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Economics of Adaptation to Climate Change

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Economics of Adaptation to Climate Change

ETHIOPIA

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Acronyms

AR4	IPCC Fourth Assessment Report
BAU	Business-as-usual
CAADP	Comprehensive Africa Agriculture Development Program
CGE	Computable general equilibrium
CO_2	Carbon dioxide
CMI	Climate moisture index
CRU	Climate Research Unit
CSIRO	Commonwealth Scientific and Industrial Organisation
EACC	Economics of Adaptation to Climate Change
ENSO	El Niño-Southern Oscillation
GCM	General circulation model
GDP	Gross domestic product
GHG	Greenhouse gases
GIS	Geographical information system
HDI	Human Development Index
IFPRI	International Food Policy Index
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Conversion Zone
MDGs	Millennium Development Goals
NCAR	National Center for Atmospheric Research
NAPA	National Adaptation Plans of Action
NCCAS	National Climate Change Adaptation Strategy
NGO	Nongovernmental organization
ODA	Official development assistance
PaMs	Policies and measures
PET	Potential evapotranspiration
Ppm	Parts per million
R&D	Research and development
SRES	Special Report on Emissions Scenarios
SSA	Sub-Saharan Africa
SST	Sea surface temperature
TAR	Third Assessment Report
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
VFS	Vulnerability and food security

CURRENCY EQUIVALENTS
(Exchange Rate Effective)

Currency Units = Birr
US$1.00 = 11.7 Birr in 2009 (annual average)
Note: Unless otherwise noted, all dollars are U.S. dollars.

FISCAL YEAR (FY)
July 8 – July 7

WEIGHT AND MEASURES
Metric System

Acknowledgments

The report was prepared by a team coordinated on the World Bank side by Raffaello Cervigni. Principal authors were Kenneth Strzepek, Sherman Robinson, Len Wright and Raffaello Cervigni; additional experts on the team were Paul Block, Brent Boehlert, Paul Chinowsky, Chas Fant, William Farmer, Alyssa McCluskey, Michelle Minihane, Niko Strzepek, and Gete Zeleke.

The World Bank team comprised, in alphabetical order, Aziz Bouzaher (former team leader), Marie Bernadette Darang, Susmita Dasgupta, Edward Dwumfour, Achim Fock, Francesca Fusaro, Anne Kuriakose, Stephen Ling, Sergio Margulis (team leader of the overall EACC study), Stephen Mink, Kiran Pandey (Coordinator EACC country studies) , Dawit Tadesse, and Fang Xu. Robert Livernash provided editorial services, Jim Cantrell contributed editorial input and coordinated production, and Hugo Mansilla provided editorial and production support. The peer reviewers were John Nash, Vahid Alavian, Michael Jacobsen, and Roger Gorham.

From the government of Ethiopia, policy guidance was provided by Dr. Tewolde Birhan Gebre Egziabher Yohannes (Director General of the Environmental Protection Authority), Ato Dessalegen Mesfin (Deputy Director General, EPA); and Dr. Abera Deresa (State Minister, Ministry of Agriculture).

The team is grateful for the comments received from participants to the initial consultation workshop held in Addis Ababa in November 2009, as well as the final workshop in Addis Ababa in October 2010. These included: Assefa Tofu, Kumelachew Yeshitela, Sisay Nune, Abdissa Megersa, Abera Tola, Ahmed Khalid Eldaw, Alessandra Tisot, Amare Kebede, Amare Worku, Amelie Blume, Angus Friday, Belay Simane, Berhanu Adenew, Berhanu Ayalew, Berhanu Kassa, Daniel Danano, Daniel Tewodros, Dessalegen Mesfin, Dubale Admasu, Gelila Woodeneh, Getu Zegye, Girma Balcha, Hailu Tefera, Hiwot Michael, Ian Campbell, Jeremy Webb, Mahary Maasho, Mahlet Eyassu, Mersha Argaw, Mesfin Mengistu, Michael Cat, Moges Worku, Negusu Aklilu, Peter Mwanakatwe, Praveen Wignarajah, Seleshi Getahun, Shewaye Deribe, Tamiru Sebsibe, Tesfaye Alemu, Tewolde Egziabher, Tibebu Tadesse, Valdemar Holmegen,Wondosen Sentayehu, Wondwossen Mekuria, Wolt Soer, Yacob Mulugeta, Zenebe Gegziabher and Zerihun Ambaye.

