	-2.06%
Soybeans	-0.03%	-0.91%	-4.53%	-2.61%	-3.66%	-6.62%	-10.87%	-5.85%	-3.95%	-11.85%	0.68%	-1.98%	4.43%
Sweet Potatoes and Yams	-1.23%	-1.55%	-9.96%	-4.46%	-4.56%	-7.95%	-9.74%	-10.88%	-4.56%	-7.80%	-10.72%	-5.47%	-6.57%
Wheat	-4.30%	4.59%	-11.26%	-5.80%	-2.94%	-7.03%	-5.86%	-5.85%	-4.07%	-9.43%	-1.57%	-1.21%	5.33%
Ground-nuts	-0.89%	-0.68%	-7.10%	-4.08%	-0.51%	-2.20%	-8.78%	-6.14%	-4.21%	-5.20%	-6.98%	-3.18%	4.16%
Maize	-2.47%	-0.47%	-3.94%	-4.62%	-0.94%	-2.19%	-6.67%	-7.64%	0.45%	-3.77%	-18.61%	-16.59%	-5.62%
Millet	-11.56%	2.66%	-28.96%	15.07%	-3.37%	-6.21%	-7.02%	-12.89%	-9.59%	-19.88%	-0.24%	-4.24%	-9.70%
Potato	-2.36%	1.70%	-10.94%	-3.32%	-5.37%	-3.47%	-13.61%	-5.78%	-5.68%	-8.80%	-7.22%	-5.26%	-5.84%
Average	-3.47%	-0.70%	-9.83%	-5.32%	-3.60%	-5.12%	-8.52%	-7.42%	-4.27%	-9.33%	-6.63	-4.96%	-5.76%

TABLE 6 MEDIAN OF THE PERCENT CHANGE IN YIELD FOR MOZAMBIQUE

	North				Central				South				
	csiro30_a2	ncarc_a2	ukmo1_a1b	apsl_a2	csiro30_a2	ncarc_a2	ukmo1_a1b	apsl_a2	csiro30_a2	ncarc_a2	ukmo1_a1b	apsl_a2	
Crop	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Average
Cassava	-3.44%	1.75%	-5.92%	0.08%	-6.47%	-5.08%	-5.33%	-3.77%	-3.31%	-7.70%	-3.02%	0.05%	-3.51%
Sorghum	-0.83%	0.56%	-0.54%	-1.36%	0.11%	-0.72%	-0.53%	-1.70%	0.47%	-1.03%	1.84%	-0.82%	-0.38%
Soybeans	-0.30%	0.24%	-2.01%	-0.64%	-0.98%	-3.63%	-5.32%	-1.79%	-1.08%	-5.55%	5.39%	1.24%	-1.20%
Sweet Potatoes and Yams	0.03%	0.16%	-5.13%	-1.78%	-0.88%	-4.04%	-6.65%	-5.30%	-0.17%	-3.33%	-3.66%	-0.46%	-2.60%
Wheat	-1.65%	-1.81%	-3.97%	-0.04%	-1.17%	-4.30%	-2.45%	-2.94%	-1.67%	-4.56%	2.58%	0.23%	-1.81%
Ground-nuts	0.58%	1.31%	-3.10%	-2.15%	1.23%	-0.24%	-4.23%	-3.10%	-1.70%	-2.91%	-3.88%	0.84%	-1.45%
Maize	-1.48%	0.76%	-1.50%	-2.81%	0.33%	-0.61%	-1.91%	-2.36%	3.35%	0.80%	0.19%	-2.57%	-0.65%
Millet	-7.23%	10.06%	-16.67%	-7.93%	-1.56%	-3.91%	-1.14%	-5.36%	-1.83%	-7.33%	6.49%	0.32%	-3.01%
Potato	-0.68%	3.97%	-5.71%	-1.44%	-3.62%	-1.41%	-7.39%	-1.71%	-3.97%	-7.49%	-3.39%	-0.89%	-2.81%
Average	-1.67%	1.89%	-4.95%	-2.01%	-1.44%	-2.66%	3.88%	-3.11%	-1.10%	-4.35%	0.28	-0.23%	-1.94%

TABLE 7 90TH PERCENTILE OF THE PERCENT CHANGE IN YIELD FOR MOZAMBIQUE

	North				Central				South				
	csiro30_a2	ncarc_a2	ukmo1_a1b	apsl_a2	csiro30_a2	ncarc_a2	ukmo1_a1b	apsl_a2	csiro30_a2	ncarc_a2	ukmo1_a1b	apsl_a2	
Crop	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Global Dry	Global Wet	Moz. Dry	Moz. Wet	Average
Cassava	-1.09%	6.68%	-3.56%	3.30%	-1.64%	-0.68%	-2.72%	2.80%	0.31%	-3.43%	5.88%	6.33%	1.01%
Sorghum	-0.23%	2.13%	-0.01%	-0.42%	1.10%	0.37%	0.44%	-0.47%	1.99%	0.04%	4.35%	1.13%	0.87%
Soybeans	0.30%	1.46%	-1.02%	-0.01%	2.51%	-0.89%	-0.86%	3.91%	1.50%	-1.19%	11.52%	5.57%	1.90%
Sweet Potatoes and Yams	2.35%	3.30%	-2.55%	2.11%	0.91%	-0.30%	-3.01%	-1.35%	3.67%	-0.66%	-0.20%	4.25%	0.71%
Wheat	-0.52%	-0.55%	-0.46%	5.76%	0.82%	-1.83%	-0.60%	-0.29%	0.41%	-1.51%	5.81%	1.71%	0.73%
Ground-nuts	3.05%	4.11%	0.06%	1.28%	2.69%	2.24%	-1.41%	-0.92%	0.58%	-0.39%	-0.10%	3.43%	1.22%
Maize	0.08%	3.05%	-0.23%	-1.25%	2.71%	4.46%	0.32%	0.40%	18.93%	14.10%	5.63%	2.33%	4.21%
Millet	0.05%	17.88%	-10.66%	-1.62%	0.84%	-0.31%	1.79%	-1.70%	1.85%	-1.86%	18.10%	4.06%	2.37%
Potato	2.62%	7.21%	-1.28%	2.14%	-0.93%	2.00%	-4.26%	4.07%	-2.34%	-3.85%	1.06%	1.47%	0.66%
Average	0.74%	5.03%	-2.19%	1.25%	1.00%	0.56%	-1.15%	0.72%	2.99%	0.14%	5.78	3.36%	1.52%

FIVE

Roads

Background

Mozambique's strategy for the road sector stated that the total road length in the country was 32,348 km as of April 2006. Unpaved roads represent a little over 80 percent of the total road length (26,035 km), while paved roads represent about 20 percent (6,314 km). The sector strategy also estimated that 65 percent of the paved roads were in good condition, 23 percent in fair condition, and 11 percent in poor condition. The quality of unpaved roads was less favorable with 17 percent, 35 percent, and 48 percent in good, fair, and poor condition respectively. Assessment of the road usage measured in vehicle-kilometers indicates that the paved road network carries the largest share (85 percent) of traffic (ANE 2006). Table 8 illustrates the Mozambican road network in 2006 by class of road, with a further subdivision between paved and unpaved roads.

Table 9 provides estimates of unit maintenance costs for the existing road network. An estimate of per year cost can be obtained by dividing the total cost by the return period. By using this calculation (and assuming that the rehabilitation return period for unpaved roads is 20 years) and then multiplying by the size of the road network for each type, one ends up with an average annual maintenance cost of about $250 million per year.

TABLE 8 BASE CLASSIFIED AND URBAN ROAD NETWORKS (KM)

Class	*Unpaved*	*Paved*	*Total*
Primary	1,407	4,459	5,866
Secondary	3,983	809	4,792
Tertiary	11,645	516	12,161
Vicinal	6,500	30	6,530
Subtotal Classified	23,535	5,814	29,348
Urban	2,500	500	3,000
Grand total	26,035	6,314	32,348

Source: Road Sector Strategy 2007-2011 (ANE, 2007)

This is a significant amount in the Mozambican context, representing about 12 percent of total government spending (recurrent plus investment) in 2006.

Modeling the Sectoral Economic Impacts

The stressor-response methodology used in this report is based on the concept that exogenous factors, or stressors, have a direct effect on and subsequent response by focal elements. In the context of climate change and infrastructure, the exogenous factors are the individual results of climate

TABLE 9 UNIT MAINTENANCE COST RATES ($) AND RETURN PERIODS

Type of Maintenance	*Transitability*	*Routine*		*Periodic*		*Rehabilitation*	
Road Class	*Unpaved*	*Unpaved*	*Paved*	*Unpaved*	*Paved*	*Unpaved*	*Paved*
Primary	N/A	1,500	1,100	35,000	55,000	80,000	300,000
Secondary	N/A	1,200	880	28,000	44,000	50,000	240,000
Tertiary	300	750	660	10,000	44,000	25,000	200,000
Vicinal	200	350	660	2,500	44,000	17,500	175,000
Return period (years)	Annual	Continuous	Continuous	5	8		20

Notes: Values in US$ per km per year for transitability and routine
Source: Road Sector Strategy 2007-2011 (ANE, 2007)

change, including changes to precipitation levels and temperatures. Therefore, a stressor-response value is the quantitative impact that a specific stressor has on a specific infrastructure element. For example, an increase in precipitation level will have a specific quantitative impact on an unpaved road in terms of the impact on its life span based on the degree of increase in precipitation. In this manner, the methodology diverges from the focus on qualitative statements to an emphasis on quantitative estimates.

Variation in these relationships by infrastructure type reflects, among other factors, differences in the materials with which different types of infrastructure are constructed and the ways in which different types of infrastructure are used (e.g., buildings often provide heating and cooling). In addition, variation in the stressor-response relationship by country reflects inter-country variation in labor and materials costs as well as terrain (e.g., varying degrees of flat versus mountainous terrain). In this analysis, stressor-response factors were developed based on multiple inputs. A combination of material science reports, usage studies, case studies, and historic data were all used to develop response functions for the infrastructure categories. Where possible, data from material manufacturers were combined with historical data to obtain an objective response function. However, when these data were not available, response functions were extrapolated based on performance data and case studies from sources such as Departments of Transportation or government ministries.

To provide a contextual boundary for the function derivation, two primary climate stressors were included: temperature and precipitation. Cost data for the general study were determined based on both commercial cost databases and specific country data where available.

Finally, the stressor-response factors presented below are divided into two general categories: impacts on new construction costs and impacts on maintenance costs. New construction cost factors are focused on the additional cost required to adapt the design and construction of a new infrastructure asset, or rehabilitate the asset, to changes in climate expected to occur over the asset's life span. Maintenance cost effects are those that either increase or decrease and are anticipated to be incurred due to climate change to achieve the design life span. In each of these categories, the underlying concept is to retain the design life span for the structure. This premise was established as a baseline requirement in the study due to the preference for retaining infrastructure for as long as possible rather than replacing the infrastructure

TABLE 10 **DOSE-RESPONSE DESCRIPTIONS FOR MAINTENANCE COSTS**

Class	*Precipitation*	*Temperature*
Paved roads—existing	Change in annual maintenance costs per km per 10 cm change in annual rainfall projected during life span relative to baseline climate	Change in annual maintenance costs per km per 3° C change in maximum of monthly maximum temperature projected during life span
Unpaved roads	Change in annual maintenance costs per 1 percent change in maximum of monthly maximum precipitation projected during life span	Not estimated; impact likely to be minimal

on a more frequent basis. Achieving this goal may require a change in the construction standard for new construction or an increase in maintenance for existing infrastructure. As documented, this strategy is realized individually for the various infrastructure categories.

CLIMATE CHANGE IMPACTS

The dose-response relationship between climate change and the cost of maintaining road networks is a central concern for climate change adaptation. To determine the costs of climate change impact, two different elements are considered: (1) costs to maintain existing roads, and (2) costs to adapt roads by improving the roads at regular design life intervals.

PAVED ROAD MAINTENANCE

In determining the climate-change-related costs for paved roads, the underlying focus is to maintain the road network that is in place by increasing spending on maintenance to retain the 20-year design life cycle. The 20-year life cycle is based on the assumption that roads are repaved at the end of each 20-year life cycle in a standard maintenance cycle. To determine the increased impact of climate change stressors on this maintenance cycle, the impact of temperature and precipitation is applied to the road. These two factors are the significant factors for road maintenance, as precipitation impacts both the surface and the roadbed, while temperature impacts the asphalt pavement based on the design of the asphalt mix. In this approach, the impact is based on potential life-span reduction that could result from climate change if maintenance practices are not adjusted to meet the increased climate stress.

As indicated by Equation 1, implementation of this approach involves two basic steps: (1) estimating the life-span decrement that would result from a unit change in climate stress and (2) estimating the costs of avoiding this reduction in life span. For example, if a climate stressor is anticipated to reduce the life span by 2 years or 10 percent, and the cost to offset each percent of reduction is equal to a percentage of the current maintenance cost, then the total would be (10 percent)*(current maintenance cost) to avoid decreasing the current design life span.

Equation 1: $MT_{ERB} = (L_{ERB})(C_{ERB})$

Where
- MT_{ERB} = Change in maintenance costs for existing paved roads associated with a unit change in climate stress
- L_{ERB} = Potential percent change in life span for existing paved roads associated with a unit change in climate stress
- C_{ERB} = Cost of preventing a given life-span decrement for existing paved roads

To estimate the reduction in life span that could result from an incremental change in climate stress (L_{ERB}), we assume that such a reduction is equal to the percent change in climate stress, scaled for the stressor's effect on maintenance costs, as shown in Equation 2.

Equation 2: $L_{ERB} = \frac{\Delta S}{BaseS}$ (SMT)

Where	L_{ERB} =	Potential percent change in life span for existing paved roads associated with a unit change in climate stress
	ΔS =	Change in climate stress (i.e., precipitation or temperature)
	BaseS =	Base level of climate stress with no climate change
	SMT =	Percent of existing paved road maintenance costs associated with a given climate stressor (i.e., precipitation or temperature)

Also as indicated in Equation 2, the potential change in life span is dependent on the change in climate stress. For precipitation effects, a reduction in life span is incurred by existing paved roads with every 10 cm increase in annual rainfall. For temperature, a life-span reduction is incurred with every 3-degree change in maximum annual temperature for existing paved roads (FDOT 2009a; FEMA 1998; Miradi 2004; Oregon DOT 2009; Washington DOT 2009).

Equation 2 also illustrates that the estimate of the potential reduction in life span associated with a given change in climate stress reflects the contribution of that stressor to baseline maintenance costs (i.e., variable SMT). For paved roads, precipitation-related maintenance represents 4 percent of maintenance costs and temperature-related maintenance represents 36 percent (Miradi 2004).

After assessing the potential reduction in life span associated with a given climate stressor, the cost of avoiding this reduction in life span is estimated. To estimate these costs, it is assumed that the change in maintenance costs would be approximately equal to the product of (1) the potential percent reduction in life span (L_{ERB}) and (2) the base construction costs of the asset. Therefore, a 10 percent potential reduction in life span is projected and the change in maintenance costs is estimated as 10 percent of base construction costs. In this way, the base construction cost for a primary paved road is estimated at $500,000 per km.

UNPAVED ROAD MAINTENANCE

To estimate dose-response values for unpaved road maintenance costs, an approach is adopted that associates costs with a unit change in climate stress as a fixed percentage of maintenance costs, as illustrated by Equation 3.

Equation 3: $MT_{URR} = M \times B_{URR}$

Where	MT_{URR} =	Change in maintenance costs for unpaved roads associated with a unit change in climate stress[10]
	M =	Cost multiplier
	B_{URR} =	Baseline maintenance costs

The stressor-response relationship represented by Equation 3 is applied as the change in maintenance costs associated with a 1 percent change in maximum monthly precipitation. Research has demonstrated that 80 percent of unpaved road degradation can be attributed to precipitation, while the remaining 20 percent is due to traffic rates and other factors (Ramos-Scharron and MacDonald 2007). Given this 80 percent attribution to precipitation, maintenance costs increase by 0.8 percent with every 1 percent increase in the maximum of the maximum monthly precipitation values projected for any given year. Published data indicate that the baseline cost of maintaining an unpaved road is approximately $960 per km (Cerlanek et al 2006). Therefore, for every 1 percent increase in maximum precipitation, a maintenance cost increase of $7.70 per km can be assumed.

ROAD TRANSPORT MAINTENANCE IMPACTS

The stressor equations introduced above provide the basis for determining the maintenance impact of climate change on paved and unpaved roads. Based on the road inventory in Mozambique and the climate projections provided to the team, it is

10 The readily available data suggest that temperature has no effect on paved road maintenance costs and that precipitation has no effect on the cost of maintaining railroads.

TABLE 11 MAINTENANCE COST INCREASES FOR DIFFERENT TYPES OF ROADS THROUGH 2050 ($)

	ncar_ccsm3_0_a2	*csiro_mk3_a2*	*ipsl_cm4_a2*	*ukmo_hadgem1_a1b*
Cumulative cost increase for maintaining paved roads	40.3 million	66.0 million	30.7 million	8.9 million
Cumulative cost increase for maintaining gravel and earth roads	87.3 million	180.5 million	67.4 million	50.8 million
Total cumulative maintenance costs from climate change	**127.6 million**	**246.5 million**	**98.1 million**	**59.7 million**

estimated that maintenance on paved roads that is directly attributable to climate change ranges from $0.5 million to $5 million per year depending on the climate model used for the projection. As illustrated in Figures 9 and 10, maintenance costs on paved roads are the highest in the first decades as climate change impacts are realized on existing road inventory not designed for increased temperature and precipitation. These maintenance costs drop off over time as new inventory is assumed to be adapted to the future climate change impacts with enhanced design standards.

Similarly, the increased maintenance cost for unpaved roads is estimated between $0.5 million and $5 million per year, depending on the climate model used. In contrast to paved roads, which see reductions in maintenance costs due to enhanced design standards, unpaved roads continue to see increases in maintenance costs depending on the climate scenario due to limited options for making unpaved roads resistant to climate change effects.

Overall, the total increase in maintenance costs due to climate change is therefore estimated to be between $2 million and $11 million per year, depending on the climate model used. Within Mozambique, these impacts are consistent over the time frame due to the consistent impact of the climate change effects. The significant costs associated with unpaved road maintenance should be considered in the overall policy impact, as changing some unpaved roads to paved roads may be economically beneficial.

FIGURE 7 DECADE AVERAGE COST INCREASE FOR MAINTAINING GRAVEL AND EARTH ROADS

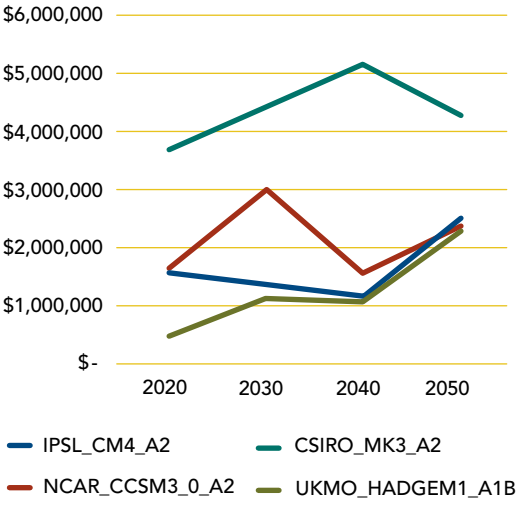
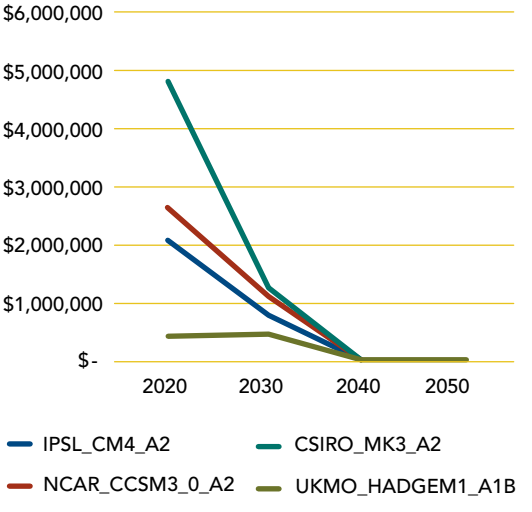


FIGURE 8 DECADE AVERAGE COST INCREASE FOR MAINTAINING PAVED ROADS



Adaptation Options

Adaptation options for roads include changing transportation operation and maintenance; developing new design standards that consider projected climate changes; transferring relevant transportation technology to stakeholders; and enhancing transportation safety measures. Working on a climate change impact study for the World Bank, Neumann and Price (2009) proposed a specific set of climate change adaptation strategies for roads and bridges. These were categorized as follows: operational responses, design strategies, new infrastructure investment, monitoring technologies, new road construction materials, decision-support tools, and new organizational arrangements. These are described in greater detail below.

Operational responses to the impacts of climate change would entail responding to increased precipitation in routine, periodic, and rehabilitation maintenance operations. The Mozambique roads strategy includes these three types of operations in the budgeted costs for 2007–10 and beyond. The result of the EACC study will show the required higher levels of maintenance in response to the different climate change scenarios.

The category of "design strategies" includes the creation of higher design standards for roads and bridges such that these new designs consider the risk of increased precipitation. These design strategies encourage building infrastructure with enhanced materials and technologies that are able to withstand the increased climate stressors. The EACC report's final results will show the total additional investment in construction of roads and bridges based on the design strategy approach.

The new infrastructure investment strategy suggests using the funds left, if any, after the funding requirements for maintenance operations are fulfilled. Using a transportation investment allocation algorithm created for the Mozambique case study, the total required investment in roads and bridges will be reported for the different climate change scenarios.

DESIGN STRATEGY ADAPTATION FOR PAVED ROADS

The adaptation approach for paved roads is based on the premise that continuous research is conducted into safer design standards for specific infrastructure types. This approach is derived from standard practices in earthquake and hurricane mitigation. Following this practice, the design standard approach focuses on the concept that new structures such as paved roads will be subject to code updates if it is anticipated that a significant climate change stressor will occur during their projected life span. Historic evidence provides a basis that a major update of design standards results in a 0.8 percent increase in construction costs (FEMA 1998). The readily available data suggest that such code updates would occur with every 10 centimeter (cm) increase in precipitation or 3 degree Celsius maximum temperature increase for paved roads (Blacklidge Emulsions 2009; Whitestone Research 2008). The general dose-response relationship for paved roads is expressed as follows:

Equation 4: $C_{P,BHP} = 0.8\% (B_{BHP})$

Where $C_{P,BHP}$ = change in construction costs associated with a climate stressor

B_{BHP} = base construction costs for paved roads

A cost of $500,000 per kilometer (km) is assumed for construction of a new paved road in Mozambique, which represents the average cost per km of constructing a 2-lane collector road in rural areas based on in-country data, and a cost of $117,700 per km is assumed for re-paving a road (World Bank 2009c; Washington DOT 2009; Oregon DOT 2009). These numbers can be adjusted for specific instances where data are available, or can

be adjusted to represent a composite or average value of roads within a specific location. Using this approach, the total additional cost for adaptation is determined based on the number of stressor thresholds that are achieved during the projected 20-year design life span. For example, it is estimated that precipitation will increase 11 cm over the next 20 years and temperature will increase 4 degrees, so one precipitation threshold and one temperature threshold has been exceeded. The adaptation cost for this threshold increase is 0.8 percent of the construction costs for precipitation and 0.8 percent of construction costs for temperature. Thus, a total increase of 1.6 percent of construction costs is noted, translating into $8,000 per km, which will be required to adapt to the projected change in climate.

DESIGN STRATEGY ADAPTATION FOR UNPAVED ROADS

For unpaved roads, the adaptation approach costs are directly related to specific changes in climate or infrastructure design requirements. In general terms, this approach is summarized by Equation 5.

Equation 5: $C_{URBT} = M \times B_{URBT}$

Where	C_{URB} =	change in construction costs for unpaved roads associated with a unit change in climate stress or design requirements
	M =	cost multiplier
	B_{URB} =	base construction costs for unpaved roads

The stressor-response relationship represented by Equation 5 associates the change in construction costs with a 1 percent change in maximum monthly precipitation. Research findings have demonstrated that 80 percent of unpaved road degradation can be attributed to precipitation (Ramos-Scharron and MacDonald 2007). The remaining 20 percent is attributed to factors such as the tonnage of traffic and traffic rates. Given this 80 percent attribution to precipitation, we assume that the base construction costs for unpaved roads increase by 80 percent of the total percentage increase in maximum monthly precipitation. For example, if the maximum monthly precipitation increases by 10 percent in a given location, then 80 percent of that increase is used (8 percent) as the increase in base construction costs. The readily available data suggest no relationship between temperature and the cost of building unpaved roads.

ADAPTATION APPROACHES IN A POLICY CONTEXT

The approaches to maintenance and new construction for paved and unpaved roads described above can be implemented in a number of ways depending on the policy approach implemented by government ministries.

Paved road alternatives—non-policy change approach. Once the cost per kilometer impact is determined for maintaining paved roads based on the climate stressors and dose-response values, it is necessary to determine how to apply these values to the existing road network maintenance program. The simple approach is to apply the increase in maintenance costs to the kilometer of road throughout the remainder of the time span in question. To illustrate, if a road was last repaved in 2005 and the 3° C threshold is reached in 2015, then the road will incur the increase in annual maintenance costs per kilometer for the remainder of the 10-year life span (2015–25) until the scheduled repaving. At that point, using the non-policy change approach, the road will be paved to the existing design standard, resulting in a continued $17,500 annual maintenance surcharge (based on in-country costs) due to the temperature increase. This additional cost will then be incurred annually until 2050, totaling $612,500 per kilometer in additional maintenance costs due to temperature increase.

Policy change approach: new paving. An alternative to the previous approach is to adopt

TABLE 12 COST IMPACTS PER POLICY APPROACH (IN $)

	Annual temperature based cost Increase for maintenance	*One-time temperature-based increase for repaving*	*Design standard cost increase per climate threshold*	*Total climate change increase through 2050*
Non-Policy Approach	17,500		4,000	612,500
Policy Change at New Paving	17,500		4,000	179,000
Policy Change at Immediate Paving		55,000	4,000	59,000

Representative comparison of the three approaches to paved road maintenance and climate change adaptation. The comparison is based on a 3° C temperature increase by 2015. The road is a primary road with a base construction cost of $500,000 per kilometer.

a policy where, when the road is repaved at the end of its 20-year life span, it is repaved according to a design standard that compensates for the change in climate. Using the same scenario as the "non-policy change approach," the road continues to incur the $17,500 increase for temperature in annual maintenance costs per kilometer from 2015 to 2025 when it is scheduled for repaving. At this point, the road is repaved as per standard procedure, but with a design standard that is appropriate for the new climate scenario. The increased cost for the design standard is $4,000 per kilometer. In this case, climate change has resulted in a total cost increase of $179,000 per kilometer (the $175,000 for maintenance prior to repaving and the $4,000 at repaving), reflecting the ten years of maintenance increases prior to repaving. However, no further additional costs are incurred unless further climate change is encountered.

Policy change requiring immediate repaving. A final option that can be considered to account for climate change impact is to repave the road immediately after the climate change stressor threshold is reached. In this case, as soon as the 3° C or the 10 cm in precipitation increase is reached, the road is immediately repaved to avoid the annual increase in maintenance charges. Using the previous scenario once again, the road would immediately be repaved in 2015 when the 3° C increase threshold is reached. The additional cost for this increase is based on a base cost for repaving a kilometer of road at $110,000. Using this as a base cost and a constant cost perspective, if a road is repaved ten years earlier than scheduled, then the kilometer of road incurs a one-time 50 percent climate change charge (10 years early repaving / 20 years standard repaving cycle) plus the $4,000 increase in design standard costs. In this case, that amount would equal a one-time climate charge of $59,000. It should be noted that this approach is highly dependent on the ability of the Ministry of Transportation to repave roads when the threshold is reached.

Paved road maintenance summary. In summary, the impact of climate change on paved road maintenance can vary depending on the approach adopted. Table 12 summarizes the cost impacts of the three scenarios outlined above that can occur for a specific road type.

Unpaved road policy alternatives. The policies and costs associated with unpaved road maintenance differ from those of paved roads: unpaved roads are directly affected in terms of life-span reduction when increased maintenance is not provided. This is illustrated in two possible scenarios: delayed response to climate change and immediate reaction to climate change. Both scenarios are described below in greater detail.

Delayed reaction. In the delayed reaction scenario, it is assumed that no increased maintenance

is done on the unpaved road until the end of the 5-year grading and sealing cycle. In this case, the effect of increased precipitation has a direct impact on the life span of the road surface. As indicated above, 80 percent of road degradation is due to precipitation on unpaved roads. However, unpaved road degradation tends not to be linear. As the road begins to deteriorate, additional stress on the road compounds the existing problem. Although this degradation is very site-specific and is contingent upon severity and frequency of precipitation events, a simple assumption can be made that degradation effects increase based on the length of time that the precipitation increase is incurred.

Using this degradation scenario as a basis, a delayed reaction approach can be considered where it is decided to not increase maintenance until a retreatment is scheduled. In this case, the increased costs are incurred due to reduced road capacity. Specifically, the percentage reduction in treatment cycle time is equated to the increase in costs for the unpaved road due to climate change. For example, in a scenario where a 5 percent maximum precipitation increase is reached 2.5 years into the treatment cycle and the threshold is exceeded seven times during the next year, the remaining treatment cycle of the road will be reduced by 35 percent, or 10.5 months (5 percent X 7 occurrences). As the 5-year cost for treating a secondary road in-country is $28,000, a 10.5 month reduction in cycle time is equal to a 17.5 percent overall reduction in cycle time, which has an equivalent value of $4,900 (17.5 percent of the $28,000 five-year cost).

This concept can be expanded to consider impacts through 2050 by examining the effect of reduced

TABLE 13 **TREATMENT CYCLES AND COST ($)**

Cycle	*percent reduction in cycle life*	*Actual end of cycle*	*CC cost incurred per cycle*	*Total # of cycles per 20-year life span*	*Total # of cycles through 2050*	*Total CC cost through 2050*
Standard Treatment Cycle	0	60 months	0	4	8	$0
Climate Change-Based Treatment Cycle	17.5	50 months	4,900 per km	4.8	10.8	$53,000 per km

treatment cycles due to not increasing maintenance. To illustrate, changing the example slightly to a scenario that the 5 percent maximum is exceeded seven times per every 5-year treatment cycle, the following becomes the actual change in treatment cycles and the associated costs (Table 13).

Immediate reaction. The second option for responding to climate change impacts on unpaved roads is to increase maintenance immediately upon the precipitation exceeding existing maximum levels. Continuing with the previous scenario, if a new maximum of 5 percent precipitation increase is reached with 2.5 years remaining in the life span, then an increase in maintenance can be applied of $7.70 per kilometer per percent increase for a total of $38.50 for the 5 percent increase. However, by treating the road immediately, no loss of design life is incurred. Therefore, if the same seven occurrences happen during the next year, a total of $270 will be expended in maintenance per kilometer, but no life-span loss is incurred. The significant reduction in costs in this scenario is due to the elimination of the compounding effects from the erosion that occurs when the maximum precipitation threshold is reached.

Taking the "increasing maintenance" approach out to 2050, assuming the same seven occurrences each five-year cycle, the total climate change-based cost is $270 per five-year cycle x 8 cycles, or $2,160. A significant decrease from the $53,000 per kilometer occurs if no immediate action is taken.

CONCLUSION

In developing countries, maintenance—as well as increasing design standards when new roads are constructed or existing roads are repaved or resealed—is a key concern for alleviating the worst aspects of climate change. The following two points are key for policy makers to consider for climate impacts on the road sector:

Relative impact on unpaved roads. Developing countries have a greater susceptibility to climate change in the road sector than developed countries for a single primary reason: the relative amount of more unpaved to paved roads. In contrast to developed countries, where primary and secondary paved roads are the primary means of transportation, developing countries rely heavily on rural, unpaved roads to connect outlying and rural communities. Unfortunately, these are the same roads that are impacted to the greatest extent with climate change. Increases in precipitation account for 80 percent of the degradation of unpaved roads. Therefore, in countries that are experiencing increases in precipitation, the rate of degradation for unpaved or gravel roads significantly increases. In response, these countries will need to make a focused effort to mitigate damages through actions such as sealing unpaved roads to mitigate the rate of degradation caused by increased precipitation.

Maintenance on paved roads. In many parts of the developed world, maintenance of paved roads is considered a necessity and maintenance

cost is part of the standard operating budget and is undertaken on a daily basis. However, in developing economies, this maintenance is often subsumed by the need to put money into new roads or other government priorities of the moment. With the introduction of climate change, this lack of maintenance will be highlighted as temperature increases over time will result in reduced life span of asphalt road pavement. Specifically, increases in temperature account for over 30 percent of the maintenance issues with pavement. Therefore, as the temperature increases due to climate change, if roads are not maintained, significant cracking and degradation will occur, resulting in reduced life span and the need for repaving in an earlier timeframe. In response, developing countries must focus on policy changes that anticipate climate change and design roads accordingly to anticipate the harsher climate conditions that will occur during the design life span.

SIX

Hydropower

Background

Large-scale hydropower generation relies on a combination of flow and elevation drop of water to generate electricity by turning turbines. Turbines are the mechanical inverse of a pump, converting hydraulic energy (in the form of water flow and head[11]) to electricity, whereas a pump converts electricity to hydraulic energy. A schematic representation of a hydropower facility is shown below in Figure 11.

There are four existing large-scale hydroelectric generating facilities in Mozambique. Attributes of these facilities are listed below in Table 14.

The total annual electrical demand in Mozambique in 2007 was 2,099 GWh. Demand is expected to grow to 8,290 GWh by 2030 based on an average growth in annual electrical demand of 6.2 percent. The peak load increases from 364 MW in 2007 to 1.352 GW in 2030, based on an average annual growth in peak demand of 5.9 percent. Current demand is being met by a mix of thermal and hydroelectric generation. Future demand is expected to be met by expanded thermal and hydroelectric capacity, as well as wind and solar energy (Republic of Mozambique Ministry of Energy 2009).

TABLE 14 ATTRIBUTES OF EXISTING PRIMARY HYDROPOWER GENERATION IN MOZAMBIQUE

	Power (MW)	Turbine Head (m)	Discharge (m3/sec)	Location (Province)	River
Cahora Bassa	2075	120	2000	Tete	Zambeze
Chicamba	34	50	60	Manica	Buzi
Mavuzi	48	160	23	Manica	Buzi
Corumana	16.6	36	25	Maputo	Incomati

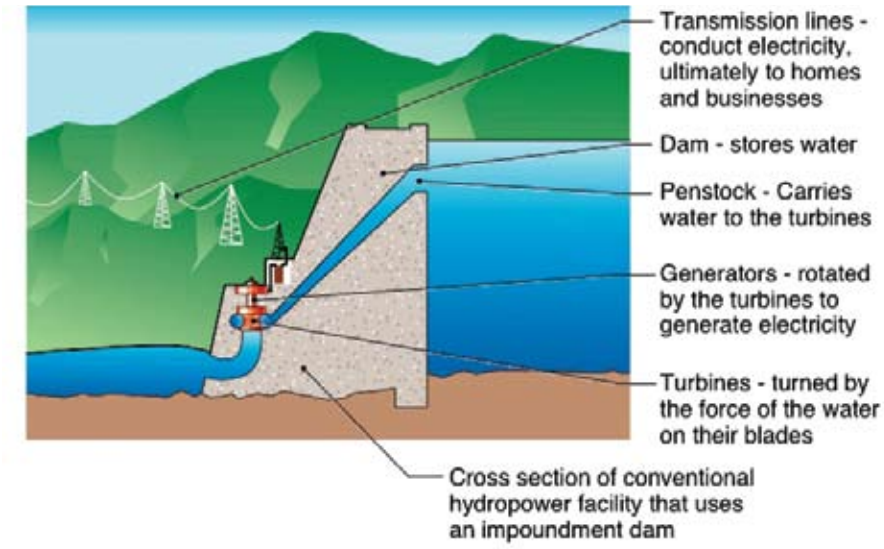
Source: World Bank, 2007

Planned and existing generation facilities—including hydropower, thermal, and renewable sites—in relation to land use are shown below in Figure 12.

The electrical transmission system is an important and costly component of power generation planning. Because efficient hydropower is geographically "fixed" due to specific conditions of flow and terrain, transmission costs can be especially high. Conversely, thermal options have the flexibility to be located near the energy source (i.e. "mouth of mine generation") or near the demand centers of population and/or industry, allowing for trade-offs between fuel transport and electric transmission costs to minimize costs. Renewable

11 The pressure exerted by the weight of water above a given level.

FIGURE 9 SCHEMATIC REPRESENTATION OF A LARGE-SCALE HYDROPOWER FACILITY



Source: Norconsult, Ministry of Energy, 2009

options may or may not be geographically fixed to a location, depending on the fuel source.

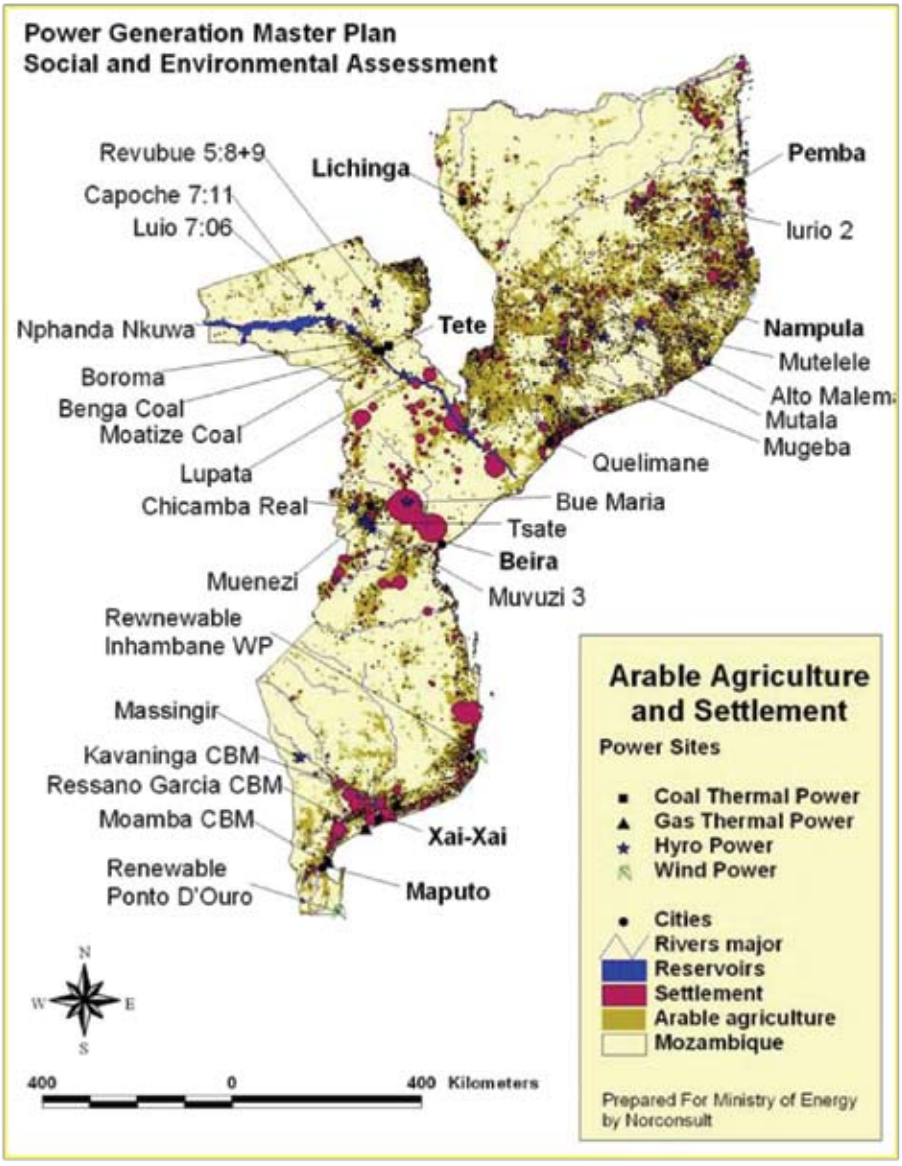
Mozambique is connected to the regional transmission grid via international power connections with South Africa, Swaziland, Malawi, Zambia, and Zimbabwe. These transmission lines allow for power sharing between countries and allow for a more reliable energy source. Existing and planned transmission lines, showing locations of international connections, are shown in Figure 13.

Modeling the Sectoral Economic Impacts

Potential future hydropower generation in Mozambique was simulated for five time periods: one historic 20th century estimate of climate (1951–2000) and four 21st century potential climates (2000–50). Hydropower simulation was done using a hydropower planning model originally developed for Ethiopia, the IMPEND model (Block and Strzepek 2009). IMPEND was developed to plan reservoirs and power generation facilities on the Upper Blue Nile River in Ethiopia. It is a water accounting and optimization program written in the general algebraic modeling system software (GAMS 2005) and requires measurements or estimates of monthly stream flow, net evaporation at each reservoir, and discount rate, along with reservoir attributes including surface area of each reservoir, design head, and peak energy output. Output includes a time series of energy generation and associated project costs.

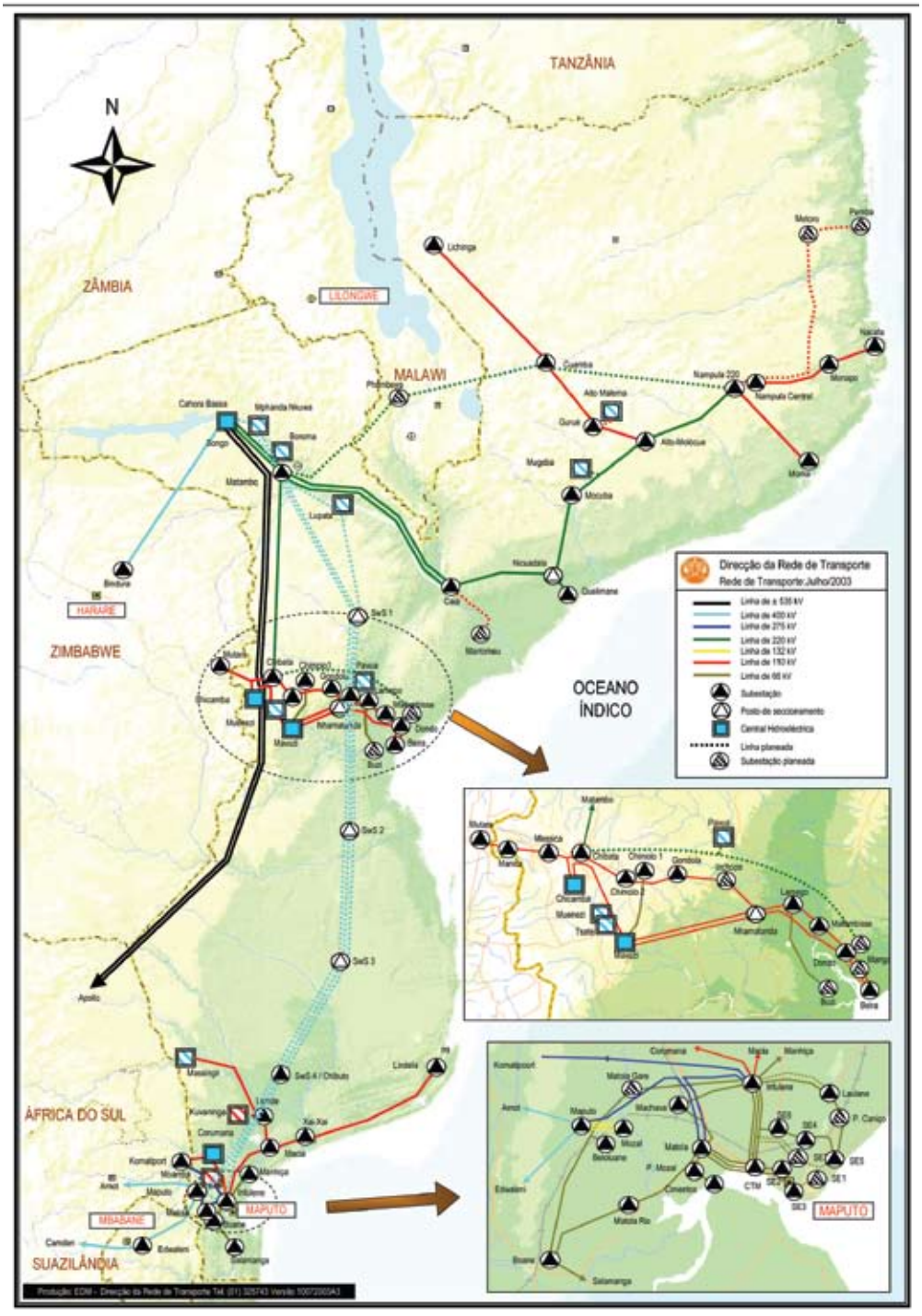
The Ministry of Energy recently completed the "Energy Master Plan for Mozambique." This report contains nearly all the relevant information pertaining to planned thermal, hydropower, and renewable capacity expansion from 2010 to 2030. The information from this report was used to define the baseline condition used in IMPEND, as well as to inform potential adaptation strategies. While the Ministry of Energy, as of September 2009, has no formal policy related to climate change adaptation, the scenarios, costs, and revenue from hydropower generation were used to evaluate potential adaptation strategies. These policy adjustments include defining alternative generation sources that may be used to

FIGURE 10 POWER GENERATION MASTER PLAN, FACILITY LOCATION



Source: Norconsult, Ministry of Energy, Energy Master Plan for Mozambique, 2009

FIGURE 11 EXISTING AND PLANNED TRANSMISSION LINES IN MOZAMBIQUE



Source: Norconsult, Ministry of Energy, Energy Master Plan for Mozambique, 2009

make up potential hydropower losses due to climate change, along with altering the scale and sequencing of already-planned projects.

The IMPEND simulation required estimates of monthly flow and net evaporation from the hydrologic model "CliRun," which is described in greater detail in Annex 2. Tributary sub-basins were identified for each existing and potential hydropower site, and coded into IMPEND. CliRun output files were accessed by IMPEND for historical and future climate simulations, and in turn used to calculate electric power generation potential.

Seven electric power generation scenarios were developed in the Energy Master Plan to compare the costs and benefits of various energy strategies of interest to Mozambique. The attributes of these scenarios are shown in Table 15. All contain a mix of new thermal, hydropower, and renewable generation sources. Of these scenarios, the baseline hydropower generation scenario for this report was developed primarily from the "extended hydro" option shown in Table 16.

The "extended hydro" scenario was used as the basis to estimate climate change impacts on hydropower in Mozambique because it relied least on thermal generation options (zero coal generation) and contained the largest number of feasible hydro projects.

The baseline scenario used in IMPEND consisted of all "extended hydro" projects from the Master Plan, plus four additional projects. These four additional projects were added because the Master Plan did not cover projects beyond 2030. However, the EACC report required additional projects beyond the extent of the Master Plan, from 2030 to 2050. These four additional projects were from a set of projects that were not included in the final "extended hydro" scenario in the Master Plan because hydrologic data from the river basins fell short of the 38 years deemed necessary for the Master Plan. For this report, however, it was assumed that by 2030 sufficient data would have been collected in these basins to plan reservoirs, so these projects were selected to augment the ten projects in the "extended hydro" scenario from the Master Plan.

The hydro projects included in the "extended hydro" scenario, as well as the four additional projects, are shown in Table 16. The IMPEND model was used to simulate the potential hydropower generated from these 18 projects.

TABLE 15 GENERATION SCENARIOS DEVELOPED IN THE ENERGY MASTER PLAN FOR MOZAMBIQUE

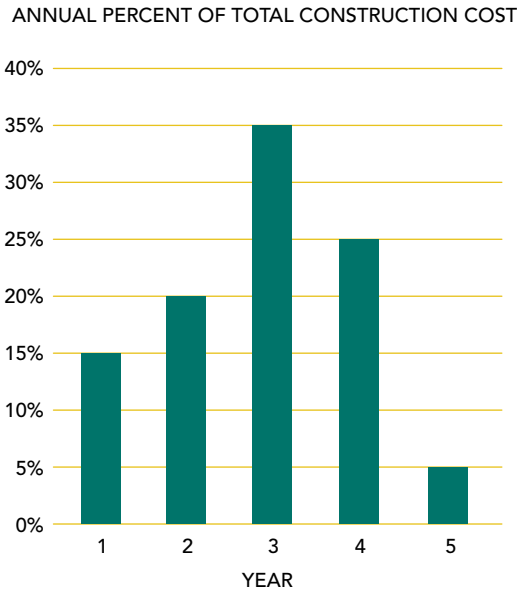
		Reference	*Mphanda Nkuwa*	*Mphanda Nkuwa + CBNB**	*Coal*	*"Least-Cost" Backbone*	*Extended Hydro*	*Mphanda Nkuwa – no RE*
Installed Capacity (MW)	Hydro	0	1500	2330	0	2745	3461	1500
	Thermal Ga	705	705	705	705	705	705	705
	Thermal Coal	0	0	0	4400	4400	0	0
	Renewable	160	160	160	160	160	160	0
	Total Capacity	865	2365	3195	5265	8010	4326	2205
Costs (MUS$)	Generation Cost	$1,709	$3,344	$3,816	$10,799	$13,103	$7,247	$2,645
	Transmission Cost	$57	$777	$1,051	$2,003	$2,778	$1,544	$777
	Total Cost	$1,766	$4,121	$4,867	$12,802	$15,881	$8,791	$3,422

* CBNB: Cahora Bassa North Bank project. *Source:* Ministry of Energy, 2009

TABLE 16 PROJECTS INCLUDED IN THE BASELINE HYDROPOWER SIMULATION

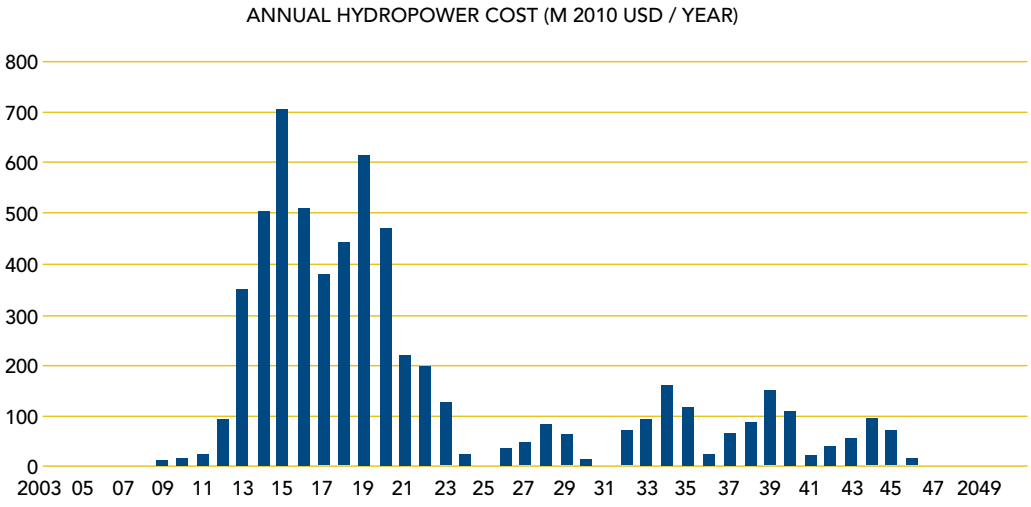
Plant Name	*River Basin*	*Installed Capacity (MW)*	*Earliest year online*	*"Extended Hydro" year online*	*Baseline IMPEND Simulation year online*
Cahora Bassa	Zambezi	2075	Existing	Existing	**Existing**
Chicamba	Buzi	38.4	Existing	Existing	**Existing**
Corumana	Incomati	16.6	Existing	Existing	**Existing**
Mavuzi	Buzi	52	Existing	Existing	**Existing**
Massingir	Limpopo	40	2012	2019	**2012**
Muenezi	Revue	21	2015	2021	**2021**
Tsate	Revue	50	2015	2023	**2023**
Pavua	Pungwe	60	2015	2020	**2020**
Cahora Bassa–NB	Zambezi	850	2015	2016	**2015**
7:11	Zambezi	62	2016	N/A	**2029**
7:6	Zambezi	280	2016	N/A	**2035**
Nphanda Nkuwa	Zambezi	1500	2015	2015	**2015**
Boroma	Zambezi	160	2018	2019	**2019**
5:8+9	Zambezi	120	2016	2040	**2040**
Lupata	Zambezi	650	2018	2020	**2020**
Mugeba	Licungo	100	2014	2023	**2023**
Alto Malema	Lurio	60	2014	2022	**2022**
Lurio 2	Lurio	120	2015	N/A	**2045**

FIGURE 12 ASSUMED TEMPORAL DISTRIBUTION OF PROJECT COSTS



The timing of project construction is important to hydropower planning. Construction timing depends on energy demand as well as the availability of capital resources. As shown in Table 16, hydro project timing varies in the Master Plan. The "earliest online" represents the most optimistic view, while the dates associated with the "extended hydro" use a more delayed approach. Based on information from the World Bank Mozambique country office, at least three projects were under way or close to under way: Massingir, Cahora Bass North Bank, and Nphanda Nkuwa. The model therefore uses the "earliest online" time (as shown in Table 16) only for these three projects. The remaining "extended hydro" projects used the later completion time, and the four additional projects were sequenced over the 20-year period from 2030 through 2050.