Financial support from DFID, the governments of the Netherlands and Switzerland, and the Trust Fund for Environmentally and Socially Sustainable Development (TFESSD) is gratefully acknowledged.

Executive Summary

This report is part of a broader study, the Economics of Adaptation to Climate Change (EACC), which has two 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 nationa strategies for adapting to it.

In addition to a "global track" (World Bank 2010), where multicountry databases were used to generate aggregate estimates at a global scale, the EACC project includes a series of country-level studies, where national data were disaggregated to more local and sector levels, helping to understand adaptation from a bottom-up perspective.

Key Concepts

In accordance with the broader EACC methodology, climate change impacts and adaptation strategies were defined in relation to a baseline (no-climate change) development trajectory, designed as a plausible representation of how Ethiopia'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 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.

For Ethiopia, a baseline, no-climate-change scenario reflecting current government plans and priorities and spanning the 2010–2050 time horizon, was established in consultation with government officials at a workshop in November 2009. The baseline includes an ambitious investment program in dams, hydropower development, irrigation, water management, and road building.

Impacts are evaluated as the deviation of the variables of interest—economic welfare, sector development objectives, and so on—from the baseline trajectory. 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. These 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. To capture these uncertainties, this study utilizes the two "extreme" GCMs used in the global track of the

EACC (labeled Wet1 and Dry1), as well as two additional models that are better suited to represent climate model uncertainty in the specific case of Ethiopia (labeled here Wet2 and Dry2). The Wet1 and Dry1 are used to ensure consistency with the EACC global track; but the Ethiopia Dry (Dry2) and the Ethiopia Wet (Wet2) capture more adequately the range of variation of climate outcomes specific to Ethiopia.

Ethiopia's Vulnerability to Climate Variability and Change

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

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

Impacts

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

Changes in precipitation and temperature from the four GCMs were used to estimate (a) changes in yields for major crops and impacts on livestock, (b) flow into hydropower generation facilities and the consequent changes in power generation, (c) the impact of flooding on roads; (d) the effects of more frequent droughts on government expenditure on vulnerability and food security (VFS); and (e) the loss of irrigation and hydropower due to conflicts among competing demands. The analysis assesses deviations in GDP and other variables from the no-climate-change baseline growth path for the four climate change scenarios mentioned above, which are intended to capture the range of possible variability in Ethiopia: Dry1, Dry2; Wet1, and Wet2.

For the baseline (no-climate-change scenario), the analysis uses historical monthly climate data and projects the historical pattern into the future. For the climate change scenarios, stochastic representations of weather variability in each global circulation model are superimposed on the baseline to capture the variability of the future. The scenarios include projections of extreme weather events such as droughts and floods.

Economy-wide impacts of climate change were assessed using a computable general equilibrium (CGE) model. The results of the modeling suggest that the GDP losses are significant, but diverse across scenarios. Under the Dry2 scenario, losses are large (6 to 10 percent) and regularly distributed during the time horizon considered. In contrast, in the case of the Wet 2 scenario, the loss of GDP is quite substantial in the 2040–49 decade because of the costs of coping with damage caused by extreme weather events, especially floods, from the 2030 decade onward. The 10-year average GDP for the final decade is nearly 8 percent lower than in the baseline. While these are not forecasts of future climate impacts, they highlight the high degree of vulnerability of Ethiopian agriculture and infrastructure to the climate shocks of the future.

Climate change brings about increased weather variability, which translates into large swings in the growth rate of agricultural GDP, illustrated in Figure 2 by the increase in standard deviation compared to the baseline. While the simple means of annual growth rates are similar across the scenarios, high variability leads to significant welfare losses. A priority for adaptation investment is therefore to reduce income variation and the related welfare losses.