FIGURE 13 **ASSUMED TIMELINE OF PROJECT INVESTMENT SCHEDULE**



The temporal project cost distribution was assumed to follow a 5-year sequence, as taken from the Master Plan. Each project cost was distributed over five years, ending in the "online" year shown above in Table 16. This distribution is shown below in Figure 14. The total cost (in 2010 $) in Table 16 was multiplied by the vector (0.15, 0.20, 0.35, 0.25, 0.05) to obtain the project cost for years 1 through 5.

CLIMATE CHANGE IMPACT

The CliRun model was used to estimate flow into the eighteen hydropower generation facilities for four future climate realizations as described above. These flow estimates were used in IMPEND to estimate the potential power generation available under these hydrologic conditions. All other assumptions and conditions were identical with the historic run; operating assumptions and surface areas of the reservoirs, among others, were all held constant. Only influent flow changed.

The IMPEND modeling provided an estimate of the potential change in hydropower generation capability for these plants under the above investment schedule. The results of these comparisons are shown in Figure 16.

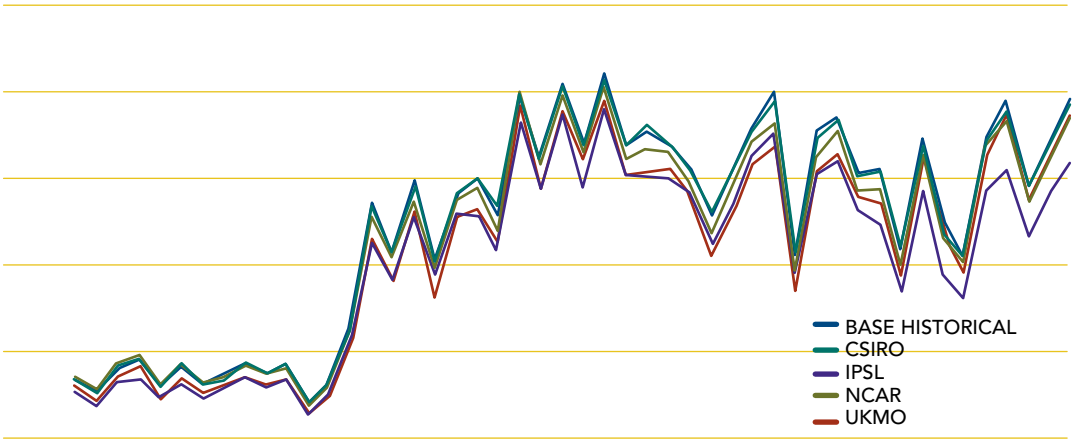
The "base historical" run is the energy generated if the future climate follows historical trends. The other four runs represent four different future climate realizations expressed as deviations from the historical. It is evident from these estimates that the historical simulation provides the maximum hydropower energy production of the five simulations; all four future climate scenarios tended to diminish the volumes of energy generated.

The cumulative annual project costs (the sum over each year of all project costs incurred that year) and the expected energy output were then sent to the CGE model to estimate the economic impact of climate change vis-à-vis changes in river flow.

Adaptation Options

Hydropower generation capacity diminishes under all four future climate scenarios simulated for this study when compared with the historic hydrological trends using identical hydropower investment schedules. Since the vast majority of

FIGURE 14 COMPARISON OF HYDROPOWER ENERGY PRODUCTION IN MOZAMBIQUE (GW-HRS/YEAR)



energy generated in Mozambique is exported to the regional grid, the drop in electric potential represents lost revenue to Mozambique.

One adaptation strategy to mitigate this lost revenue would be to make up for "lost" generation capacity. Additional capacity could come from additional hydropower investment (large or small scale), traditional thermal energy (coal and gas), or through renewable fuel sources that are less sensitive to climate than hydropower.

The above strategy of "making up the difference" ignores the possibility that decreased energy production will adversely affect the economic feasibility of the hydropower generation facility by decreasing the net benefits over the life cycle of the facility. Because the climate models show that the energy capacity will be something less than planned due to decreased flow in the river, the benefit-cost analysis underlying the feasibility of the project will be incorrect and should be reviewed.

A climate change adaptation strategy may include more hydropower projects. There are a number of potential projects in Mozambique that were not considered in the final planning scenarios in the Master Plan because of insufficient hydrological data. Over time, these small, medium, and large-scale hydropower projects may yet take place.

Fuel sources that are less sensitive to climate change may be an attractive alternative or supplement to large-scale hydropower generation. These include thermal sources (coal and gas), renewable sources (bio-fuel, solar, and wind power) and micro-hydropower. While thermal sources are generally discouraged due to atmospheric carbon releases, there is currently no carbon surcharge or penalty for Mozambique to use these sources. From a climate change perspective, it is in Mozambique's best long-term interest to promote sustainable energy sources.

Wind. Wind is a complex energy source, strongly affected by terrain and tending to be intermittent. Commercial wind generators are available up to 5MW each and are typically grouped in "wind farms" of approximately twenty generators spaced five to ten rotor diameters apart. Therefore, a typical wind farm may require 3–4 square kilometers of space, while only occupying

1 percent of this area, the remainder of which may be farmed in a conventional manner. The Energy Master Plan for Mozambique states:

> *"The net energy output of a typical 600 kW machine operating in a wind farm would be around 1,600 MWh/year on a site with an annual mean wind speed (AMWS) of 7.5 meters per second (m/s) at a height 45 m above ground level (AGL) and 2,050 MWh/year on a site with an AMWS of 9.0 m/s at 45 m."*

Solar. There are several technologies available to harness solar power. The two primary technologies are photovoltaic and concentrated solar power. Photovoltaic materials generate direct current when exposed to solar radiation, and concentrated solar power uses direct sunlight, "concentrated" several times by mirrors or lenses to reach higher energy densities. The heat is then used to operate a conventional power cycle through a steam turbine, which drives an electrical generator.

SEVEN

Coastal Zone

Background

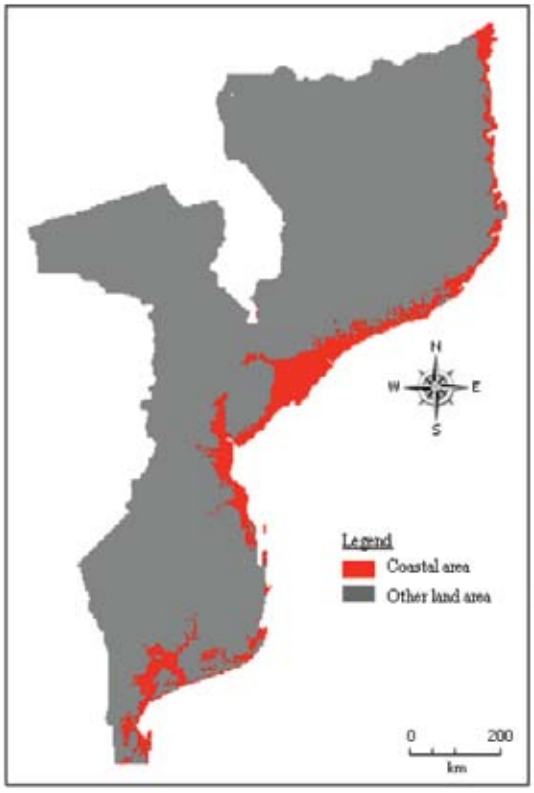
Human-induced climate change presents many global challenges, with the coastal zone being a particular focus for impacts and adaptation needs. The coastal zone contains unique ecosystems and typically has higher population densities than inland areas (Small and Nicholls 2003; McGranahan et al. 2007), and contains significant economic assets and activities (Bijlsma et al. 1996; Sachs et al. 2001; Nicholls et al. 2008; Dasgupta et al. 2009). Sea level rise, as a direct consequence of human-induced climate change, has significant implications for low-lying coastal areas and beyond, including the major direct impacts—inundation of low-lying areas, loss of coastal wetlands, increased rates of shoreline erosion, saltwater intrusion, higher water tables, and higher extreme water levels, which lead to coastal flooding. Hence, coastal areas are highly vulnerable and could experience major impacts associated with the changing climate and its variability,

TABLE 17 LAND AREA DISTRIBUTIONS OF THE TEN PROVINCES OF MOZAMBIQUE (DIVIDED INTO THREE ZONES)

				Land Area in the Coastal Zone (CZ)*	
No.	Zones	Provinces	Land Area (km2)	Total (km2)	Percentage (%)
1	North	Cabo Delgado	79,033	3,495	4.4
2		Nampula	79,121	5,067	6.4
3		Niassa	129,090	—	—
4	Central	Manica	62,808	—	—
5		Sofala	67,349	16,003	23.8
6		Tete	100,922	—	—
7		Zambezia	103,094	16,267	15.8
8	South	Gaza	75,512	5,342	7.1
9		Inhambane	68,107	4,732	6.9
10		Maputo – Capital	23,657	4,654	19.7
TOTAL FOR MOZAMBIQUE:			788,693	55,560	7.0

*The Coastal Zone (CZ) is defined here as the land area within 30m of mean sea level.

FIGURE 15 TWO-LAND ZONING (COASTAL AND OTHER LAND AREA) OF MOZAMBIQUE



Note: The coastal area is defined as the area within 30m contour of mean sea level; the rest is above 30m mean sea level.

as well as sea level rise. For over 60 percent of the nation's population (of 21 million, 2008 estimate) living in coastal areas (World Bank 2009), future climate change and sea level rise could only exacerbate existing coastal risks, highlighting the need for coastal adaptation measures and improved coastal management.

The country has 10 administrative units (termed provinces), seven of which are coastal, predominantly with maritime climate. The coastline is the third longest (about 2,700 kilometers) in Africa, and is characterized by low-lying areas (Figure 17) and a vast variety of ecosystems such as sandy beaches, estuaries, mangrove forests, recent dunes, and inland lagoons, coastal lakes, banks and coral reefs, marine weed, and swamps (Chemane et al. 1997; NAPA 2007; INGC 2009a). These ecosystems present important habitats of ecological importance and economic value. The morphology of the coastal areas is characterized by low lands rising above 200m in elevation at distances between 15 and 140 kilometers from the shore (Ruby et al. 2008).

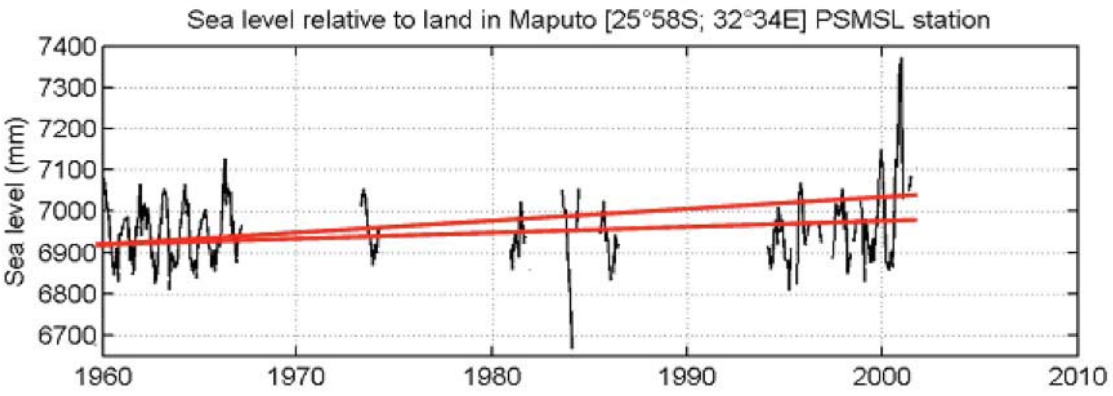
Observed historic sea level change measurements during the period of 1960–2001 (medium-length) from the Maputo station (25o58'S; 32o34'E) in Mozambique and the regional measurements (as marked in red lines) are shown in Figure 18. The linear best fit trend line shows a positive slope of approximately (2.17 ± 0.76) mm/year. Although Maputo's sea level change record is admittedly poor, it is consistent with regional trend estimates (Church et al. 2004), and recent global sea level rise trends (IPCC 2007).

Modeling the Impact

This national assessment uses an improved form of the DIVA (dynamic interactive vulnerability assessment) model based on selected climate (such as sea level rise) and [??] (such as population and GDP) scenarios combined with two planned adaptation options. The DIVA model includes flood and erosion simulation algorithms that estimate both the damage and associated costs of planned adaptation options. Adaptation options include dike construction (and upgrade) and beach/shore nourishment. Dike operation and maintenance costs, port upgrade, and the potential for a retreat policy via land use planning are also considered. Collectively, these results quantify the potential costs of a range of plausible adaptation scenarios and hence provide some indicative costs for subsequent interpretation.

The DIVA model is an integrated model of coastal systems that assesses biophysical ?? and impacts of

FIGURE 16 OBSERVED ANNUAL MEAN SEA LEVEL RECORDS AT THE MAPUTO STATION, 1960–2001



Source: INAHINA 2008;INGC 2009.

sea level rise due to climate change and development (DINAS-COAST Consortium 2006; Vafeidis et al. 2008; Hinkel et al. 2009). DIVA is based on a model that divides the world's coast into 12,148 variable length coastal segments based on political and physical characteristics. It associates up to 100 data values with each segment (DINAS-COAST Consortium 2006; Vafeidis et al. 2005, 2008).In the DIVA model, the coast of Mozambique is represented by 50 coastal segments.

DIVA is driven by climate and scenarios. The main climate scenario in DIVA is sea level rise, while coastal population change and GDP growth represent the primary scenarios. DIVA down-scales the sea level rise scenarios by combining global sea level rise scenarios due to global warming with an estimate of the local vertical land movement. These local components vary from segment to segment and are taken from the global model of glacial-isostatic adjustment of Peltier (2000). For segments that occur at deltas, additional natural subsidence of 2mm/year is assumed. Note that human-induced subsidence associated with ground fluid abstraction or drainage may be much greater in deltas and susceptible cities than considered here (e.g., Nicholls 1995; Ericson et al. 2006; Syvitski et al. 2009).

The social and economic consequences of the physical impacts of sea level rise are also estimated using DIVA. The social consequences are expressed in terms of a selected indicator of the cumulative number of people forced to migration. This represents the total number of people that are forced to migrate either from the dry land permanently lost due to erosion or they are flooded more than once per year. On the other hand, the economic consequences are expressed in terms of residual damage costs (e.g., costs of land loss and floods) and adaptation costs (e.g., costs of dike construction and upgrade, and beach/shore nourishment).

Adaptation costs are estimated for the two planned adaptation options considered: (1) dike (sea or river) building and upgrade, and (2) beach/shore nourishment. Dike costs are taken from the Global Vulnerability Assessment carried out by Hoozeman et al. (1993), which is the most recent global assessment of such costs. The costs of nourishment were derived by expert consultation, based primarily on the project experience of Delft Hydraulics (now Deltares) in the area of beach nourishment. Different cost classes are applied that depend on how far the sand for nourishment needs to be transported, as this is a significant determinant of such costs.

Adaptation Options

Adaptation has costs but it comes with benefits: the costs for planning, facilitating, and implementing adaptation measures, and the benefits expressed in terms of avoided damages (e.g. reducing potential climate change impacts) or the accumulated benefits (positive consequences) following the implementation of adaptation measures. DIVA implements the different adaptation options according to various complementary adaptation strategies. The simplest strategy is no adaptation, in which DIVA only computes potential impacts in a traditional impact analysis manner. In this case, dike heights (in 1995) are maintained (but not raised), so flood risk rises with time as relative sea level rises. Beaches and shores are not nourished. With adaptation, dikes are raised based on a demand function for safety (Tol and Yohe 2007), which is increasing in per capita income and population density, but decreasing in the costs of dike building (Tol 2006). Dikes are not applied where there is very low population density (< 1 person/km2), and above this population threshold, an increasing proportion of the demand for safety is applied. Half of the demand for safety is applied at a population density of 20 persons/km^2, and 90 percent at a population density of 200 persons/km$_2$. Hence, this is not a cost-benefit approach but rather illustrates scenarios of response based on the demand for safety function. For nourishment, a cost-benefit adaptation (CBA) strategy that balances the costs and the benefits (in terms of avoided damages) of adaptation is used in these analyses.

The specific adaptation assessment options considered in this analysis are described in Table 18. Apart from port upgrade costs (which are developed independently), all the impact and cost estimates are developed within the global DIVA model of impacts and adaptation to sea level rise. The adaptation measures considered in this study focus on reducing flood risk by raising the existing and constructing new flood defense dikes, and reducing beach erosion through nourishment.

IMPROVEMENTS FOR THE MOZAMBIQUE NATIONAL ASSESSMENT

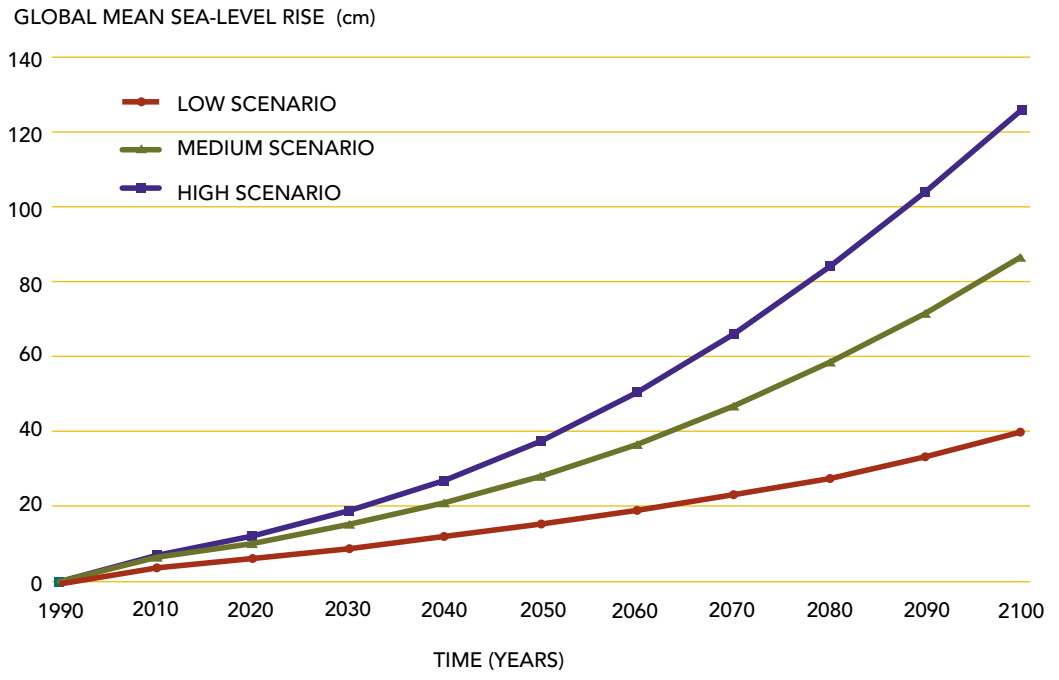
In the Mozambique national assessment, four improvements/extensions have been made directly or indirectly to the DIVA model as follows:

- Improvements following the World Bank global assessment (see Nicholls et al. 2010):
  - Considerations of the costs of port upgrade due to sea level rise.
  - Consideration of dike maintenance and operating costs, as DIVA only considers capital costs.
- Additional improvements in this national assessment.

TABLE 18 ADAPTATION OPTIONS CONSIDERED IN THE DIVA ANALYSIS

Effects of Sea level Rise	*Physical Impacts*	*Adaptation Modes*	
		With Adaptation	*No Adaptation*
Beach Erosion	Land loss; Infrastructure loss	Beach Nourishment	No increase in flood defense dike heights from baseline No nourishment
Land Submergence	Land loss; Infrastructure loss	Flood Protection (e.g. dikes)	
Flooding due to storm surges and the backwater effect	Infrastructure damage	Flood protection (e.g. dikes)	
	Port damage (not evaluated)	Port raising	*Not evaluated*

FIGURE 17 GLOBAL MEAN SEA LEVEL RISE SCENARIOS USED (RELATIVE TO 1990 LEVELS)



Source: World Bank 2010.

- Use of improved elevation data by changing from the GTOP30 dataset to the SRTM dataset by using the DIVA Database [1.7.2] version.
- Estimates of river dike costs were improved by considering six additional major rivers in Mozambique that were not included in the DIVA Database [1.7.2] and the number of distributaries at river mouths. Both capital and operation and maintenance costs are considered.

Sea level rise and scenarios. Sea level rise impacts throughout the 21st Century are dependent upon the sea level scenarios, and the adaptation measures employed. A scenario is not a prediction, but represents a plausible future. The purpose of exploring a range of scenarios as analyzed in this report is to elucidate a range of possible sea level changes resulting from a set of plausible future conditions and known science. Four sea level rise scenarios based on the IPCC AR4 Report (Meehl et al. 2007) and the Rahmstorf (2007) analysis are used to capture a range of possible changes, as listed below:

- High scenario—derived from the Rahmstorf (2007) maximum trajectory
- Medium scenario—derived from the Rahmstorf (2007) A2 temperature trajectory
- Low scenario—derived from the midpoint of the IPCC AR4 A2 range in 2090-2099
- No SLR scenario—no climate-induced sea level rise is a reference case. This allows estimates of the incremental costs of climate change.

TABLE 19 SEA LEVEL RISE SCENARIOS USED IN THIS STUDY FOR THE BEACH EROSION/NOURISHMENT AND PORT UPGRADE (NO PROACTIVE ADAPTATION), AND FOR FLOODING AND DIKE COSTS (WITH PROACTIVE ADAPTATION OVER 50 YEARS)

YEAR	SEA LEVEL RISE SCENARIOS (in cm relative to 1990 levels)							
	Flooding, Beach/Shore Erosion/Nourishment and Port Upgrade Predicted SLR Scenarios				Sea/River Dike Costs Projected SLR Scenarios			
	No SLR	Low	Medium	High	No SLR	Low	Medium	High
2010	0.0	4.0	6.6	7.1	0.0	4.0	6.6	7.10
2020	0.0	6.5	10.7	12.3	0.0	13.1	26.8	36.9
2030	0.0	9.2	15.5	18.9	0.0	22.1	46.9	66.7
2040	0.0	12.2	21.4	27.1	0.0	31.2	67.1	96.5
2050	0.0	15.6	28.5	37.8	0.0	40.2	87.2	126.3

These scenarios give a global mean sea level rise of 16–38cm by 2050, and 40–126cm by 2100 (Table 19). For flooding, beach erosion/nourishment and port upgrade scenarios from 2000 to 2050 are used, while for dike costs, sea level from 2050 to 2100 is used, assuming a 50 year timescale proactive adaptation.

As accepted in engineering practice; the sea and river dikes scenario is based on anticipated future sea level heights in 50 years; that is, based on the assumption that expected extreme sea levels in 2100 determine the dike height built in 2050. Again as per accepted engineering practice, other adaptation measures such as beach/shore nourishment are not assumed to be implemented in an anticipatory manner.

IMPACTS OF SEA LEVEL RISE AND ADAPTATION COSTS

This section summarizes the physical impacts and adaptation costs of climate change and sea level rise in Mozambique. Predictions are presented for decades from 2010 to 2050, taking the 2010s, 2020s, 2030s, and 2040s to be the mean values of the results for 2015 and 2020, 2025 and 2030, 2035 and 2040, and 2045 and 2050, respectively. The results are discussed under the following three sections.

1. **Residual Damage (non-monetary):** comprising total land loss (due to erosion or submergence) and cumulative forced migration

2. **Total Residual Damage Costs (monetary):** comprising land loss costs, forced migration costs, sea flood costs, and river flood costs
3. **Adaptation Costs (monetary):** comprising total river dike costs, total sea dike costs, total beach/shore nourishment costs, and total port upgrade costs.

Residual damage. The residual damages are (a) loss of land area due to erosion and submergence, and (b) number of people forced to migrate. Figures 20 to 23 show the distribution of the loss of land areas under different sea level rise scenarios along with the two adaptation modes. With no adaptation, the total loss of land area ranges between 102 and 106 km^2/yr in the 2010s, and between 23 and 42 km^2/yr in the 2040s across all the scenarios. More than 98 percent of these damages are caused by submergence.

The potential land area lost to erosion with and without adaptation is shown in Figures 20 and 21. If no adaptation measures are considered, a total land area of ranging between 1 and 3.3 km^2/yr could be lost to erosion in the 2040s across the

range of the sea level rise scenarios (Figure 20). The cumulative land lost by 2050 ranges between 39 and 106 km^2. These damages are distributed across the coastal provinces—about 27 percent in Inhambane, 18 percent in Zambezia, 17 percent in Nampula, 14 percent in Sofala, 11 percent in Cabo Delgado, 8 percent in Maputo, and about 5 percent in Gaza.

The potential total land losses due to submergence under the two (i.e., "with" and "without") adaptation modes are shown in Figures 22 and 23. Results show that under the no-adaptation high sea level rise scenario, a total land area as high as 105 km^2/yr in the 2010s and more than 38 km2/yr in the 2040s could be lost to submergence (Figure 22). As a reference scenario for a no climate-induced sea level rise, a total land area loss of about 1.1 km^2/yr could still be expected in the 2040s. This demonstrates that while there will be some losses even without climate change, about 98 percent of these losses are linked to climate change. The cumulative land loss due to submergence by 2050 ranges between 2,655 and 4,744 km^2 without adaptation (or up to 0.6 percent of national land area). Associated with their low-lying nature, the estimated damages are mainly concentrated in the Zambezia (about 49 percent), Nampula (about 25 percent) and Sofala (about 20 percent) provinces.

However, when appropriate adaptation measures in terms of protection via dikes are considered, the total land area that could be lost to submergence is significantly reduced by a factor more than 50 to 2 km^2/yr in the 2010s, and no loss thereafter (Figure 23).

If land is lost, the people dwelling on the land will be forced to migrate. In this study, it is assumed that people who are flooded more often than once a year, or who lose their land to erosion, will be forced to migrate. Results show that for the high sea level rise scenario combined with future population growth, between 44,000 and 90,000

FIGURE 18 TOTAL ANNUAL LAND LOSS (EROSION) DUE TO SEA LEVEL RISE FROM 2010 TO 2050 IN MOZAMBIQUE FOR THE HIGH, MEDIUM, LOW, AND NO SLR SCENARIOS STUDIED, WITH NO ADAPTATION MEASURES EMPLOYED

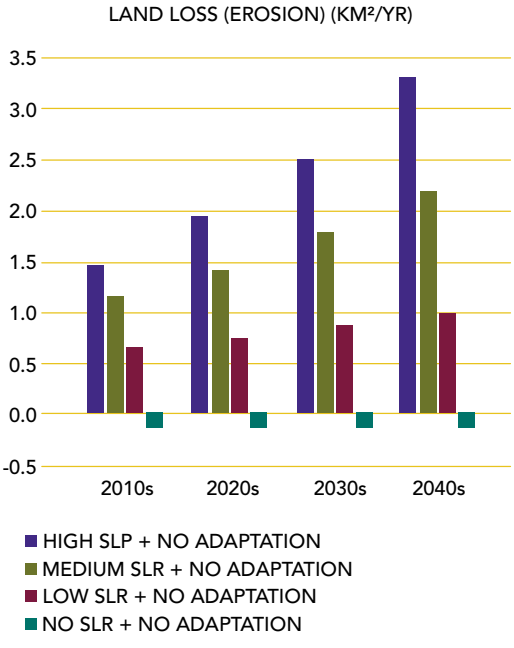


FIGURE 19 TOTAL ANNUAL LAND LOSS (EROSION) DUE TO SEA LEVEL RISE FROM 2010 TO 2050 IN MOZAMBIQUE FOR THE HIGH, MEDIUM, LOW, AND NO SLR SCENARIOS, WITH ADAPTATION MEASURES EMPLOYED

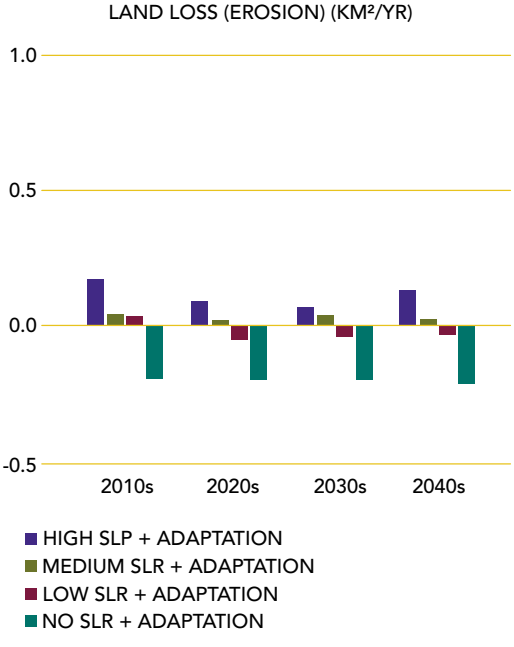


FIGURE 20 TOTAL ANNUAL LAND LOSS (SUBMERGENCE) DUE TO SEA LEVEL RISE FROM 2010 TO 2050 IN MOZAMBIQUE FOR THE HIGH, MEDIUM, LOW, AND NO SLR SCENARIOS, WITH NO ADAPTATION MEASURES EMPLOYED

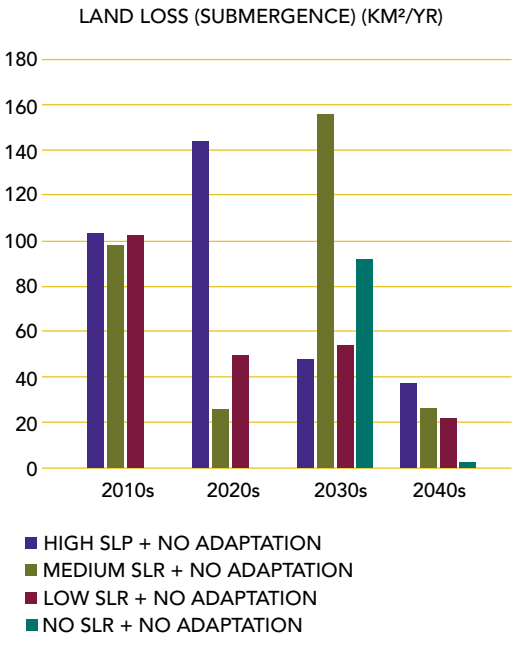
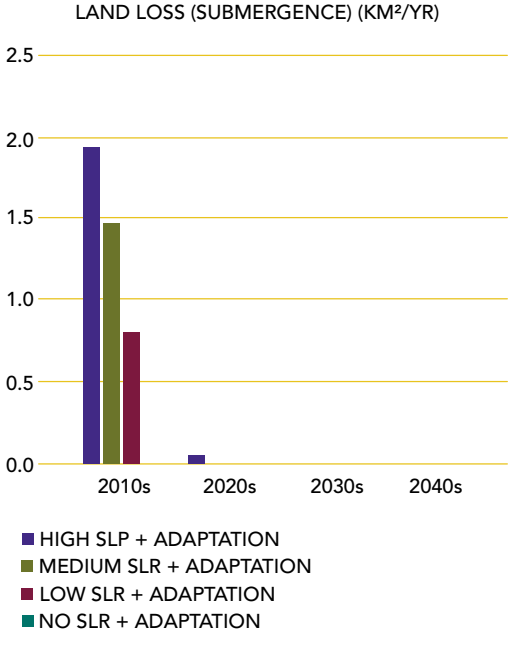


FIGURE 21 TOTAL ANNUAL LAND LOSS (SUBMERGENCE) DUE TO SEA LEVEL RISE FROM 2010 TO 2050 IN MOZAMBIQUE FOR THE HIGH, MEDIUM, LOW, AND NO SLR SCENARIOS, WITH ADAPTATION MEASURES EMPLOYED



migrants will be forced to leave their dwellings due to flooding and land area lost to erosion (Figure 24). This number grows to 916,000 displaced persons by the 2040s. These migrants are distributed as follows: 52 percent in Zambezia, 23 percent in Nampula, and 16 percent in Sofala provinces. Maputo, Inhambane, and Cabo Delgado provinces collectively account for the remaining 8 percent of damages.

However, considering adaptation measures in terms of protection via dikes and nourishment, the cumulative number of people forced to migrate could be dramatically reduced by a factor of 30 to about 3,000 (in the 2010s) and by a factor of 140 to 7,000 (in the 2040s) for the high SLR scenario, and down to effectively no migrants under a no sea-level rise scenario (Figure 25).

Total residual damage costs. The total residual damage costs are estimated on four components: (1) land loss costs, (2) forced migration costs, (3) sea flood costs, and (4) river flood costs. The total damage costs under different sea level rise scenarios and for the two adaptation modes considered are shown in Figures 26 and 27. These damage costs significantly increase with time.

Without adaptation and assuming future population growth, the total damage costs with sea level rise are estimated to range between $8.9 and $11.2 million per year in the 2010s across the range of sea level rise scenarios considered. In the 2040s, the damage costs range between $31.6 and $87.0 million per year (Figure 26). For the reference scenario of no climate-induced sea level rise considered with future population growth, the damage costs are estimated at $6.6 million per year in the 2010s, rising to $25.7 million per year in the 2040s (Figure 26). These show that about 70 percent (in the 2040s) of these total damage costs could occur even without climate change.

However, the damage cost is considerably reduced when adaptation measures in the form of

nourishment and dike construction and upgrades are considered. For instance, for the high sea level rise scenario with population growth, the total damage cost is reduced by a factor of 2 to $6 million per year in the 2010s, and by a factor of about 4 to $24 million per year in the 2040s (Figure 27). Even further reduction of these potential damage costs can be achieved by controlling future population growth and hence development as shown in Figure 28, in which for the high sea level rise scenario the costs are reduced by a factor of 3 to $3.9 million per year in the 2010s, and by a factor of 9 to $9.9 million per year in the 2040s.

Considering the distribution of the total damage costs across the coastal provinces, it is estimated that in the 2010s approximately 45 percent (about $5 million per year) is in Sofala, 30 percent (about $3.3 million per year) in Zambezia, and 12 percent (about $1.3 million per year) in Nampula provinces.

Adaptation costs. The protection options considered are (1) dike construction and upgrade, including operation and maintenance, (2) nourishment, and (3) port upgrade. They assume a proactive response to sea level rise that is anticipating future risks up to 50 years. The component costs of adaptation options are made up of the following: (a) annual sea dike costs (sea dike capital costs and maintenance and operation costs), (b) annual river dike costs (river dike capital costs and maintenance and operation costs), (c) annual beach/shore nourishment costs, and, (d) total port upgrade costs by 2050. These component costs are presented in detail in Annex VI, but overall the adaptation costs presented in Figure 28 are dominated by the first component—that is, sea dike capital and maintenance costs, which make up at least 75 percent of the total adaptation costs in all scenarios. Beach nourishment costs also make up a significant component of total adaptation costs, followed by port upgrade and river dike costs.

FIGURE 22 CUMULATIVE FORCED MIGRATION SINCE 2000 DUE TO SEA LEVEL RISE IN MOZAMBIQUE FOR THE HIGH, MEDIUM, LOW, AND NO SLR SCENARIOS, WITH NO ADAPTATION MEASURES EMPLOYED

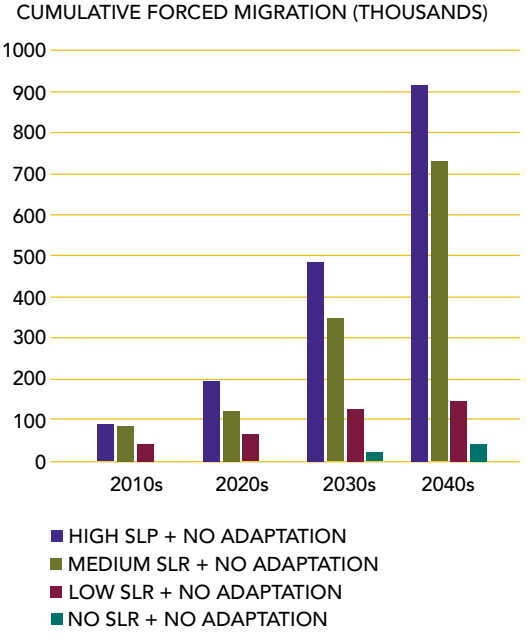


FIGURE 23 CUMULATIVE FORCED MIGRATION SINCE 2000 DUE TO SEA LEVEL RISE IN MOZAMBIQUE FOR THE HIGH, MEDIUM, LOW, AND NO SLR SCENARIOS, WITH ADAPTATION MEASURES EMPLOYED

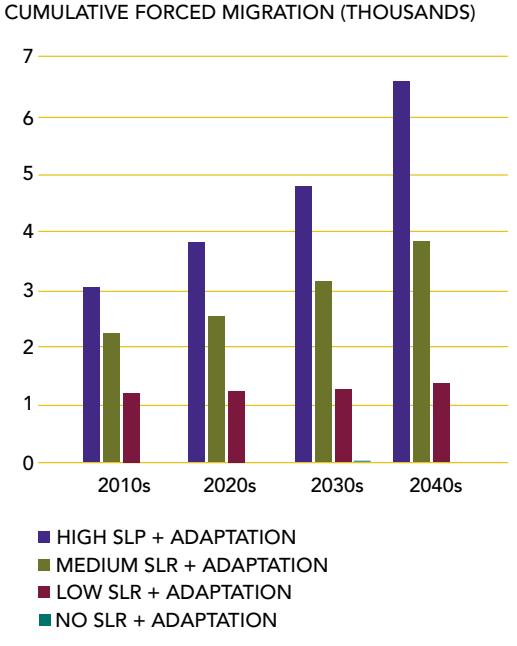


FIGURE 24 TOTAL RESIDUAL DAMAGE COSTS DUE TO SEA LEVEL RISE FROM 2010 TO 2050 IN MOZAMBIQUE FOR THE HIGH, MEDIUM, LOW, AND NO SLR SCENARIOS, WITH NO ADAPTATION MEASURES EMPLOYED

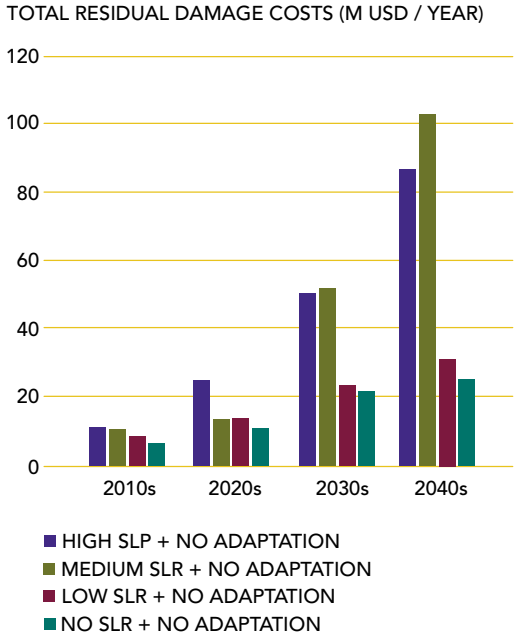
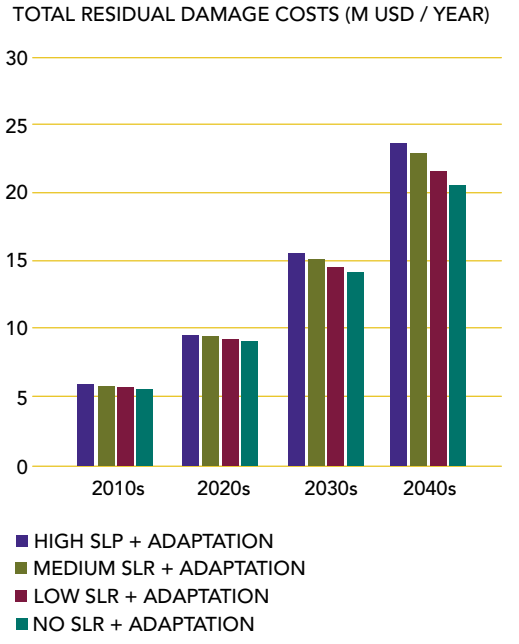


FIGURE 25 TOTAL RESIDUAL DAMAGE COSTS DUE TO SEA LEVEL RISE FROM 2010 TO 2050 IN MOZAMBIQUE FOR THE HIGH, MEDIUM, LOW, AND NO SLR SCENARIOS, WITH ADAPTATION MEASURES EMPLOYED

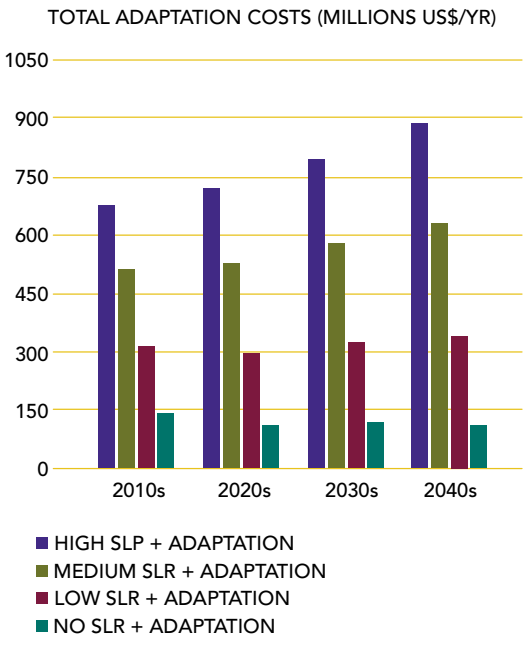


The protection cost with no global sea level rise (i.e. relative sea level rise due to subsidence only) is estimated at more than $112 million per year in the 2040s. Assuming global sea level rise, the total costs of adaptation for Mozambique are estimated to range between $316 and $682 million per year in the 2010s across all the range of the sea level rise scenarios considered. These costs could rise to between $342 and $893 million per year in the 2040s (Figure 26). These costs are distributed across the coastal provinces as follows: 22 percent in Inhambane, 20 percent in Nampula, 17 percent in Zambezia, 15 percent in Sofala, 15 percent in Cabo Delgado, 7 percent in Maputo, and 5 percent in Gaza provinces respectively. Note that the adaptation strategy we evaluated, a large-scale sea dike system for Mozambique focused on urban areas, would be more costly than the estimated benefits of $103 milllion that accrue through 2050, but as long-term capital assets this dike system would also yield long-term benefits in the form of avoided land-loss protection and avoided population displacement well beyond the 2050 scope of this analysis, and in fact through 2100, as SLR and storm surge risks accelerate. Those long-term benefits of adaptation, while outside the scope of the current study, are considered in the modeling of the choice of coastal adaptive strategies, and could reasonably be far in excess of the reported benefits through 2050.

POLICY OPTIONS

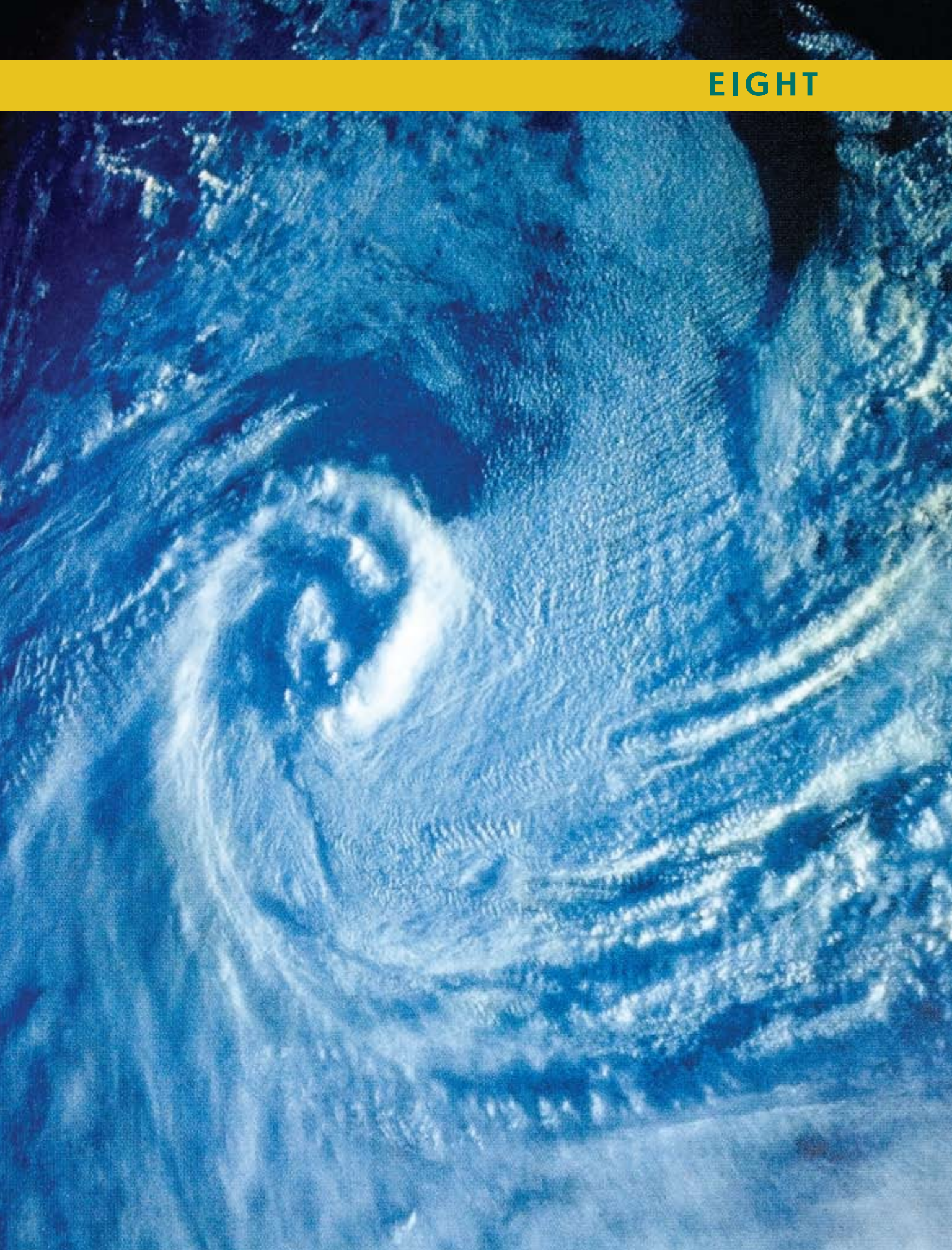
Since the baseline option, in this case, is to not implement or build anything that would reduce the costs of a cyclone or flood event, the costs in the baseline scenario will be the cost of either a flood or a cyclone event occurring, with the added probability of their occurrence. With this as a baseline, the project team feels that “hard”

FIGURE 26 TOTAL ADAPTATION COSTS DUE TO SEA LEVEL RISE FROM 2010 TO 2050 IN MOZAMBIQUE FOR THE HIGH, MEDIUM, LOW, AND NO SLR SCENARIOS



cyclone mitigation strategies (sea barriers, dikes, and so forth) are unlikely to be feasible from a risk management perspective; the probability of a cyclone striking any particular coastal zone is small and the costs of protecting large coastal zones will be exorbitant. With this low probability, it is economically and socially more effective to focus on soft measures when they become necessary. Thus, planning for a coastal event needs to be a priority at these early stages.

EIGHT



Cyclone Assessment

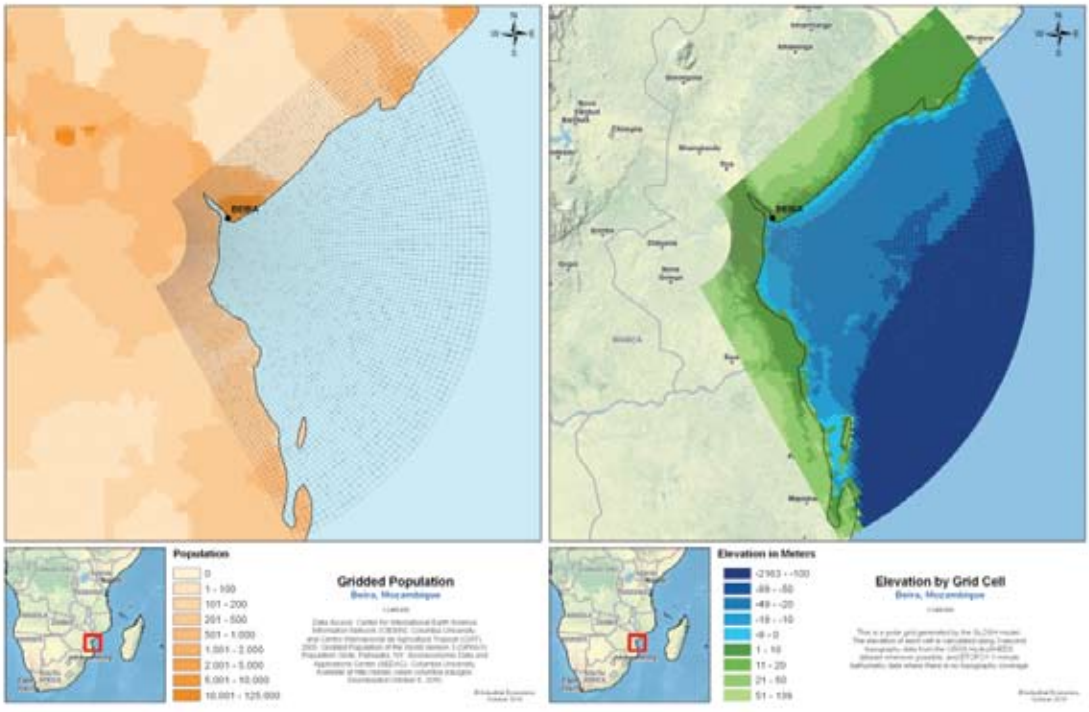
Background

The geographical location of the country, being in the preferred path of potentially deadly tropical cyclones, and the low-lying nature of the coastal zone have made Mozambique one of the most vulnerable countries to natural disasters (INGC 2009). This chapter presents an analysis of the economic and spatial effect of sea level rise, storm surge, and cyclone damage based on data from some sites in Mozambique.

Mozambique's coastal area is home for nearly two-thirds of its total population, with many more migrating toward the towns and villages in the coastal zone and a strong urbanizing trend. Figure 29 illustrates the confluence of population density and low-lying coastal land in Beira, one of the more vulnerable coastal cities.

Historically, Mozambique has been hit by about 13 intense tropical cyclones,, killing approximately 700 people and affecting nearly 3 million people during the period 1956–2008. These have caused significant negative social and economic consequences, mainly in the central and southern provinces such as Zambezia, Manica, Sofala, Maputo, Gaza, and Inhambane (INGC 2009). Table 20 presents a list of historic (1984–2008) cyclone events that have struck different parts of the coast of Mozambique. Although cyclones due to tropical depressions originating from the Indian Ocean normally affect the coastal regions of the country, the impacts sometimes extend to interior regions of the country as well. Figure 30 shows the extent of the cyclones and zones that are often affected. It has also been reported that devastating flooding incidents due to massive precipitation accompanied by tropical cyclones during the rainy season of 2000 affected approximately 4.5 million people and destroyed vast areas of agricultural land and other infrastructures throughout the central part of the country and along its coastline in the south (INGC 2009). This was reported as the worst event in the country in 50 years (Africa Recovery 2000). Earlier, in 1994, tropical cyclones had also affected about 2 million people along the coast in the central region of the country (INGC 2009). Records and historic trends in the period 1950–2008 show floods to have occurred on average every 1.6 years in the Limpopo and Pungue, 2.6 years in the Licungo and Umbeluzi, 2.8 years in the Maputo, and 4.8 years in the Incomati rivers (INGC 2009). Although it is difficult to associate these with climate change, extreme events like these clearly show the high vulnerability of the country to climate variability.