FIGURE 1 DEVIATIONS OF GDP FROM BASE SCENARIO

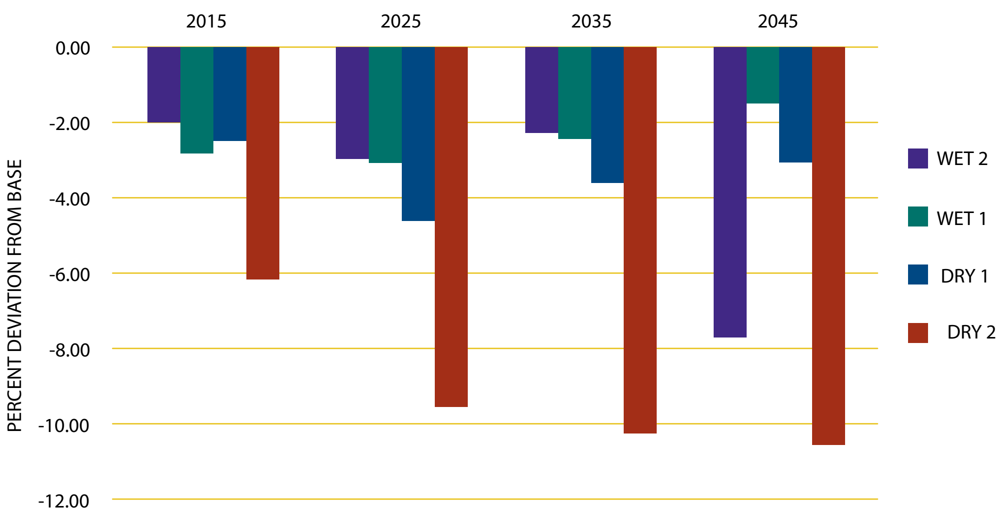


FIGURE 2 AGRICULTURAL YEAR-TO-YEAR GROWTH RATES: STANDARD DEVIATIONS

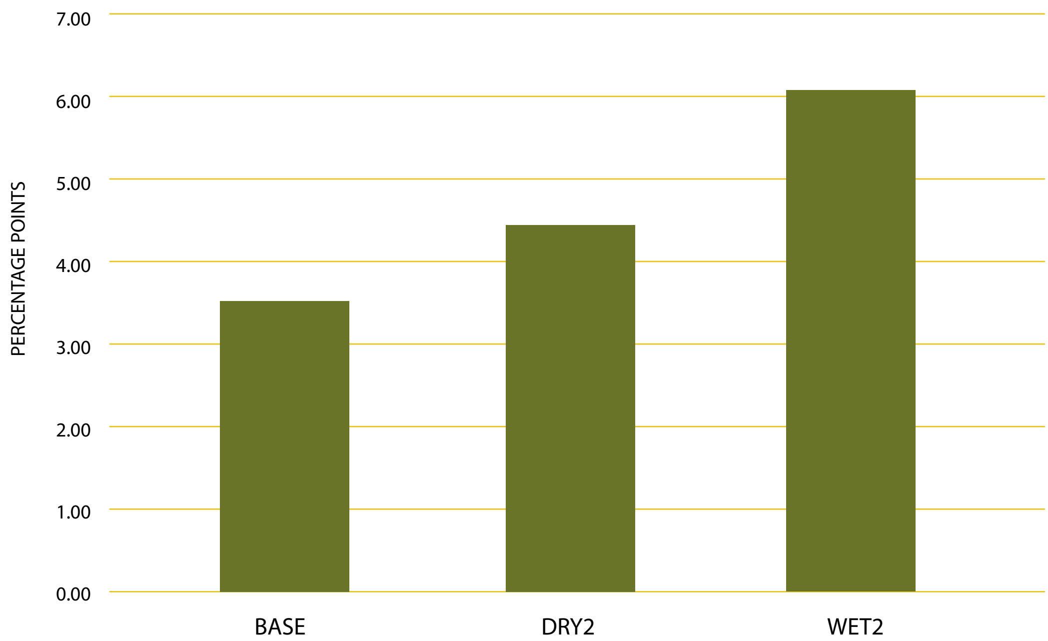
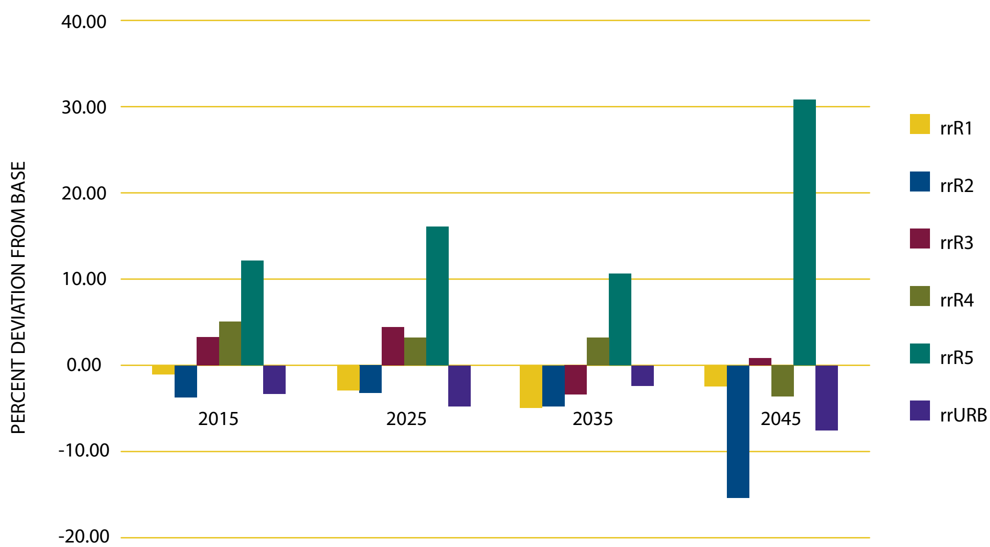