FIGURE 27 **BEIRA'S POPULOUS AREAS ARE AT LOW ELEVATION**



Flooding and tropical cyclones pose major threats to Mozambique. Previous studies have identified potentially vulnerable sites and impacts of climate change and sea level rise in Mozambique (Nicholls and Tol 2006; Boko et al. 2007; Brown et al. 2009; Dasgupta et al. 2009).

Dasgupta et al. (2009) did a comparative study on the impacts of sea level rise with intensified storm surges on developing countries globally in terms of impacts on land area, population, agriculture, urban extent, major cities, wetlands, and local economies, based on a 10 percent future intensification of storm surges compared to 1-in-100-year current storm surges. They found that Sub-Saharan African countries will suffer considerably from the impacts. The study estimated that Mozambique, along with three other countries (Madagascar, Nigeria, and Mauritania) account for more than half (9,600km^2) of the total increase in the region's storm surge zones. It is also estimated that Mozambique alone could experience an incremental impact loss of 3,268 km^2 of land area (over 40 percent of the coastal total), over 380,000 people (over 51 percent of the coastal total), over $140 million in GDP (over 55 percent of the coastal total), 291 km^2 of agricultural land (about 24 percent of the coastal total), 78 km2 of urban extent (over 55 percent of the coastal total), and 1,318 km2 of wetland area (over 45 percent of the coastal total).

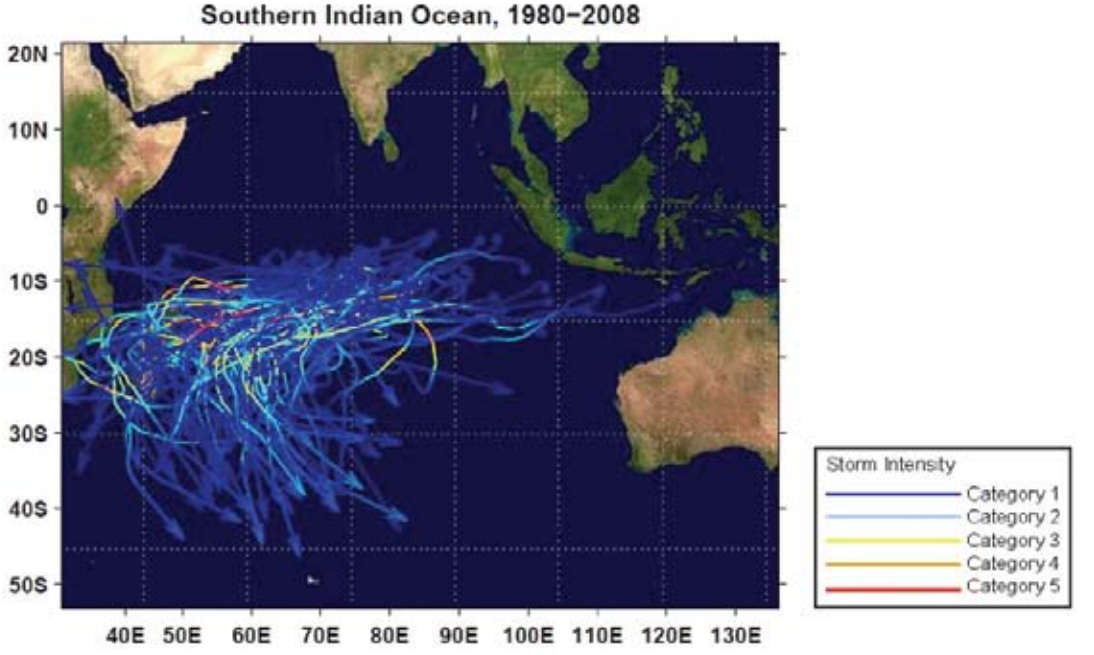
Moreover, according to Nicholls and Tol, (2006), extending the global vulnerability analysis of Hoozemans et al. (1993)—on the impacts of and responses to sea level rise with storm surges over the 21st Century—shows East Africa (including small island states and countries with extensive coastal deltas) as one of the problematic regions

TABLE 20 HISTORIC TROPICAL CYCLONES (CATEGORIES 1-4), STORMS (TS), AND DEPRESSIONS (TD) STRIKING THE COAST OF MOZAMBIQUE, 1984-2008

Date and Year	*Category and Name*	*Landfall Location*	*Strength*	*Recorded Wind Speed (km/hr)*
January 28, 1984	TS – Domoina	South	TS	102
January 9, 1986	TS	Central	TS	83
March 2, 1988	Category 2 – Filao	Central	Category 1	121
November 25, 1988	TS	North	TS	74
March 24, 1994	Category 4 – Nadia	North	Category 1	139
January 22, 1995	TS – Fodah	Central	TD	37
January 14, 1996	Category 4 – Bonita	Central	Category 1	130
March 2, 1997	Category 1 – Lisette	Central	TS	111
January 17, 1998	TS	North	TD	56
February 22, 2000	Category 4 – Eline	Central	Category 4	213
April 8, 2000	Category 4 – Hudah	Central	Category 1	148
March 2, 2003	Category 4 – Japhet	South	Category 2	167
November 13, 2003	TS – Atang	North	TD	46
January 1, 2004	TS – Delfina	Central	TS	93
February 22, 2007	Category 4 – Favio	South	Category 3	185
March 8, 2008	Category 4 – Jokwe	North	Category 3	180

Source: INGC 2009

FIGURE 28 MAP OF TROPICAL CYCLONE HISTORICAL EVENT TRACKS AND INTENSITY IN THE SOUTH INDIAN OCEAN, 1980 TO 2008 (SAFFIR-SIMPSON SCALE CATEGORIZATION)



that could experience major land loss. These findings demonstrate Mozambique's high exposure to impacts of tropical cyclones, the high vulnerability of long stretches of its coastline, and its low adaptive capacity due to the low wealth of the country. A recent study—based on human losses to climate-related extreme events as an indicator of vulnerability and the need for adaptation assistance—showed vulnerability may rise faster in the next two decades than in the three decades thereafter (Patt et al. 2010).

Modeling the Impact

The effects of climate change on cyclones can include changes in the intensity, frequency, and track of individual storms. Changes in temperature are a potentially important factor in altering storm patterns, but because cyclones are relatively rare events, differences in storm generation activity that might be experienced by 2050 are difficult to discern with current methods. In particular, because historical data on storm surges in Mozambique are sparse, extrapolation of trends in past storm activity is generally not useful.

Another important effect of climate change on the damage that could occur as a result of cyclones is the effect of sea level rise. Higher sea level provides storm surge with a higher "launch point" for the surge. This increases both the areal extent of surge, all else equal, and the depth of surge in areas already vulnerable to coastal storms. In addition, future sea level rise, while uncertain, is more reliably forecast to 2050 than future storm activity. In general, even if it was assumed that there is no change in storm activity as a result of climate change, the increase in sea level would make existing storms more damaging. The method focuses on this more reliable forecast, marginal effect of SLR on the extent and effective return period of these already damaging storms. Using a simulated data set for storms and surges, and three alternative forecasts for future SLR in Mozambique, this study estimates the effect of climate change induced SLR on surge risk from cyclones. The overall method involves four steps:

1. ***Simulate storm generation activity over the 21st century.*** The method generates 3,000 "seeded" events, and estimates which of these events become cyclones and where they might track.

2. ***Use wind fields as inputs to a storm surge model.*** The U.S. National Weather Service's SLOSH (which stands for Sea, Lake, and Overland Surge from Hurricanes) model is used to estimate how wind-driven water during a cyclone event generates a storm surge over coastal land.

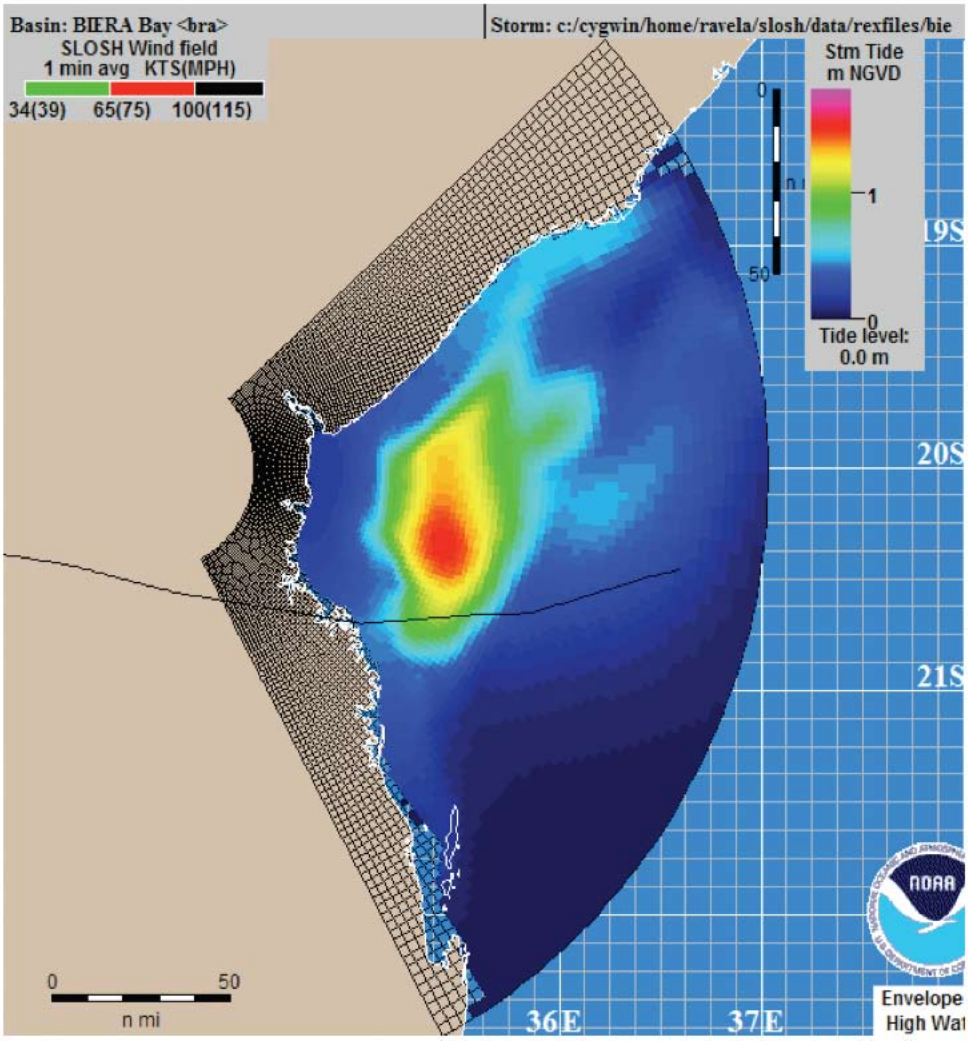
3. ***Generate a cumulative distribution function of storm surge height for selected key locations in the SLOSH domain.*** SLOSH results generated for each of the simulate events provide a "base case" of surge heights for future storms when there is no rise in sea level.

4. ***Estimate effect of SLR on return time of storms.*** Using the distribution of storm surge in the base case, the study estimates how SLR effectively increases the frequency of damaging storm surges for three scenarios of future SLR magnitude in 2050.

These steps are described briefly in the remainder of this section.

Storm generation. Existing event-set generation techniques begin with historical compilations of hurricane tracks and intensities, such as the so-called "best track" data compilations maintained by forecasting operations such as the National Oceanic and Atmospheric Administration's Tropical Prediction Center (TPC) and the U.S. Navy's Joint Typhoon Warning Center (JTWC). The records typically contain storm center positions every six hours, together with a

FIGURE 29 **SLOSH MODEL SETUP FOR BEIRA**



single intensity estimate (maximum wind speed and/or central pressure) every time period. Early risk assessments (Georgiou et al. 1983; Neumann 1987) fit standard distribution functions, such as log-normal or Weibull distributions, to the distribution of maximum intensities of all historical storms coming within a specified radius of the point of interest, and then, drawing randomly from such distributions, use standard models of the radial structure of storms, together with translation speed and landfall information, to estimate the maximum wind achieved at the point of interest. A clear drawback of this extrapolation of past history approach is that estimates of the frequency of high intensity events are sensitive to the shape of the tail of the assumed distribution, for which there is very little supporting data.

Many wind risk assessment methods rely directly on historical hurricane track data to estimate the frequency of storms passing close to points of interest, and must assume that the intensity evolution is independent of the particular track taken by the storm. Moreover, the relative intensity method

must fail when storms move into regions of small or vanishing potential intensity, as they often do in higher latitude areas, which have experienced infrequent but enormously destructive storms but for which the historical record is sparse.

As a step toward circumventing some of these difficulties, team member Dr. Kerry Emanuel has developed a technique for generating large numbers of synthetic hurricane tracks, along each of which we run a deterministic, coupled numerical model to simulate storm intensity. The method is based on randomly seeding a given ocean basin with weak tropical cyclone-like disturbances, and using an intensity model to determine which one of these develop to tropical storm strength or greater. A filter is applied to the track generator to select tracks coming within a specified distance of a point or region of interest (e.g. a city or county). In filtering the tracks, a record is kept of the number of discarded tracks and this is used to calculate the overall frequency of storms that pass the filter. In this work, two locations in Mozambique were selected as focal points, the city centers of port cities Maputo and Beira.

Once the tracks have been generated, a coupled hurricane intensity model is then run along each of the selected tracks to produce a history of storm maximum wind speed. This model uses monthly climatological atmospheric and upper ocean thermodynamic information, but is also affected by ambient environmental wind shear that varies randomly in time according to the procedure described in the previous paragraph. The coupled deterministic model produces a maximum wind speed and a radius of maximum winds, but the detailed aspects of the radial storm structure are not used, owing to the coarse spatial resolution of the model. Instead, we use an idealized radial wind profile, fitted to the numerical output, to estimate maximum winds at fixed points in space away from the storm center. The overall method has been described in several published sources (for example, Emanuel et al. 2008).

For each point of interest, the intensity model is run several thousand times to produce desired statistics such as wind speed exceedance probabilities for that point. Both of the synthetic track generation methods and the deterministic model are fast enough that it is practical to estimate exceedance probabilities to a comfortable level of statistical significance.

SLOSH model. SLOSH is a computerized model developed by the Federal Emergency Management Agency (FEMA), United States Army Corps of Engineers (USACE), and the National Weather Service (NWS) to estimate storm surge depths resulting from historical, hypothetical, or predicted hurricanes by taking into account a storm's pressure, size, forward speed, forecast track, wind speeds, and topographical data.

Graphical output from the model displays color-coded storm surge heights for a particular area in feet above the model's reference level, the National Geodetic Vertical Datum (NGVD), which is the elevation reference for most maps. Figure 31 illustrates one of the graphical outputs from SLOSH that shows storm surge above sea level at a simulated point in time when a storm generated by the above-described method is offshore of Beira. Wind field output from the storm generation step described above is one of the key inputs to the SLOSH model.

Storm surge generation calculations are applied to a specific locale's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads, and other physical features. These aspects of the SLOSH grid were coded by our analytic team and are among the most time-intensive components of the overall method.

The SLOSH model is generally accurate within plus/minus 20 percent variation. For example, if the model calculates a peak 10-foot storm surge for the event, users can expect the observed peak to range from 8 to 12 feet. The model accounts for

FIGURE 30 **STORM TRACKS**

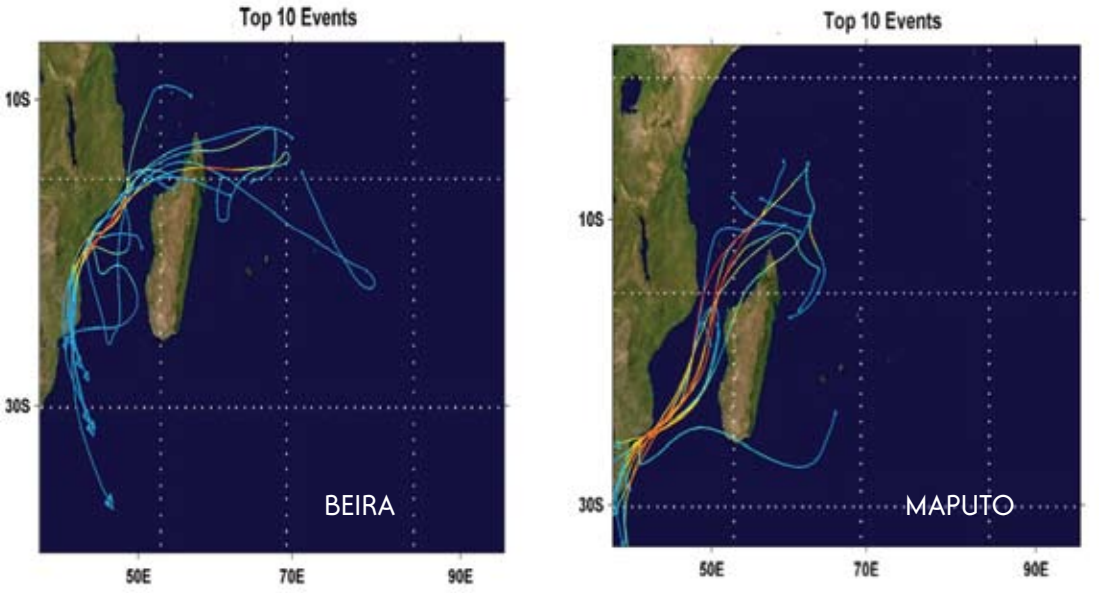
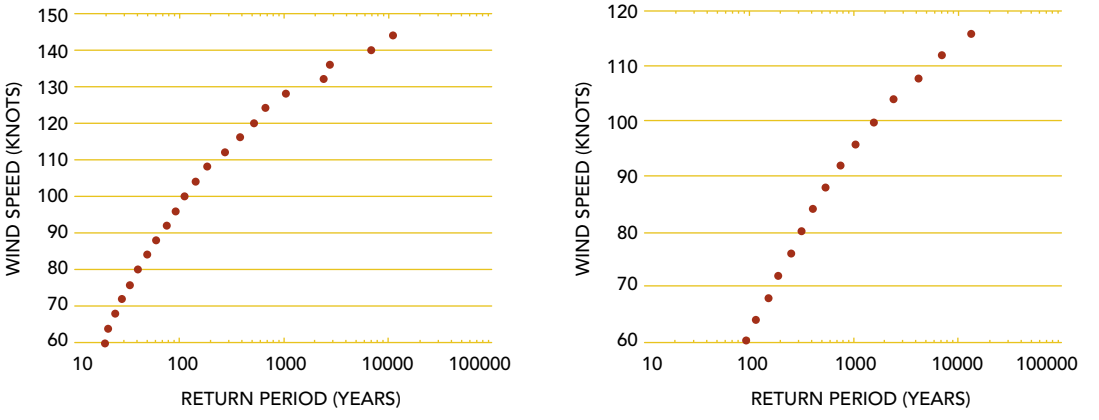


FIGURE 31 **RETURN TIMES**



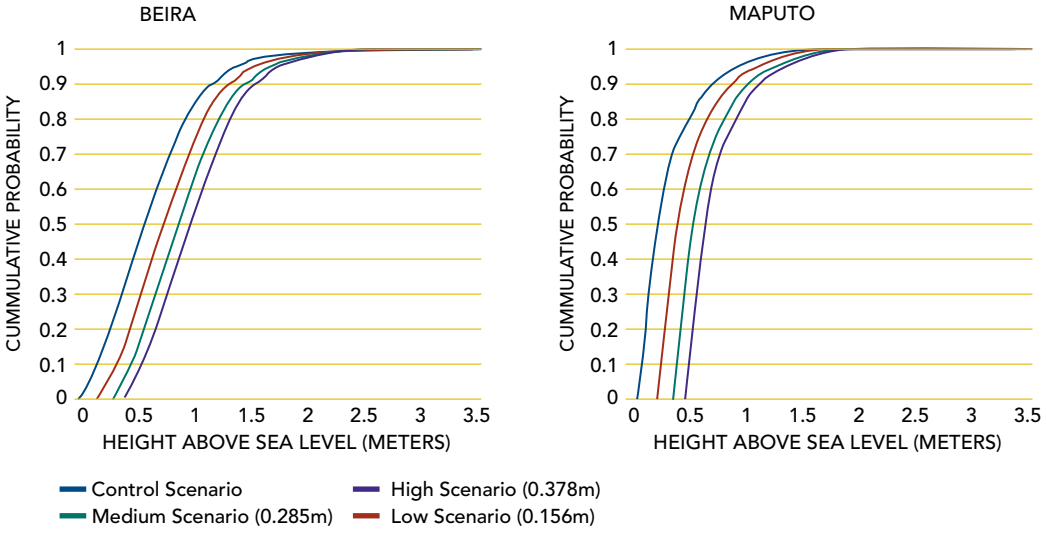
astronomical tides (which can add significantly to the water height) by specifying an initial tide level, but does not include rainfall amounts, river flow, or wind-driven waves (only wind-driven "stillwater" flood heights).

The point of a hurricane's landfall is crucial to determining which areas will be inundated by the storm surge. This information is also available from the storm generation step of the analysis, but the synthetic nature of those results, and the fact that it is a forecast, adds uncertainty to the landfall location. Where the precise landfall location is uncertain, the SLOSH model developers state that the SLOSH model is best used for defining the potential maximum surge for a location.

SLR OVERLAY AND EFFECT ON STORM RETURN TIMES

The base case (no SLR) storm surge results provide a probabilistic representation of the likelihood of

FIGURE32 **SLOSH-ESTIMATED STORM SURGE EXCEEDANCE CURVE, WITH AND WITHOUT SLR**



storm surge height at a particular point on the coast over a future period, in our case over the 21st century. This storm surge exceedance curve can then be modified to reflect the effects of sea level rise on surge height, and the effect of SLR on the effective return time can be identified. The modification of the exceedance curve is done for three future SLR scenarios through 2050, consistent with those scenarios used in the main SLR analysis.

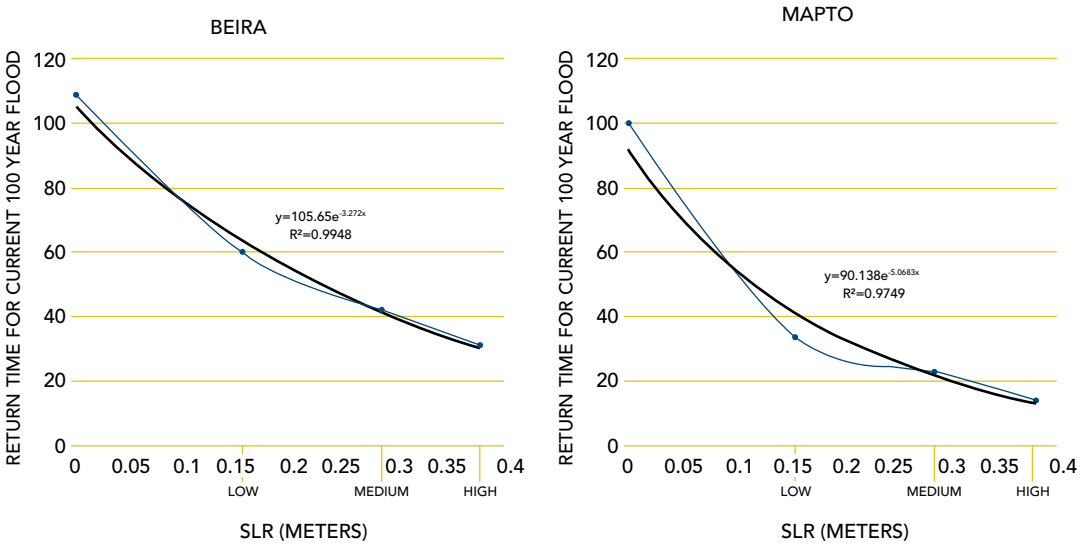
A function for the effect of SLR on effective return time is generated through the following procedure. First, the storm surge height for a particular "reference storm" in the base case data is identified– in the example results presented below, the no-SLR 100-year storm surge height was chosen as the reference. Then the modified exceedance curves for SLR scenarios were examined to determine the modified return period for that storm surge height under each of three SLR scenarios. Finally, a curve is estimated, using regression techniques, for the relationship of the return period with SLR magnitude. Typically this relationship is not linear but exponential in form.

Conclusion

The results of this four-step process are presented here. Figures 32 and 33 illustrate the results of the storm generation step for Beira and Maputo in two forms: (1) the tracks for the ten highest wind-speed storms at either Beira or Maputo; and (2) the exceedance curve for wind speeds. The tracks traced in Figure 32 also indicate storm intensity, with blue being the least intense and red being the most intense. Although the storm tracks illustrated in Figure 32 might suggest comparable risks in the two locations, the data in Figure 33 provide an interesting result, that wind risks in Beira are much higher than in Maputo. This difference is attributable to two factors. First, Maputo has higher latitude, so storms dissipate energy to a greater extent before they make landfall. Second, Maputo is more effectively "shielded" by the Madagascar land mass, which also tends to dissipate cyclone energy. As a result, the probability of intense wind events is much higher in Beira than in Maputo.

Wind risks correlate well with storm surge risks, as estimated by the SLOSH model. The exceedance

FIGURE 33 ESTIMATED CHANGE IN EFFECTIVE RETURN TIME FOR THE 100-YEAR STORM AS A RESULT OF SLR



curves for storm surge, with and without SLR, are shown in Figure 34. These results further support the conclusion that, while storms of high intensity may strike Maputo with significant frequency, the risks of intense storms in Beira are much greater. As noted in the figure, in Beira storm surges of over 1 meter are at the 90th percentile in the base case (meaning they are estimated to be a roughly 1-in-10-year event, see the dark blue line), but with the highest scenario of SLR (the red line) they are at the 60th percentile, which suggests they could become a roughly 1-in-2.5-year event. In Maputo, by contrast, a 1-meter storm surge is very rare in the base case, and becomes a 1-in-10-year event only along the highest SLR scenario.

Finally, Figure 35 provides the estimates of the changes in effective return time for the current 100-year storm surge event, as affected by the height of SLR in 2050. As shown, in Beira, the 100-year event in the base case can be expected to occur more frequently with SLR. Rather than every 100 years with no SLR, it can be expected to occur approximately every 60 years by 2050 under the low-SLR scenario, every 40 years under the medium-SLR scenario, and every 33 years under the high-SLR scenario. We see similar reductions in expected return periods for storms with other base case return periods as well.