FIGURE 3 REGIONAL GDP, DEVIATION FROM BASE, WET2



Notes: Regions R1 to R5 and Urban.

Variability in agricultural income tends to affect the poor more, with values of the standard deviation on average some 10 percent higher than for the non-poor, under both wet and dry scenarios.

Finally, as shown in Figure 3 for the Wet2 scenario, climate change impacts are likely to vary significantly across regions.

The arid lowland zone 5 (R5) derives substantial benefits from the increase in total rainfall, which supports livestock, while relative losses are concentrated in the cereals-based highlands zone 2 (R2) and in urban areas. The latter reflects the downstream consequences of flooding and weather variability. The dry scenarios have reverse impacts, with the arid lowlands and livestock suffering greatly.

In addition to analysis of the three priority sectors (agriculture, roads, and hydropower), the study also analyzed potential conflicts under climate change in the use of water across sectors. A water planning model was used to evaluate the potential interactions among growing municipal and industrial (M&I), irrigation, and hydropower demands under climate change. The model evaluates these intersectoral effects between 2001 and 2050 and generates time series of impacts to irrigated agricultural yields and hydropower generation under each of the climate scenarios.

The result of the intersectoral analysis indicates that hydropower production is impacted by irrigation and M&I withdrawals. Under the Dry2 scenario, if priority is given to agricultural demands, there is a loss of hydropower capacity equivalent to 100 percent of the 2000 installed capacity and 10 percent of the hydropower capacity planed by the government for the period 2011–15.

If, on the other hand, priority is given to hydropower, up to a billion cubic meters of water might be taken away from irrigated agriculture. That would cause a 30–40 percent yield drop in an area of some 250,000 hectares that would be forced to revert to rainfed conditions.

Adaptation

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

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

These strategies were first assessed on a sector-by sector basis. When the full set of economywide linkages is taken into account, direct plus indirect adaptation costs increase significantly, as indicated in Table 1.

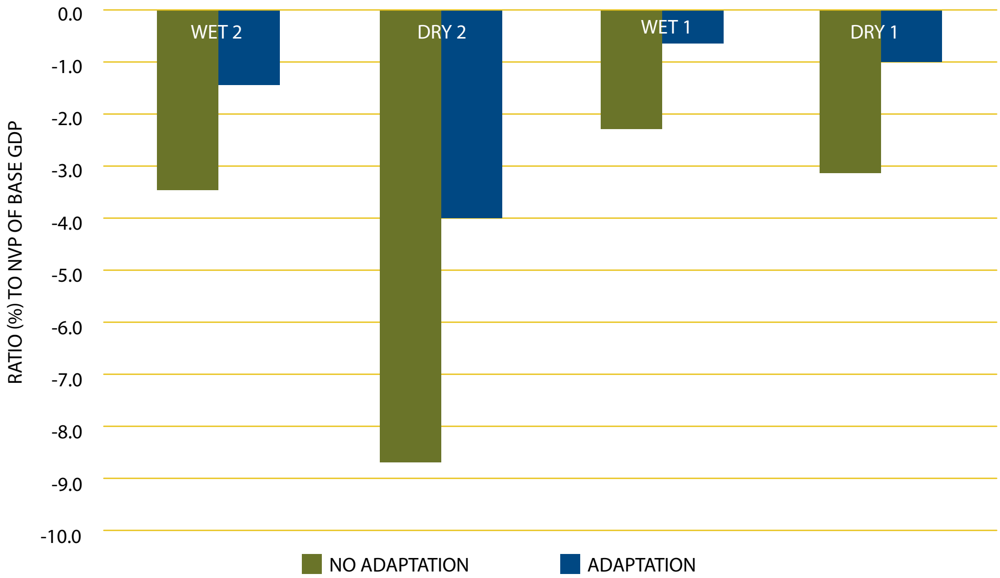
TABLE 1 ADAPTATION COSTS (ANNUAL AVERAGE, 2010–50, US$ BILLIONS)