The results in Maputo show similar, and even more dramatic, changes in the return period of the 1-in-100-year storm, with a reduction to a 1-in-20-year event along the medium-SLR scenario. As shown in Figure 34, however, the current 100-year storm surge in Maputo (about 1 meter) is much less than in Beira (where it is almost 2 meters). It is important to keep in mind that risk levels incorporate both frequency and severity of extreme events, with the former characterized in Figure 35 and the latter characterized in terms of the height of storm surge in Figure 34. Ultimately, the expected physical and dollar damages from storm surge require a third element: estimates of the vulnerability and value of Beira and Maputo's low-lying areas. We hope to explore those aspects of storm surge risk associated with climate change and SLR in future works.

NINE

Social Dimensions of Climate Change

Background

The social component adopted IPCC definitions of vulnerability as comprising physical exposure, socioeconomic sensitivity, and adaptive capacity components (including skill and asset bases, institutional "thickness," and degree of market integration)."

Methodology

The vulnerability assessment included a literature review, identification of select "hotspots" (representing both physically exposed and ally vulnerable areas), and fieldwork in 17 districts across eight provinces (including 45 focus group discussions, 18 institutional stakeholder interviews, and a survey of 137 households). The identification of adaptation options consisted of a series of two participatory scenario development (PSD) workshops at the local/regional level (Xai-Xai and Beira), and one at the national level (Maputo) in order to determine local stakeholders' development visions for the area, their assessment of livelihood and other impacts of climate change in the area, and preferred adaptation options for investment.

The investigation aimed to answer the following research questions:

- What factors make particular individuals, households, or subnational regions more vulnerable to the negative impacts of climate change?
- What are people's experiences of climate events to date and what adaptation measures have they taken (both autonomous and planned)?
- How do different groups and local and national representatives judge various adaptation options and pathways?
- How do identified adaptation priorities align with existing development strategies and policy emphases?

Preparation for fieldwork included a first phase of reviewing existing data and literature to identify "sociogeographic zones" for the country (i.e., agro-ecological zones with a social and hazard overlay).

Six zones in Mozambique were identified based on secondary literature and poverty and disasters data on vulnerable populations. These were:

- **Coastal urban areas**, most importantly Maputo and Beira. This zone is marked by highly differential vulnerability across income

FIGURE 34 MAP OF STUDY SITES IN MOZAMBIQUE

groups, with large peri-urban areas vulnerable to flooding from both rivers and the ocean.

- **Non-urban coastal strip.** This zone is marked by high vulnerability to coastal flooding and storm surges from tropical cyclones, as well as threats of erosion. It is relatively food secure, with low rates of poverty.
- **Limpopo River valley districts upstream of Xai-Xai.** This zone is unique in being highly exposed to two very different threats: river flooding and drought. It has relatively high population density, and thus high numbers of poor people. Further, this region has been studied extensively and significant baseline data are available.

- **Other flood-prone river valleys** (less susceptible to droughts). These zones, in particular in the Buzi and Zambezi river valleys, are highly susceptible to floods (especially those caused by tropical cyclones), but less so to droughts. The Buzi River region has also been extensively studied as part of German-funded activities, so there is no shortage of baseline data.

- **Drought-prone inland areas** (especially in the South). These areas are highly susceptible to drought: adequate rainfall to support agriculture is an exception rather than the rule. Inhabitants of this region are often dependent on remittances for survival. Population densities are low.

- **Inland areas of higher agricultural productivity,** including the highly productive and populated areas in Zambézia. These areas are perhaps the least vulnerable in Mozambique, facing adequate rainfall most years, and no extreme risks from flooding or tropical cyclones. They are somewhat heterogeneous in terms of poverty rates and food security. The highly productive regions stand out for their high population density and relatively low vulnerability.

Following zone identification, a further vulnerability mapping exercise was conducted wherein the team delineated the zones in terms of districts, and identified districts constituting risk hotspots (by mapping different levels of risk, overlaid with population figures). Figure 36 shows the locations of the study sites selected, which by design covered multiple administrative posts.

FIELDWORK

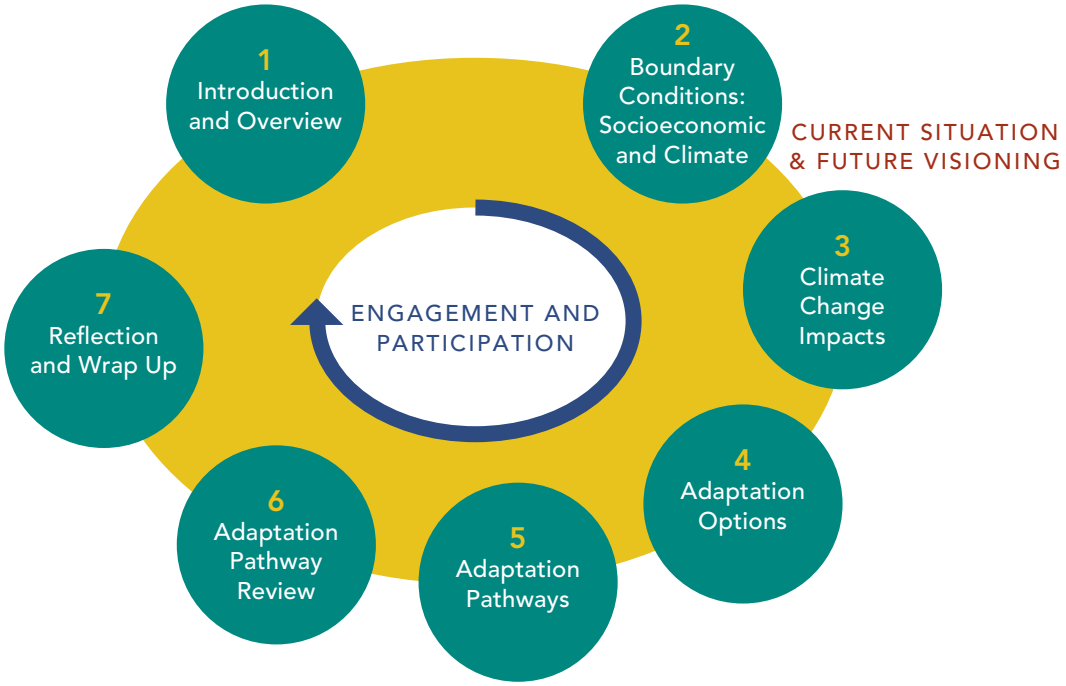
Fieldwork was undertaken at sites shown in Figure 36, using qualitative and quantitative tools. The EACC social component team conducted participatory rural appraisal (PRA) exercises as well as key informant interviews with local government officials, NGOs, and traditional leaders. PRA examines village history, creates impact diagrams of climate events and community risk mapping, and involves wealth-ranking exercises and focus group discussions of men, women, and different age groups. Household interviews were also carried out: ten 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.

Results were synthesized to identify livelihood strategies for different income tiers and zones, including adaptation practices in relation to household and area assets, determinants and household/local criteria for adopting particular adaptation strategies, and preferred adaptation and development investments. In parallel, the PSD workshop process identified local development visions, expected impacts of climate change on these visions, and preferred adaptation options and combinations of options over time. Results regarding adaptation practices and preferences were shared to identify effective investments and program approaches at the national level.

PARTICIPATORY SCENARIO DEVELOPMENT PROCESS

The national PSD workshop began with presentations by local experts to characterize current climate and projections for the coming decades as inputs to participants creating visions of a "preferred future" for 2050. After this, participants considered the specific impacts of climate change on their future vision, and then identified adaptation options necessary to reach it (Figure 37). Finally, participants created an adaptation pathway showing diverse priorities for adaptation actions over time. They also identified prerequisites, synergies and trade-offs among their adaptation options and with other known development

FIGURE 35 **PSD WORKSHOP STEPS**



priorities. The PSD workshops drew from downscaled climate and poverty scenarios offered as graphic "visualizations" used in handouts, presentations, and posters. They also helped identify locally relevant paths of autonomous and planned adaptation in the context of development choices and informed local actors on potential tradeoffs and consequences of adaptation actions.

The process allowed for a joint assessment of required interventions and distribution of benefits, and also pointed to key politico-economic issues in adaptation planning and implementation. Local-level PSD workshops followed similar approaches, with some modification of materials and exercises depending on the audience. The PSD approach was particularly effective in identifying multicausal linkages and drivers of vulnerability in climate-affected regions. The PSD component of the study had a capacity-building emphasis from the start, including participation of national teams in workshop design and in training on development of visualizations and scenarios (ESSA and IISD 2009).

Climate impacts. Results suggest that rainfed agriculture takes the hardest direct hit from climate hazards. Across the field and workshop sites, participants mentioned climate impacts affecting a variety of livelihood activities, including agriculture, fishing, and forestry and charcoal production. In all cases, however, the most frequent and severe impacts were listed for rainfed agriculture, due to the severity of droughts. As a result, irrigation infrastructure was a key preferred adaptation investment.

As identified by the team, impacts of climate hazards include water scarcity, reduced crop productivity, food insecurity, and migration. Respondents at field sites reported decreases in rainfall and groundwater availability. Floods were identified as causing damage to infrastructure, settlements, and household assets, and also contributing to

disease outbreaks. Soil degradation and desertification were understood by respondents to result in increased pressure on alternative livelihood sources (e.g., farmers joined the fisheries sector). Finally, wildfire was understood to result in loss of vegetation as well as loss of timber for shelter and fuel.

Subsistence farmers and the economically and socially marginalized were identified as the most vulnerable groups. Economically and socially marginalized individuals include the elderly, orphans, widows and female heads of households, and the physically handicapped. Most communities lack support networks for these people, either formally through the government or informally through well-functioning social networks. Formal social protection offerings were reported to be less than $4 per month, per person, deemed wholly inadequate to withstand the impacts of extreme weather events over time.

Adaptation Options

The survey investigated households' adaptation coping practices in the past. Two open-ended questions asked respondents to list their primary coping strategies for a range of climatic hazards. About 25 percent of surveyed households did not identify any ex ante coping strategy for managing drought and 45 percent of households did nothing in preparation for floods or cyclones. In addition, during or after these climate events, the majority of respondents reported to have not taken action *ex-post*—about 55 percent, 70 percent, and 75 percent of respondents did nothing to manage droughts, floods and cyclones, respectively. When asked what they would do if the climate hazards in their regions became more severe, the majority of responses (70 out of 120) indicated that they would do nothing differently, suggesting lack of information or sufficient assets to adapt (see Annex 1).

To prepare for drought, about a quarter of the people did not identify any ex ante coping strategy in which they engaged. Since almost all respondents listed drought as a major concern, this could simply indicate that they did not see options available. Among strategies, the most common were planting crops in the wetter (and sometimes irrigated) lowlands, planting shorter season (i.e. more drought-tolerant) crop varieties, and improving their buildings. The latter could include the construction of granaries in order to store more surplus harvest. An additional ten different strategies were mentioned, but in each case only by one or two respondents: these constitute "other." These included preparing for fires, hunting rats, engaging in more weeding, and engaging in religious practices. During and after the droughts, the three most common strategies were to plant any new crops in the wetter lowlands, manage forest resources carefully in order to obtain income from those forests as a safety net, and manage past surplus harvests and cash receipts carefully. The majority of respondents, however, suggested that they did nothing.

A larger fraction of respondents do not prepare for floods, likely because many of them do not face a flood risk in their district. Of those who do prepare, the most common preparations were to plant in the highlands, to fortify their houses, and to plant short-season varieties. In the floodplain, these varieties are more likely to be harvested before the flood hits. During and after a flood, most people answered there was nothing they could do. The only common strategy listed was to plant in the highlands, while a number of other strategies—like building canoes, or keeping belongings in safe places—enlisted the support of only one or two respondents.

The pattern of preparation for cyclones was very similar to that for floods, albeit with fewer additional strategies covered by the "other" category, and more people listing the planting of shorter season crop varieties to improve the chances of gathering a rainy season harvest before the cyclone. Over three-quarters of respondents

indicated there was nothing they could do during and immediately after the cyclone. The two most frequently listed strategies were to plant short-season crops in the highlands and gather wild fruits to make up for the lack of a harvest.

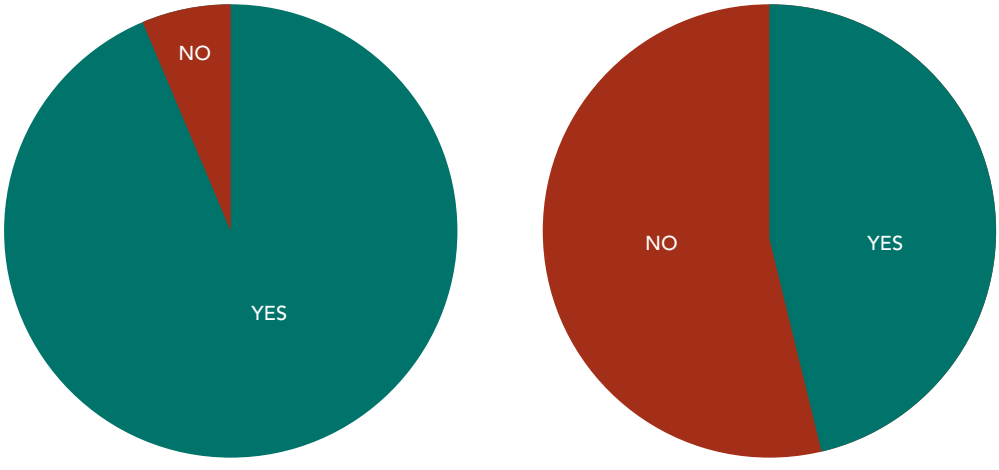
The survey asked people what, if anything, they would do if the climate hazards in their regions were to become significantly more severe. The most common answers were:

- Nothing (70 respondents)
- Move to a safer or more productive area (23 respondents)
- Seek help from others (9 respondents)
- Raise and sell animals (7 respondents)
- Improve the durability of the house (6 respondents)
- Practice drought-resistant cultivation (5 respondents)

Preferred options. The PSD workshops elicited participants' considered analyses of preferred adaptation options. Preferred adaptation options identified included a mix of hard and soft options. Key hard adaptation options were centered on infrastructure investments, including road construction, dams, flood protection and drainage investments, small-scale water storage, silos, housing, and coastal protection. Identified soft measures included the development of early warning systems, improvement of local and regional planning capacity, and promotion of participatory approaches to natural resource management. The early warning system option is particularly striking given fieldwork results in Figure 38 below, which show how few people reported receiving early warning announcements during disasters.

In looking at adaptation pathways, workshop participants examined the synergies and tradeoffs among different adaptation options identified and the extent to which particular options met the needs and interests of poor and vulnerable groups. Key synergies identified among adaptation options included (a) mainstreaming climate change in decentralized approaches to sector planning; (b) strengthening institutional capacity and the use of risk management committees;

FIGURE 36 PROPORTION AFFECTED BY CLIMATIC HAZARDS AND RECEIVING EARLY WARNING



Note: The circle on the left represents the relative numbers of respondents saying that they have been affected by a climatic hazard. The right-hand circle represents the numbers who reported receiving early warning of those hazards. n = 117.

and (c) undertaking simultaneous investments in smallholder agricultural support, including extension and credit services, soil conservation, and water infrastructure investments. Sample tradeoffs identified among the adaptation options included ecosystem health impacts of dike construction; possible forced resettlement caused by dam construction; and the potential for reduced access to agricultural or pasturelands given over to reforestation projects. On the latter, a design modification was proposed that would help ensure tenure access for smallholders and those engaged in livestock production.

Overall, the PSD results indicated broad support for investment in the hard infrastructure adaptation options suggested by the economic analyses (i.e., road infrastructure, flood management structures, and irrigation), with the caveat that these need to be complemented by soft adaptation measures, including early warning systems and social protection such as formal safety nets, food price monitoring, and use of local storage options (such as silos) to improve food security. Key soft adaptation options identified also included training and extension support for non-farm livelihoods diversification and other forms of capacity building, such as rural extension services, improved natural resource management skills, and support to local institutions.

In the PSD workshops, soft, centralized adaptation options—such as improvements to existing government programs and practices—were viewed by local populations as important in building resilience. Participants also prioritized improved access to credit, better health care and social services, as well as programs that enhance the capacity of community associations to manage local resources effectively and support livelihood diversification (Table 21). Integrating rural areas into markets—including a great deal of attention to improving transportation infrastructure and diversification away from agriculture—will also be important activities, even if costly and difficult in rural areas. Livelihood diversification is patently not just about human capital investments

TABLE 21 OVERVIEW OF SELECT ADAPTATION OPTIONS IDENTIFIED IN MOZAMBIQUE

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

Note: The items appearing in plain text directly respond to anticipated climate hazards, while those in italics respond to the need for improved adaptive capacity.

with individuals, but also broader economic shifts, including integrating rural areas into markets and improving transport infrastructure.

Discussions also revealed that policies and institutions should enforce sustainable resource management. In many cases, participants in the discussions and workshops suggested that the harvesting of forest resources—such as wood for charcoal production—as well as fishing were important income-generating activities, which often helped to buffer shocks to agricultural productivity. But these activities are suffering due to deforestation and overfishing. Technical assistance concerning better land management, such as conservation agriculture, is also needed. This can include enforcing existing laws and government policies as well as improving the capacity of community associations to manage local resources effectively.

Social protection, particularly given the expected increase in extreme events, is a key need of the poorest persons in the country. Land use planning and policy and institutional support to sustainable natural resource management were also highlighted as priority areas. Finally, education and training to support livelihoods diversification over time remains crucial. In sum, results from the social component in Mozambique were remarkably consistent with the economic analyses from the other sectors and with adaptation priorities identified in the Mozambique NAPA (National Adaptation Programme of Action).

POLICY OPTIONS

Complementary investments in both hard and soft adaptation options are needed to ensure effective use of infrastructure and to meet the needs of the poorest. Adaptation investments in hard infrastructure without complementary investments in policy, service, and extension support will not operate in an optimally efficient manner.

It is important to foster a shift from support for coping strategies for climate shocks at the household level to transformative adaptation strategies that can increase resilience at both the household and area levels. The poorest are particularly vulnerable to climate shocks as they do not have stored assets upon which to rely during times of stress. A pro-poor approach to climate change adaptation would not only look at reducing shocks to households but also engage in transformative adaptation strategies that increase resilience and overcome past biases in subnational investment.

Geographically targeted, multisectoral interventions are needed to reduce the "development deficit" of vulnerable regions. Poverty and sensitivity to climate-related hazards are increasingly concentrated in particular regions within countries. In many cases, poor communities (such as recent urban in-migrants) are relegated to the most marginal areas of the city. Adaptation policies at the national level must take into account the diverse socioecological settings within the country, and devise area-specific interventions that can support the livelihoods of these vulnerable populations. Multisectoral interventions that aim to improve area resilience through reducing the development gap are particularly effective forms of investment, including programming in education, social protection and health, roads, market services, natural resource management, and skills training.

Information-sharing and training are needed to improve adaptive capacity for responding to climate hazards. Basic knowledge about climate change and expected trends is lacking at the local level. More specific, actionable information, including real-time weather forecasts—effective early warnings—are necessary to mitigate losses to floods and cyclones. In some cases, populations also need information about when upstream dam operators will be releasing water, so they can prepare for the local flooding that is caused. Adaptation, even when undertaken by households themselves, requires support from the state and

other actors, in terms of extension, training, or greater investment in improving area characteristics such as road connectivity or weather station monitoring.

Enabling policies require attention alongside specific sectoral interventions (e.g. land policy, decentralization, natural resource management, technology). Climate change adaptation portfolios within countries cannot only be stand-alone investments in infrastructure and services, but also require attention to support for enabling environmental policies and mainstreaming of climate concerns in specific sectoral frameworks.

Conclusion

Key policy messages derived from the social component are the following. First, there is a need for both hard and soft adaptation measures in order to ensure effective utilization of infrastructure and investments that meet the needs of the poorest. Second, stakeholder consultations supported the NAPA priorities of early warning systems, smallholder agriculture support, coastal protection, and water resources management, with an additional focus on investments needed in social protection and training. Third, the social component results supported those arising from the CGE model on the importance of human capital accumulation and flexible public and private institutions. Fourth, careful attention to the policy environment and regulatory regimes is required, including such areas as land use planning and zoning, social policy (e.g., support for migrants, drought-prone areas, and those forcibly displaced by extreme events). Fifth, study findings pointed to the importance of good governance and decentralized approaches to adaptation planning and support in Mozambique. Finally, results suggest that use of an "adaptive management" approach can help ensure continuous course correction and fine-tuning in a context of model uncertainty.

TEN

CGE Model Description

The dynamic CGE model complements the sector models by providing an evaluation 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 and considers potential adaptation measures in four sectors (hydropower, agriculture, transportation, and coastal infrastructure).

Model Description

Dynamic CGE models are often applied to issues of trade strategy, income distribution, and structural change in developing countries. They have features that make 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, their structural nature permits consideration of new phenomena, such as climate change. Thirdly, they ensure that all economy-wide constraints are respected. This is a critical discipline that should be imposed on long-run projections, such as those necessary for climate change. For instance, suppose climate change worsens the conditions that are necessary for growing food, forcing Mozambique 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 Mozambique CGE model contains 56 activities/commodities, including 24 agricultural and seven food-processing sectors (Thurlow 2008). Five factors of production are identified: three types of labor (unskilled, semi-skilled and skilled), agricultural land, and capital. The agricultural activities and land are distributed across the three regions of Mozambique (North, Center, and South). This detail captures Mozambique's economic structure and influences model results. A more complete description of the model can be found in Annex VI.

Climate change is expected to influence the growth and development of Mozambique through a series of mechanisms. Five principal mechanisms that are likely to alter growth and development are considered. These mechanisms are:

1. ***Productivity changes in dry-land agriculture.*** The influence of climate variables on agricultural productivity will be obtained from the crop models (CLI-CROP). Specifically, the CGE model determines how much land, labor, capital, and intermediate inputs are allocated to a crop as well as an estimated level of production under the assumption of normal climatic conditions. CLI-CROP determines deviations from this level as a consequence of realized climate. The resource allocations determined in the CGE and the deviations obtained from CLI-CROP jointly determine the level of production.

2. ***Water availability.*** There are three principal sources of demand for water: municipal needs, hydroelectric power, and irrigation. The river basin models described earlier will track water availability under alternative climates. Available water will be allocated according to a hierarchy of use. First, the municipal demand will be satisfied. Second, flow will be used to generate hydroelectric power from available dams. Third, flow will be used to irrigate crops. The river basin models will pass their results to hydroelectric power planning models, which estimate power output given available flow. In addition, these models can assess the implications of construction of more or fewer dams for electricity output and for flow further downstream. The CGE model will directly incorporate the fluctuations in hydropower production due to variation in river flow. River flow will only affect agricultural production if the irrigated area available for planting is greater than the maximum potential area that could be irrigated given water availability constraints.

3. ***Infrastructure maintenance and upkeep.*** Changes in temperature and precipitation can influence maintenance requirements for infrastructure, particularly roads. Rainfall or temperature realizations outside of the band of design tolerances are likely to require more frequent or more expensive maintenance costs. In the CGE model, these greater maintenance requirements result in either less rapid expansion in the road network for a given level of spending on roads or an actual shrinkage in the network if the resources necessary to maintain the network are unavailable.

4. ***Extreme events.*** Rare but costly events may become more frequent under climate change. For example, most models predict that the probability of cyclone strikes on the Mozambican coast is likely to rise. In addition, the probability of severe flooding may rise due to greater intensity of rainfall.

5. ***Rising sea levels.*** Rising sea levels caused by climate change will significantly increase the risk of coastal impacts, particularly in low-lying and subsiding areas. Long-term effects of rising sea levels include increased shoreline erosion, saltwater intrusion, and loss of coastal crop lands. Immediate effects also include damages to capital assets situated along coastlines, effectively leading to higher rates of capital depreciation as a result of coastal inundation and storm surges.

Other potential impacts are recognized but not explicitly considered. For example, climate change may alter the incidence of malaria within Mozambique, with potential implications for the pattern of economic activity and rates of economic growth. Health-related implications are not considered at this stage.

It is important to highlight that climate change is projected to take place over the course of the

next century. This effort will only consider the implications of climate change up to 2050 even though climate change is expected to be most severe toward the end of the century. Nevertheless, the relatively long time frame considered (40 years into the future) means that dynamic processes are important. Economic development is in many ways about the accumulation of factors of production such as physical capital, human capital, and technology. These factors, combined with the necessary institutional frameworks to make them productive, determine the material wellbeing of a country.

It is therefore important to note that the dynamic CGE model captures these processes. 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 fewer infrastructures 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.

BASELINE

In order to estimate costs imposed by global warming on Mozambique, it is necessary to specify a baseline path that reflects development trends, policies, and priorities in the absence of climate change. The objective of specifying such a path is not to forecast the future in a world without climate change. Rather, the baseline path provides a reasonable trajectory for growth and structural change of the Mozambican economy over about 50 years (the period 2003–50 is modeled) that can be used as a basis for comparison. While the impacts of climate change are many, the analytical objective is to isolate these impacts within the context of a market economy.

The CGE model provides the simulation laboratory that allows us to estimate the economic impacts of climate change. Once a baseline path has been determined, 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. For example, if climate change is responsible for a precipitous decline in the productivity of crop A but no decline or maybe even an increase in the productivity of crop B, then, holding everything else constant, farmers could be expected to plant more of crop B and less of crop A. This is labeled "endogenous adaptation." In this simplified example, external choices and factors—such as underlying rates of productivity growth, world prices, foreign aid inflows, tax rates, and government investment rules—remain constant (i.e., no exogenous adaptation). By comparing results from the baseline path with those of the revised path, the CGE model provides an estimate of the economywide impact of climate change under the assumption that climate change only impacts dry-land agricultural productivity and that all other factors influencing the growth path remain constant.

This example is not particularly realistic in that climate change will not uniquely impact dry-land agriculture and one expects that some external policies, such as government policies, are likely to be altered in response to a changing climate. However, the example does illustrate the utility of the CGE model as a simulation laboratory and the role of the baseline path.

The CGE model permits us to impose specific aspects of climate change within a coherent economic framework. The baseline path provides the frame of reference for evaluating the changes imposed. In this sense, the principal goal in developing a baseline is to present a credible counterfactual. Because comparisons are made with specific changes imposed and everything else held constant, the interesting results—the differences in outcomes between the experiment and the baseline—are likely to be relatively consistent across a fairly broad family of baseline paths. In sum, we do not, in most cases, expect enormous sensitivity of results to the specification of the baseline path.

Results will be somewhat more sensitive to the trajectory of baseline variables that are also policy variables. In the next section, potential strategic options for adapting to climate change are presented. Augmenting irrigated area figures among these options. If the baseline plan were to expand irrigation up to the limits of land or water availability, then a potential policy option would be to consider a less aggressive irrigation expansion policy. From this example, it follows that one should take particular care in the selection of the baseline path for potential policy variables.

Policy documents, such as the Medium Term Fiscal Framework, the PARPA, and the PQG (the government's five-year plan), as well as sectoral planning documents, can be helpful. However, there are two key limitations in the extent to which these documents can inform the baseline. First, very few planning documents in Mozambique provide orientations for longer than a five-year period, while the baseline path must stretch to 2050. Second, the main policy documents are very close to the end of their five-year terms. To counter this, the study developed baseline paths in collaboration with senior staff from the Ministry of Planning and Development in order to generate a viable counterfactual.

Strategic Options

An initial temptation in confronting climate change is to direct resources to prevent damage from climate change. However, this may not be an economically sensible strategy over the long term. For example, the previous discussion on risks to coastal infrastructure due to a combination of sea level rise and elevated cyclone intensity and frequency highlights both the expected costs posed by climate change and the extremely high costs associated with countering these impacts with hard investments such as dikes and seawalls. As discussed, a more sensible strategy is likely to take a soft approach whereby valuable investments are zoned away from vulnerable areas to the greatest extent possible. Rather than build dikes or sea walls, Mozambique should employ its scarce available resources to foster development of a wealthier, more flexible, and more resilient society.

For Mozambique, three basic strategic options will be considered, including a baseline path. In all strategic options, a fixed resource envelope equivalent to the baseline will be considered. The difference between the baseline path and the climate change scenarios provides a rough resource envelope for adaptation options. The principal strategic options will include:

1. Investment in irrigated agriculture with complementary investments in other rural infrastructure.

2. Investment in dry-land agriculture with complementary investments in other rural infrastructure.

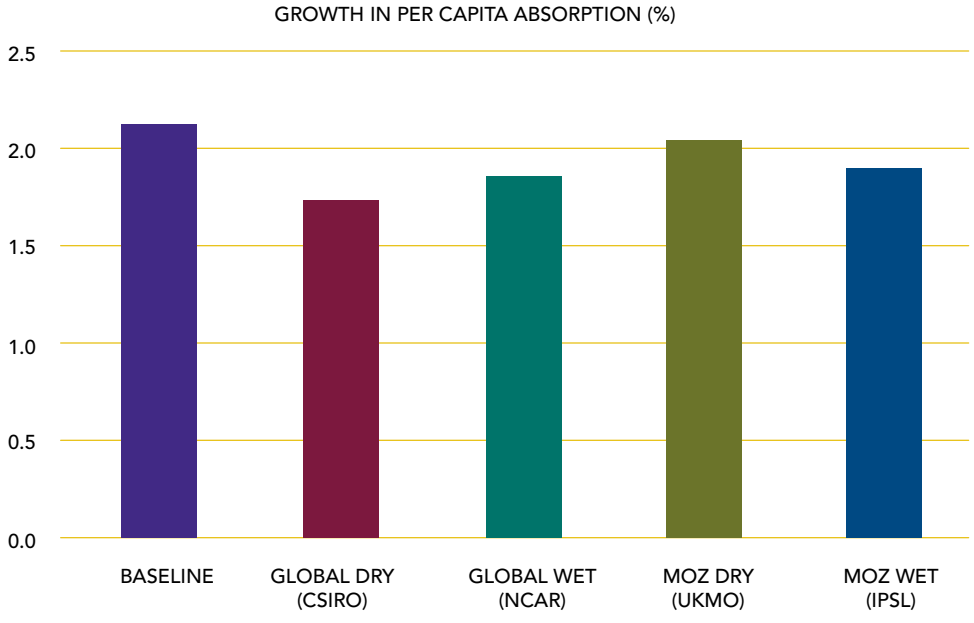
3. Investment in non-climate-sensitive sectors with greater emphasis on urban infrastructure and education (i.e., economic development as an adaptation strategy).

Finally, some adaptation options can be considered in isolation from other sectors of the economy. For example, the partial equilibrium analysis of the hydro sector finds that the proposed dam construction program remains economically viable (or very nearly so) under all climate scenarios. Therefore the same base hydroelectric investment plan remains in place across all strategic options. This is also true for decisions on road infrastructure. The strategy of sealing unpaved roads performs mildly better than the current strategy of constructing unpaved roads even under base climate. With climate change, the relative benefits of the strategy increase even more. Therefore, the revised infrastructure policy is applied to all strategic options.

IMPACTS OF CLIMATE CHANGE

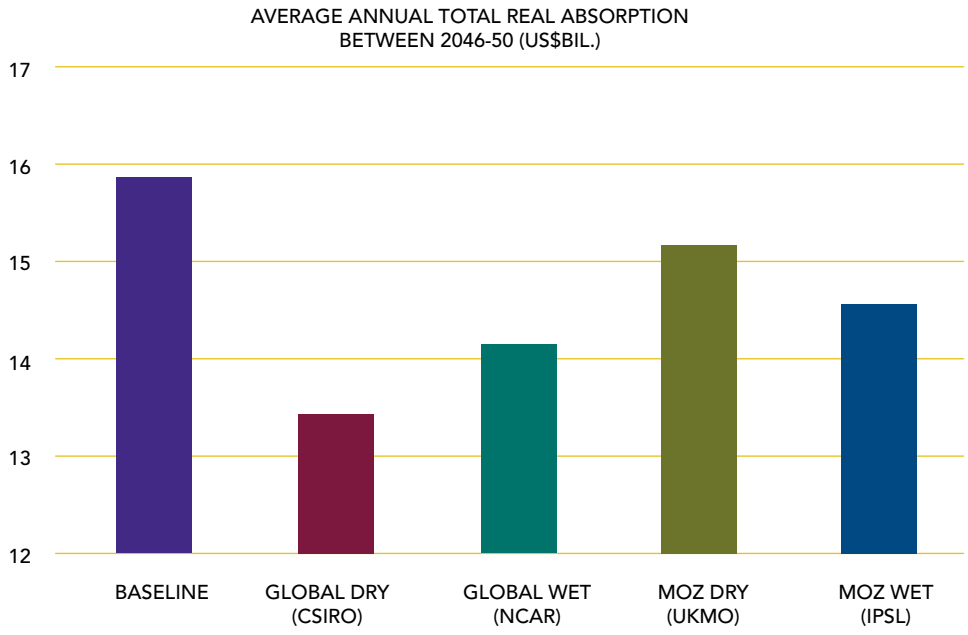
The impact of climate change is considered first. Figure 39 illustrates the growth rate of real per capita absorption over the simulation period. Real absorption is the broadest measure of welfare available in an economy. It tracks the economy's use of goods for household consumption (C), investment (I), and government expenditure (G). Absorption is often tightly related to GDP growth. Formally, absorption (A) is equal to: A=C+I+G, recalling that GDP=C+I+G+X-M where X is exports and M is imports. One can therefore write that A = GDP + M - X. In words, absorption equals the volume of goods produced by the economy plus the goods that foreigners supply to the economy (imports) less the goods sent out to foreigners (exports). In the Mozambican context, the focus on absorption is preferred because large foreign investments have the potential to add significantly to GDP but little to absorption. For example, mozal accounts for around 10 percent of GDP; however, because mozal is capital-intensive and profits are remitted, mozal adds relatively little to absorption. The same is potentially true for hydropower expansion if the majority of hydropower revenues are expatriated to cover dam construction costs.

FIGURE 37 AVERAGE ANNUAL REAL PER CAPITA ABSORPTION GROWTH RATE, 2003–50



Source: Results from the Mozambique DCGE model

FIGURE 38 AVERAGE ANNUAL VALUE OF ABSORPTION, 2046–50



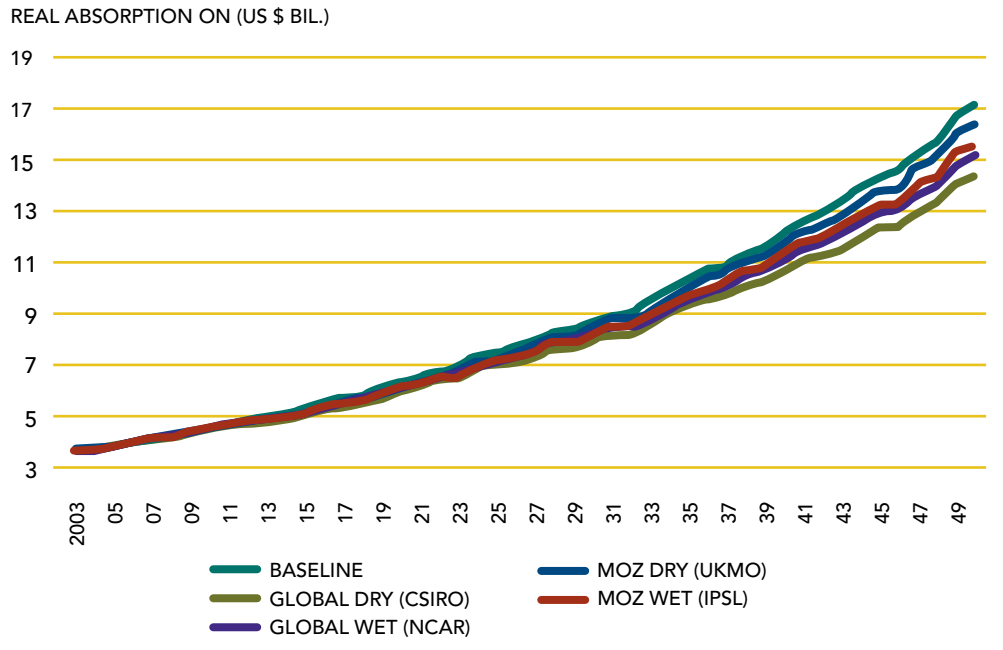
Source: Results from the Mozambique DCGE model

Consistent with the projections employed in the global track analysis of the economics of climate change, the growth rate of per capita absorption for Mozambique is about 2.1 percent per annum over the period 2003–50. This is much slower than actual growth rates recorded by Mozambique since 1992. However, for the purposes of remaining consistent with the Global Track assessment of climate change, the lower growth rate has been adopted. Nevertheless, as emphasized above, qualitative results are likely to remain fairly constant across a range of baseline paths. Hence, the results are of interest even though the baseline growth rate is not consistent with recent experience.

All climate change scenarios register declines in absorption growth rates relative to the base (no climate change scenario). The worst performing "global dry" scenario registers an annual growth rate of 1.73 percent compared with 2.11 percent in the base. The best performing "Mozambique dry" scenario yields an annual absorption growth rate of 2.02 percent. It may seem counterintuitive that the driest global scenario produces worse results than the driest local scenario. However, as will be seen below, the global dry scenario is in fact a very wet scenario for the countries within the Zambezi water basin. As such, there are large damages from flooding, which dominate overall economic losses from climate change in Mozambique. Similarly it might also seem counterintuitive that the global dry scenario, for being so wet, is in fact not the wettest local scenario. However, this highlights the importance of taking a regional perspective when assessing climate change impacts. In this case it is the climate patterns in the countries upstream of the Zambezi that determines major floods in Mozambique, rather than the climate patterns within Mozambique itself. The most severe flooding damages do not occur in the local wet scenario.

As mentioned above, climate change reduces average annual absorption growth rates by at most 0.38 percentage points. However, even

FIGURE 39 **REAL ABSORPTION, 2003–50**



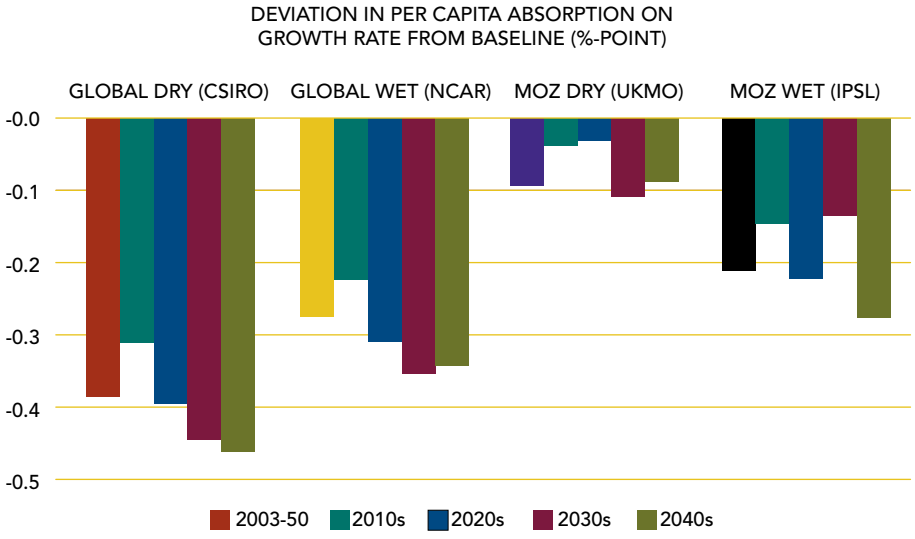
Source: Results from the Mozambique DCGE model

small reductions in rates of growth over a nearly 50-year period eventually accumulate to result in fairly significant differences in levels of absorption (or GDP) in 2050. Figure 40 shows the average level of absorption in the period 2046–50 in the base and the four climate change scenarios. In the worst performing scenarios (CSIRO), the level of total absorption is only 84 percent of the level obtained in the base. In the best performing scenario (UKMO), absorption attains more than 96 percent of the level achieved in the base.

Figure 41 provides a view of the performance of the economy through time. It shows that outcomes remain very consistent between the base and the climate change scenarios through at least the next decade and likely through two decades. There are two reasons for this. The first is the inverse of the rule that even small differences in growth rates accumulate to large differences in absolute outcomes over long periods of time. Over relatively shorter periods of time, small differences in growth rates are less material. The differentials in growth rates associated with climate change will become much more apparent after 40 years than after 20. Second, climate change impacts tend to become larger with time.

This tendency for climate change impacts to become larger with time is illustrated in Figure 42. The figure shows the average deviation in the growth rate between the base and the four climate change scenarios for various periods. For example, the global dry scenario reduces the growth rate of per capita absorption by somewhat more than 0.38 percent over the period 2003–50. However, the impact of climate change (as modeled by CSIRO) becomes more pronounced with time. By the 2041–50 period, the differential in growth rates between the two scenarios attains approximately 0.46 percent. The other climate scenarios illustrate the same general trend, though not as monotonically as CSIRO.

FIGURE 40 DEVIATION IN AVERAGE ANNUAL REAL PER CAPITA ABSORPTION GROWTH FROM BASELINE, 2003–50



Source: Results from the Mozambique DCGE model

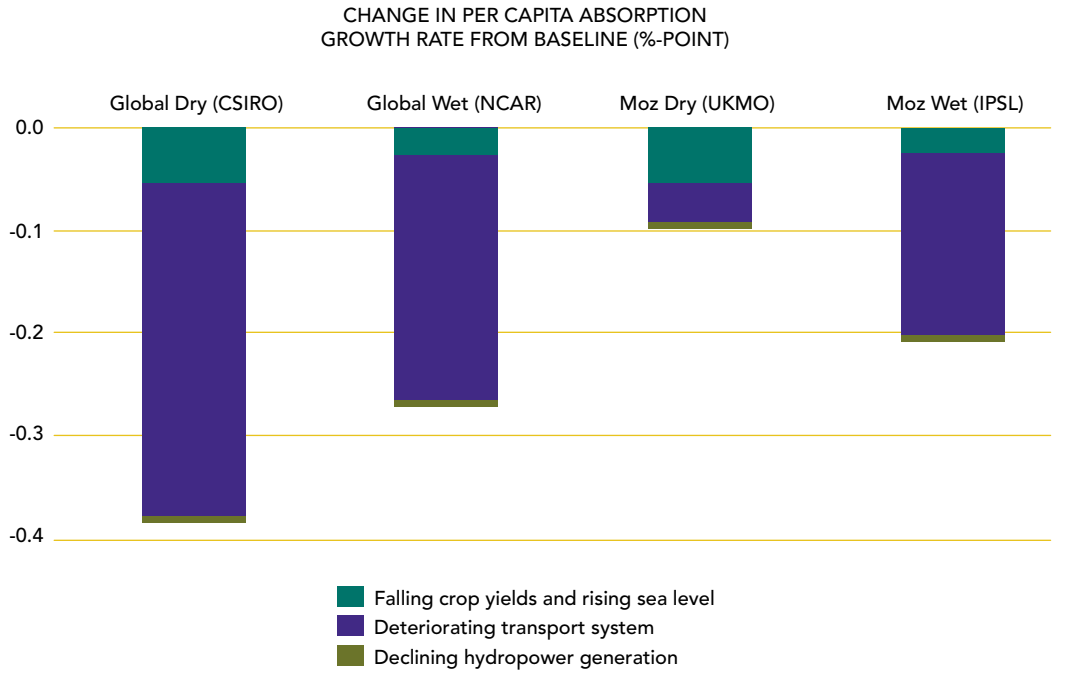
Nearly all climate models predict a pronounced aggravation of climate change impacts after about 2050. While the time horizon for this analysis ends in 2050, there is little doubt that, if the time frame were extended, the tendency for later periods to exhibit progressively stronger impacts would certainly remain in place and highly likely strengthen. This highlights the importance of the development agenda in the first half of the 21st century. Failure to register significant development progress in the next 40 years may imply serious difficulties in the latter half of the 21st century.

As indicated above, a principal advantage of CGE modeling is the ability to decompose impacts across shocks in order to determine the relative importance of different shocks.[12] Figure 43 decomposes the climate change shocks into three groups: crop yields and sea level rise (the latter is very small), the transportation system, and hydropower. The graph clearly illustrates the dominant role played by transport system disruption, principally, but not exclusively, as a result of flooding. As mentioned earlier, the global dry scenario is in fact a very wet scenario for the Zambezi water basin as a whole, and thus causes significant damage to transport infrastructure. By contrast, the local dry scenario is a very dry scenario for Mozambique and causes greater damages for agriculture, as estimated by the crop models described in earlier sections.

The impacts of flooding on transportation infrastructure are strong. A drought in year "t" may reduce agricultural output dramatically in a crop season with strong implications for the welfare of households. However, in year t+1, experience indicates that agricultural production typically returns to normal levels if the rains return. An increase in the variance of agricultural production will have little impact on long-run growth as long as underlying rates

12 Formally, CGE models are path dependent, implying that the results of the decomposition can depend upon the exact way in which the decomposition procedure is designed. In many cases, including this one, qualitative results are the same regardless of the decomposition procedure employed.

FIGURE 41 DECOMPOSITION OF TOTAL CLIMATE CHANGE GROWTH RATE LOSSES, 2003–50



Source: Results from the Mozambique DCGE model

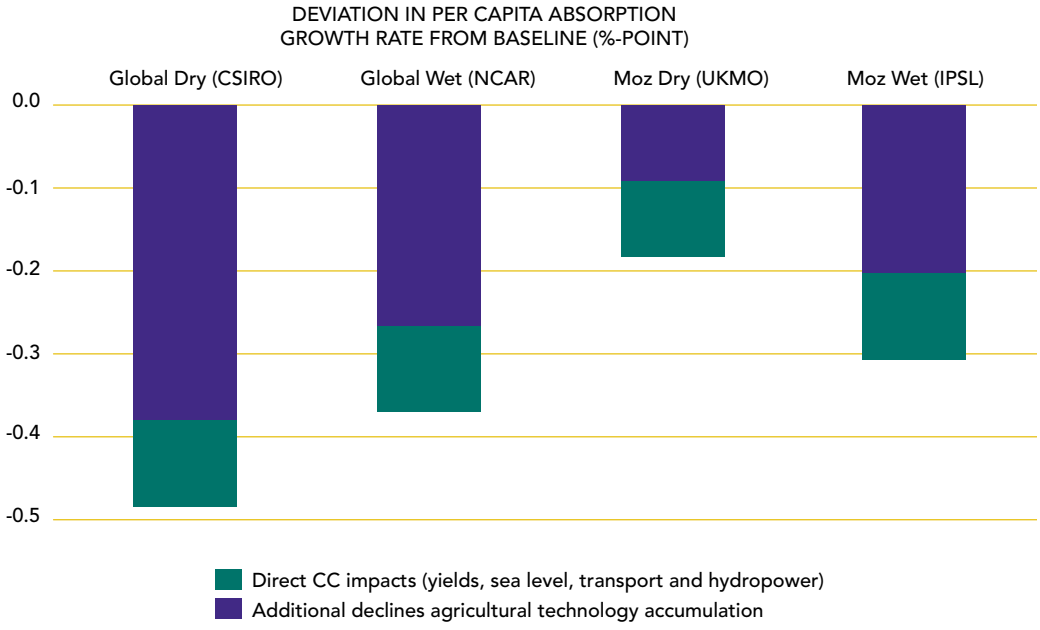
of factor accumulation and technical improvement remain relatively constant.

The same applies for hydroelectric power. Reduced river flow leads to reduced energy output. However, when the river flow returns, so does energy production. Hydroelectric power also has limited impact on absorption because of the important role of foreign financing in dam construction. The model remits 80 percent of hydroelectric power net revenues abroad in order to cover dam construction costs. This assumption provides a reasonable risk-adjusted return to investors. At the same time, it implies that hydroelectric power investments have a relatively muted impact on total absorption, at least over the repayment period.

Flood-induced destruction of infrastructure is different from the other shocks in that the shock endures. Once a road is washed away, the negative shock endures until the road is rebuilt. However, with constant resources allocated to roads, reconstruction of a section of road washed away due to heavy rainfall or flooding implies fewer resources available for construction of new roads or regular rehabilitation of existing roads. The large distances and dispersed nature of production in Mozambique reinforce the importance of the road network. Earlier analyses have highlighted the large differences between farm/factory gate prices and prices paid by final users (Tarp et al. 2002), as well as the substantial gains to the economy that can be obtained from reduction in these margins (Arndt et al. 2000). Damage to road infrastructure works in an inverse sense, increasing the implicit distance between producer and final user.

Given the magnified implications of persistent impacts, some consideration of the underlying

FIGURE 42 POSSIBLE ADDITIONAL DECLINES IN AGRICULTURAL TECHNOLOGY ACCUMULATION, 2003–50



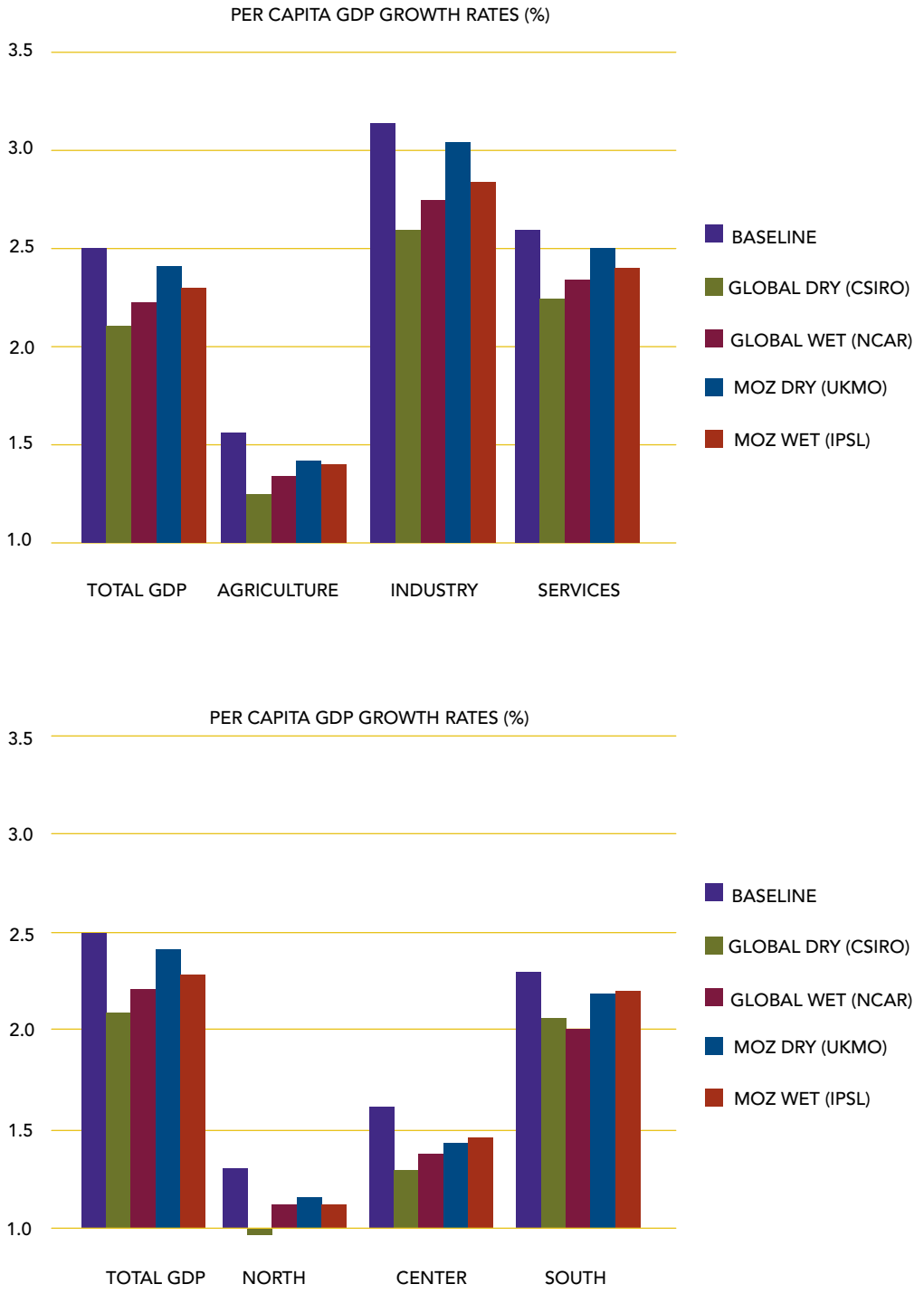
Source: Results from the Mozambique DCGE model

rate of technical change is worthwhile. Figure 44 shows the implications if the underlying rate of Hicks-neutral technical advance in agriculture is reduced from 0.8 percent per annum to 0.3 percent per annum.[13] Because climate change on the order of what will happen over the next 40 years has never occurred on a broad scale before, it is impossible to know what will happen to underlying rates of technical change in agriculture. Because of the speculative nature of this effect, it is not included in the base climate runs. However, it is not unreasonable to be concerned that resources allocated to adapting plants to an evolving climate will imply fewer resources allocated to generalized technical advance and hence a much lower rate of technical advance in agriculture. The implication of a slowdown in the underlying rate of technical advance is strong though not dominant. The result highlights the need to maintain or even accelerate (see the adaptation options) underlying technical progression in agriculture in the context of climate change.