Scenario	*Direct, sector level costs*	*Indirect costs*	*Total direct and indirect costs*
Wet 1	0.19	0.60	0.79
Dry 1	0.17	0.77	0.94
Wet 2	0.16	2.30	2.46
Dry 2	0.26	2.55	2.81

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

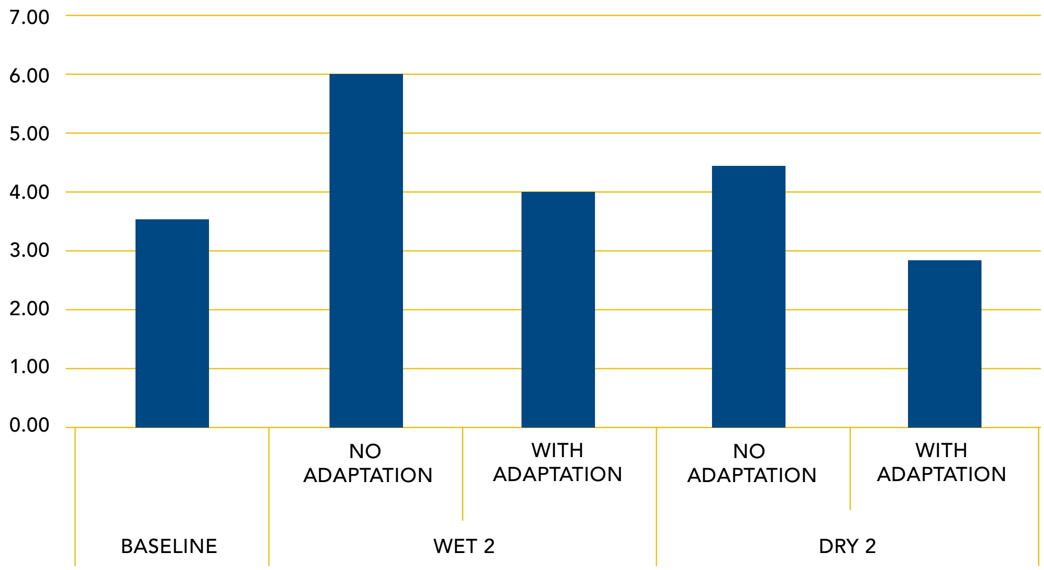
As shown in Figure 4, adaptation greatly reduces the welfare loss due to climate change (measured here by the difference from the baseline of total absorption –GDP plus imports minus exports, discounted over the 40-year time horizon).

FIGURE 4 NET PRESENT VALUE (NPV) OF ABSORPTION DIFFERENCES



Note: NPV of Absorption, Difference from Base (% of NPV of GDP). Absorption is defined as GDP, plus imports minus exports

FIGURE 5 STANDARD DEVIATION OF YEAR-TO-YEAR AGRICULTURE GDP GROWTH RATES, WITHOUT AND WITH ADAPTATION



The (undiscounted) welfare benefits of the adaptation strategy are significantly larger than the project-level costs of implementing it, resulting in benefit/cost ratios ranging from 5 to over 13. Finally, adaptation restores the variability of agriculture GDP growth close to the baseline scenario (Figure 5).

While the benefits of adaptation investments are significant, they do not fully offset the negative impact of the climate change scenarios. Two options were explored to close the "welfare gap" caused by climate change.

The first is to estimate the "residual damage costs" as the transfer (in $) that would be required to completely offset the loss of absorption from climate change shock, after implementing adaptation investments. Closing the "welfare gap" through residual compensation would entail mobilizing significant resources compared to direct project-level adaptation costs.