The sectoral and regional impact of climate change is illustrated in Figure 45. Note that in all scenarios, including the base, agriculture grows much more slowly than industry or services. Given the higher concentration of industry and services in the central regions and especially the south, this translates into relatively less rapid growth rates in the north and relatively more rapid growth rates in the south. All sectors and regions are negatively affected by climate change. The largest declines in growth rates relative to the baseline are in agriculture and in the northern region of Mozambique, where agriculture dominates the local economy. As the large metropolitan center of Maputo is in the south, it means that a larger share of this region's economy is relatively insulated from the

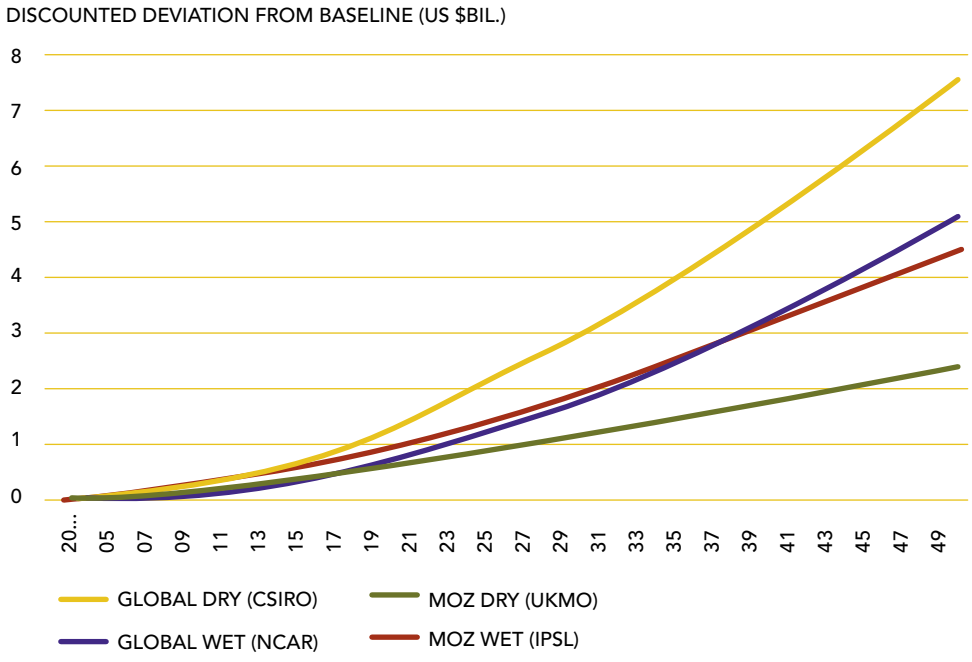
13 The model also contains factor-embodied rates of technical advance in human capital, which remain in place for all sectors.

FIGURE 43 DEVIATION IN SECTOR AND REGIONAL GDP GROWTH FROM BASELINE, 2003–50



Source: Results from the Mozambique DCGE model

FIGURE 44 **CUMULATIVE DISCOUNTED LOSSES IN REAL ABSORPTION, 2003–50**



Source: Results from the Mozambique DCGE model

direct effects of climate change. For example, the government sector is disproportionately located within the capital city and is not directly affected by climate. As such, the south experiences smaller declines in GDP than elsewhere in the country.

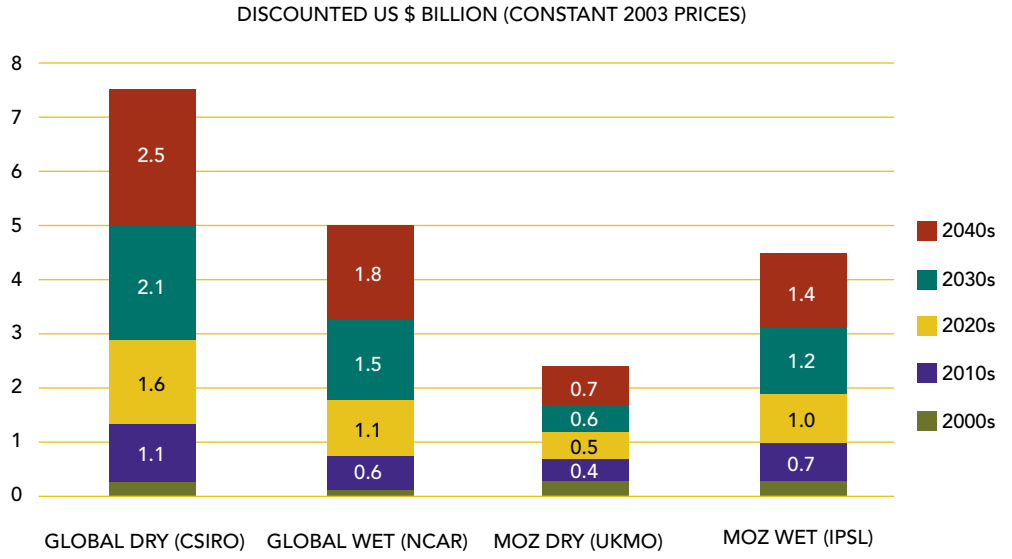
Finally, Figure 46 considers the costs of climate change. These are presented as cumulative discounted losses as a result of climate change. A 5 percent annual discount rate is used. In the figure, the horizontal axis represents the period over which the discounted losses in real absorption (relative to the base) are calculated. For example, for the global dry (CSIRO) scenario, discounted losses over the full period, 2003–50, amount to $7.5 billion in real 2003 US$. This is roughly equivalent to current GDP for the country. In the mildest scenario, Mozambique dry (UKMO), discounted total losses still amount to $2.4 billion real 2003 US$ over the full period.

Figure 47 summarizes the main results on the impact of climate change in Mozambique. First, all future climate scenarios reduce national welfare. The largest losses occur under the global dry scenario and, after discounting, amount to $7.5 billion (in 2003 $) over the period 2003–50. Secondly, economic losses caused by climate change grow over time, as shown by the cumulative decadal costs in the figure. Finally, while agriculture is adversely affected by climate change, it is major flooding and the damage it causes to transport infrastructure that dominates overall welfare losses.

Adaptation Options

As explained above, the CGE model employed contains endogenous adaptation. Resources are reallocated to areas of greater returns. If climate change has particularly strong impacts on one sector, the model will respond in accordance with

FIGURE 45 **CUMULATIVE DISCOUNTED LOSSES IN REAL ABSORPTION BY DECADE, 2003–50**



price signals. However, the model simulations described above do not contain any adaptation in terms of basic policy frameworks. For example, we have seen that damage to road infrastructure accounts for the largest share of economic damages of climate change. Despite this, there have not yet been any attempts in the model to modify transport policy or basic infrastructure arrangements in order to reduce these costs. Various options exist, however. Railways, for instance, tend to be less sensitive to precipitation and can often withstand a more severe flood than roads—though a sufficiently severe flood will destroy a rail line at large cost. Coastal shipping is also less exposed to flooding, though it is subject to other phenomena such as cyclones.

This section explores a range of adaptation investments to offset the national welfare losses caused by the most severe climate change scenario: global dry (CSIRO).Table 22 presents the adaptation options considered and the implications of those options for the growth rate of absorption. The presentation is somewhat complex and requires a few words of explanation. The first column, baseline, reproduces the results from the "no climate change" simulation, and is therefore the same for all climate scenarios. In the second column, climate change impacts by climate scenario are reproduced, and the results correspond to Figure 39. The remaining columns show the results from various simulated adaptation investments. Column (3) shows results for transport policy change. This column contains all of the shocks applied to the result from column (2) plus the change in transport policy. The remaining columns (4), (5), and (6) contain the transport policy as well as either (a) increased agricultural research and extension (R&E) to increase the rate of technical progress in agriculture; (b) expanded irrigation investment; or (c) enhanced investment in human capital accumulation. It is important to note that the final three adaptation policies are undertaken separately. Hence, results column (6) contains enhanced investment in education and should be compared to the results in column (3).

TABLE 22 AVERAGE REAL PER CAPITA ABSORPTION GROWTH RATES (%)

	Baseline	Impact	Adaptation scenarios			
	No climate change (1)	With climate change (2)	Transport infra-structure (3) = (2+)	Agriculture R&E (4) = (3+)	Irrigation expansion (5) = (3+)	Education (6) = (3+)
Global dry	2.11	1.73	1.81	2.11	1.84	2.11
Global wet	2.11	1.85	1.92	2.22	1.95	2.23
Moz dry	2.11	2.02	2.04	2.32	2.07	2.35
Moz wet	2.11	1.91	1.97	2.27	2.00	2.28

We consider the transportation sector first. Results from the simulation model for the transport sector described above indicate that flooding incurs substantial damages, especially for unpaved roads. In Mozambique, approximately 10 percent of the road infrastructure public budget is set aside for the reconstruction of washed-out roads. Under climate change, this allocation would have to increase. However, as indicated earlier, allocating more to reconstruct roads washed out by flooding implies, under constant budgets, allocating less to new road construction and regular road rehabilitation/maintenance. This has implications for the growth of the road stock. Under the CSIRO scenario, total kilometers of road are 22 percent lower in 2050 than in the baseline in the same year. The implications of more intense rainfall and associated flooding are particularly strong for unpaved roads (though large floods do impact paved roads).

The adaptation option explored is to seal the unpaved roads such that they operate like paved roads in terms of precipitation. Discussions in Mozambique indicated that these kinds of sealed roads cost about $100,000 per kilometer to construct new. According to the available data, the cost of new unpaved tertiary roads is about $70,000, unpaved secondary roads about $100,000, and unpaved primary roads cost about $150,000. We assumed that sealed roads could be constructed new for a 10 percent increment in cost or converted to sealed at the regular 20-year rehabilitation for a 10 percent increment in rehabilitation costs. For roads that are sealed, the dose response coefficients (flooding, precipitation, and temperature) applied to paved roads are also applied to the sealed (formerly unpaved) roads. It is worthwhile to note that this policy provides a mild increase in road coverage in 2050 even under base climate. In addition, properly maintained, sealed roads provide a higher level of service than unpaved roads. Hence, the policy yields a somewhat larger network that offers better service even under base climate. Advocates for this policy exist within the transport sector without consideration of climate change.

Climate change substantially reinforces the case put forward by these advocates. Table 23 illustrates the percentage change in the size of the road network (measured in kilometers) in 2050 relative to the base. The adaptation policy described above increases the stock of roads under all climate change scenarios (and under the base as emphasized above). The table illustrates the principal reason why the global dry (CSIRO) scenario provides the worst economic outcome and the Mozambique dry (UKMO) scenario the most relatively favorable. It is important to emphasize that these changes in road stocks are attained with no change in real resource allocations to the road sector.

In the CGE model, these differentials in road stocks are translated to the economy via the productivity of the transport sector. In particular, we assume that decreases in the stock of roads result in proportional reductions to the rate of total factor productivity (TFP) growth in the transport

TABLE 23 PERCENTAGE CHANGE IN THE STOCK OF ROADS (MEASURED IN KILOMETERS) RELATIVE TO BASE

Scenario	*No Adaptation*	*Adaptation*
Baseline	0 percent	1 percent
Global dry	-22 percent	-19 percent
Global wet	-16 percent	-14 percent
Moz dry	-2 percent	-2 percent
Moz wet	-12 percent	-9 percent

sector. In addition, we assume that sealed roads are more efficient, providing a further impetus to transport productivity. The results reinforce both the strength of the effect of the transport sector in contributing to losses from climate change and the potential power of alternative policies to offset these losses. For example, in the global dry (CSIRO) scenario, about a quarter of the decline in the rate of absorption is offset by the shift in transport sector policy, which required no additional resources.

The remaining adaptation policies described in columns (4), (5), and (6) differ from the transport sector policy in that they require additional resources. The maximum resource envelope is derived from the cumulative discounted adaptation costs presented in the global dry scenario. The present value of $7.5 billion in damages is converted to an annual resource transfer (with a discount rate of 5 percent). This provides a maximum resource envelope of a bit more than $400 million per year. We then consider whether improved agricultural technology (4), irrigation (5), or human capital investment (6) is capable, on its own, of making up the difference in absorption between the climate change scenarios with transport sector adaptation (3) and the base no climate change scenario (1).

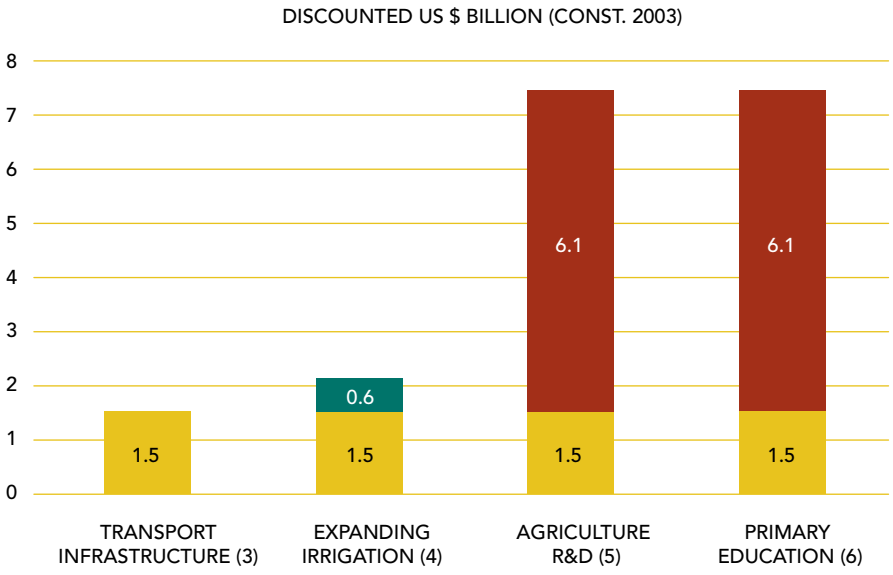
We find that increases in agricultural productivity and human capital accumulation can plausibly make up the gap for the global dry (CSIRO) scenario (the largest climate change impact). For agricultural technology, an improvement of 1.2 percentage points in the rate of agricultural technical advance returns growth of absorption to the base rate in the global dry scenario and pushes the growth of absorption above the base rate in all of the other scenarios. Given the relatively high potential and relatively low achievement to date of Mozambican agriculture, this rate of technical advance appears to be achievable within a reasonable budget envelope (likely considerably less than the maximum of $400 million). Moreover, increasing crop yields is entirely consistent with the government's existing development goals.

For human capital, the rate of growth of highly skilled labor increases by 1.3 percentage points, from 2 percent per annum to 3.3 percent per annum. For medium skilled labor, the growth increment is 1.1 percent, bringing the accelerated growth rate to 2.6 percent per annum. The growth rate in low skilled labor declines by 0.6 percent in order to keep the total number of workers in the economy constant over the simulation period.[14] These increments are consistent with an estimated transition matrix for the Mozambican education system. In addition, these increments appear to be plausible within a budget parameter considerably less than the maximum figure of $400 million.

For irrigation, an increment in irrigated area of slightly more than 1 million ha by 2050 relative to the base was assumed. This is equivalent to eventually irrigating about one sixth of cultivated land in Mozambique by 2050. However, expanding irrigation is found to have only a small impact on real absorption. This is because, as additional lands come under irrigation, the returns to agricultural land and capital decline significantly (i.e., there are diminishing returns to investing in agriculture).

14 The actual rate of human capital accumulation, particularly for highly skilled labor, is faster than the values modeled. These reduced values are necessary to attain the relatively slow growth in per capita absorption required to match the global track analysis.

FIGURE 46 REDUCTION IN NATIONAL ABSORPTION LOSSES UNDER THE ADAPTATION SCENARIOS, 2003–50



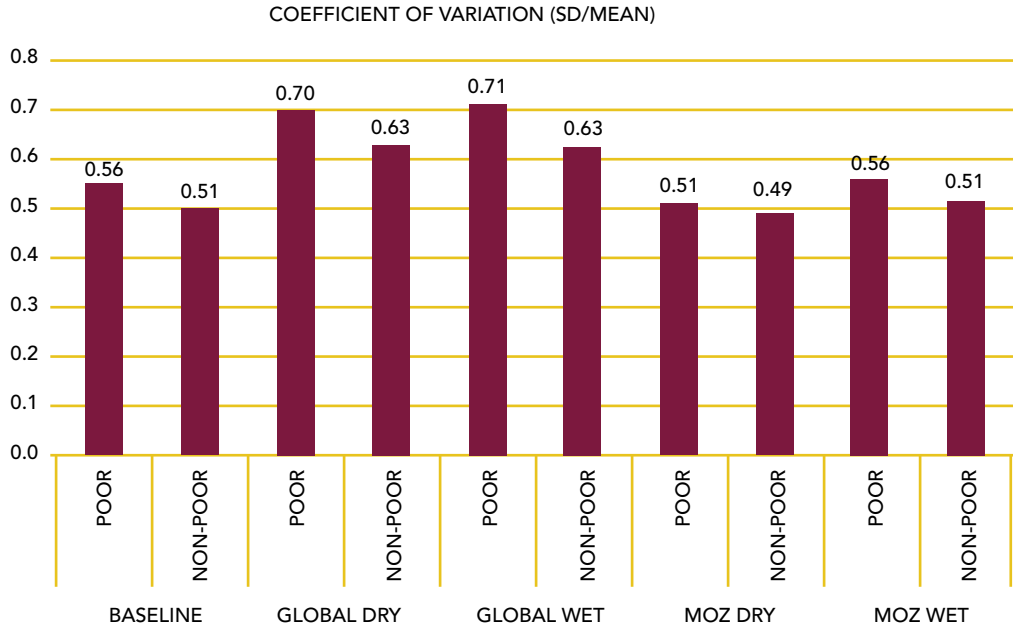
Without access to foreign markets, the decline in agricultural prices caused by rapidly expanding irrigation and agricultural production limits the gains from these investments. Overall, irrigation investments reduce the damages caused by climate change by $600 million over 2003–50 (constant 2003 prices discounted at 5 percent). This is shown in Figure 48. While this is sufficient to offset the total damages from climate change under the Mozambique dry scenario (Figure 47), it is far smaller than the additional $4.6 billion required to offset the total damages in the global dry scenario after the changes in transport sector policy have been introduced. As shown in Figure 48, this additional $4.6 billion can be made up through enhanced agricultural research and extension or through more rapid human capital accumulation.

An alternative method for considering the cost of adaptation involves using an average estimated rate of return to foreign assistance. Rajan and Subramanian (2007) developed a theoretical growth model that considers the impact of aid as a share of GDP on the growth rate of GDP. They derive an expected impact of growth of 0.1 assuming that aid has no impact on productivity growth. In other words, if aid volumes increase by 1 percent of GDP, the growth rate of GDP increases by 0.1 percent. Arndt, Jones, and Tarp (2009) estimated the relationship and found an average rate of return to aid of 0.16. In other words, aid contributes to both investment (even though some aid is invariably consumed) and productivity growth. Using these parameters, the incremental volume of foreign assistance required to replace the expected growth deficit under the CSIRO scenario is about $140 million (real 2003 US$) per year over 47 years, or a net present value of $2.55 billion.

EQUITY ISSUES

The incidence of impacts from climate change between households categorized as poor and non-poor in the base year are approximately similar. The same holds true for adaptation measures—poor and non-poor households both benefit from the adaptation measures, and the incidence of

FIGURE 47 HOUSEHOLD CONSUMPTION: COEFFICIENT OF VARIATION OF YEAR-TO-YEAR GROWTH RATES



Note: Coefficient of Variation (CV) is the standard deviation (SD) divided by the mean of the year-to-year growth rates.

these benefits is not substantially different. Poor and non-poor do appear to differ in terms of their vulnerability to shocks. Figure 49 shows the impact of the extreme wet and dry scenarios, with and without road network adaptation investments, on the coefficient of variation (CV) of the year-to-year growth rates of total household consumption. The mean of the baseline year-to-year growth rates for poor and non-poor households is 2.9 percent and 3.4 percent, respectively. The CVs range from a low of 0.49 to a high of 0.71. They represent the year-to-year changes in consumption to which households must adjust. A value of 0.56 in the baseline indicates that poor households must manage annual swings in the change in consumption of 56 percent. In all scenarios, the CVs for poor households are slightly higher than those for non-poor households—poor households must deal with more income variability than the non-poor. The impact of the climate change scenarios on the CVs is significant—rising to about 0.70 in the two global scenarios. However, it either remains constant or falls in the two Mozambique scenarios.

ELEVEN

Discussion

The following lessons emerge from the EACC Mozambique Country Case study:

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

Climate change is likely to complicate the development challenge in Mozambique. However, based on the best available understanding of the climate system and the downstream implications of climate realizations for biophysical and economic systems, these complications are not likely to be so severe that they greatly dim development prospects through 2050. It is possible, but not likely, that climate in the first half of the 21st century will be more amenable to development than the climate of the second half of the 20th century. The chances of a more favorable outcome increase substantially if carbon fertilization stimulates crop growth in the real world as it does in controlled experiments. It is also possible, but not likely, that climate over the next 40 years will prove highly unfavorable to development prospects, with devastating implications for the welfare of the Mozambican population—a sobering prospect. Nevertheless, the best current understanding indicates that climate change over the next 40 years will complicate the already considerable challenges faced by Mozambique. This study shows that it will be particularly true for agriculture, transport, and coastal cities.

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

Rather than climate change eclipsing development, we need to think of development overcoming climate change. The best adaptation to climate change is rapid development that leads to a more flexible and resilient society. As such, the adaptation agenda, in significant measure, reinforces the existing development agenda. In particular, the vast uncertainties associated with climate change underscore the importance of two already prominent items on the development agenda. The first of these is human capital accumulation. The powerful effects of improved human capital accumulation were shown in the CGE simulations of this report.

The second issue is flexible and competent public and private institutions. As discussed earlier in the report, future climate worldwide is highly likely to

be, on average, warmer, wetter (in terms of total precipitation) and more severe than it is today. Whatever changes do occur will have differential implications across the economy; particular sectors or regions may be negatively affected, while other sectors or regions may be stimulated. A more educated populace, supported by flexible and competent public and private institutions, will be better able to react to these differential implications as they present themselves. Better functioning institutions would manifest themselves quantitatively (in a growth accounting sense) through enhanced productivity growth.

Climate change also further highlights the immediacy of the development task. At some point in the middle of the 21st century, vastly more wrenching shifts in climate will begin to take place than are likely to be observed in the next 30–40 years. This is especially true if the global community fails to develop a fair and effective mitigation policy. If Mozambique reaches the middle of the 21st century with large shares of its population engaged in subsistence agriculture, with substantial illiteracy, and with inefficient institutions, it may face grim prospects indeed.

At the same time, while the bulk of good adaptation policy involves advancing the existing development agenda, there are some specific policies, beyond the continued focus on human capital accumulation mentioned above, that emerge as important responses to climate change. These are:

3. ***Cooperation in regional river basin management will be needed.***

For downstream countries, the implications of policy choices by upstream countries are potentially profound. As such, in terms of river flow, the reactions of upstream countries to the prospect of climate change could easily be more important to downstream countries than the implications of climate change. It is well-known that cooperative river basin management is vastly more efficient than non-cooperative behavior or outright rivalry. Access to water is widely acknowledged as a potential flashpoint for regional conflict; climate change raises the already considerable stakes. Unfortunately, effective international river basin management has to date proven difficult to achieve. The onset of a shift in climate patterns may accentuate these difficulties, highlighting the need for the establishment of robust cooperative frameworks as soon as possible.

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

Agriculture must adapt to the challenges posed by climate change while maintaining average annual rates of productivity advance. The latter clause is critical. If, by redirecting resources to coping with a new environment, climate change indirectly results in a reduced underlying rate of technical improvement in agriculture, there will likely be large negative impacts.

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

The prospect of more intense precipitation has implications for unpaved roads, the bulk of which are located in rural areas. Increased intensity of rainfall is highly likely to wash out a greater share of rural roads with negative implications for rural development. Single-lane sealed rural roads cost more to construct but are likely to provide a much more reliable all-weather network than unpaved roads. In addition, properly constructed, sealed rural roads should cost less over time due to reduced maintenance requirements.

6. ***"Soft" adaptation measures are potentially powerful. Because the majority of***

the capital stock in 2050 remains to be installed, land use planning that channels investment into lower risk locations can substantially reduce risk at low cost.

Over the next 40 years, the value of the capital that will be installed is likely to be much greater than the value of capital currently installed. In addition, the value of the current capital stock will have significantly depreciated. Land use planning is thus a potentially extremely powerful tool for dealing with rising probabilities of extreme events over the 21st century, especially flooding and sea inundation due to cyclones combined with sea level rise. The rule of thumb is simple: to the extent possible, install valuable new capital in safer locations.

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

Hard adaptation options, particularly expensive ones, must be subjected to serious scrutiny before being undertaken. A reasonable rejoinder to the preceding point on land use is that some capital must be allocated in vulnerable areas. For example, ports and beachfront hotels manifestly must sit near the ocean, making them more vulnerable to cyclones and sea level rise. Even so, hard options to protect these vulnerable assets, such as dikes and sea walls, should be subjected to careful consideration. Construction of a dike is followed, almost by definition, by accumulation of physical capital in the shadow of the dike because it is considered "safe." However, as the city of New Orleans dramatically illustrated in 2005, a sufficiently extreme event will breach a dike. The combination of increasing probabilities of extreme events, high costs of construction of hard protectors, and the accumulation of capital behind the protectors can mean that the expected value of loss, including an accounting for human suffering, declines little, remains constant, or even increases following construction of the hard protector.

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