TABLE 2 ADAPTATION COSTS AND RESIDUAL DAMAGE (ANNUAL AVERAGE, 2010-2050), US$ BILLIONS

Scenario	*Adaptation costs*	*Residual damage*	*Total*
Wet2	2.45	1.52	3.97
Wet1	0.79	0.43	1.22
Dry1	0.94	0.81	1.75
Dry2	2.81	3.03	5.84

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

While no information was available within the analysis' time frame to properly estimate the cost of the skill upgrading program, this finding points to the significant potential benefits of accelerating the diversification of the economy away from highly climate sensitive sectors, such as agriculture. In the Wet2 scenario, for any value of the program cost below $1.5 billion/ year, a development strategy including a skill upgrading program like the one considered here would appear to be preferable to the residual compensation approach.

ADAPTATION PRIORITIES: LOCAL-LEVEL PERSPECTIVES

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

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

Recommendations

The findings of this analysis suggest that impacts of climate change will be quite significant, particularly as Ethiopia approaches the middle of the century. While the magnitude of the impacts remains considerable—irrespective of whether the climate of the future will be wetter or drier—several important adaptation decisions are sensitive to what climate is expected.

Given the large uncertainty on future climate outcomes, the approach to enhance Ethiopia's climate resilience should be couched in terms of a gradual, adaptive, and learning paradigm. Such an approach could be articulated for both the shorter term—including the implementation of the Growth and Transformation Plan (GTP) recently issued by the government—and for the longer term.

SHORTER TERM (UP TO 2015)

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

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

AGRICULTURE

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

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

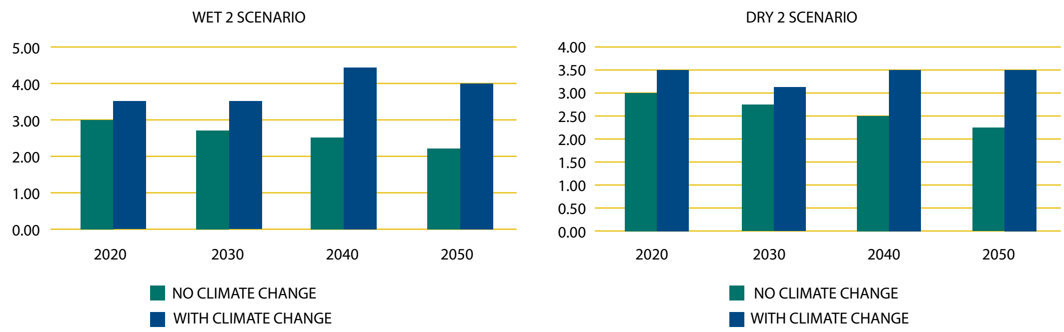
ROAD INFRASTRUCTURE

The GTP aims to expand the coverage and enhance the quality of infrastructure: "Focus will be given to the development of roads, railways, energy, telecommunication, irrigation, drinking water and sanitation, and basic infrastructure developments … With regard to roads, rural roads will be constructed on all regions and all rural kebeles will be connected (through) standardized all-weather roads with main highways." Modeling results show that existing infrastructure design standards (level of prevention against extreme events, e.g. local and regional flooding) are inadequate to address current climate variability and will impact economic growth rates in the near- and mid-term. Results from climate change analyses show that this issue is likely to become worse in the mid to long term. The government should consider enhancing infrastructure design standards as soon as possible.

Even under current climate, the direct benefits—in terms of increased lifetime—of roads designed following higher standards outweigh the corresponding costs in a discounted benefit/cost analysis. The case for improved design standards is even stronger under climate change, irrespective of climate outcomes: the benefit/cost ratio of adopting higher design standards is 17 percent to 75 percent higher than in the baseline under the Wet2 scenario, and 16 to 55 percent higher in the Dry2 scenario (Figure 6). And in addition there are important indirect economywide benefits: a more climate-resilient road network can avoid costly disruptions of communications links and supply chains that increased flood frequency might bring about.

The GTP includes ambitious targets for upgrading the road network, including 70,000 km of all-weather, Woreda (locally administrative unit) managed roads. Unpaved roads only have a 5-year design span until resurfacing and they are very susceptible to flooding damage, which has

FIGURE 6 BENEFIT/ COST RATIO OF UPGRADING ROAD STANDARDS



very large indirect, economywide costs on supply chains, health and education services, etc. The government may want to consider a more detailed economic analysis of the road expansion targets to determine if building fewer but more climate resilient roads is preferable to building a larger number of roads, which are likely to be more vulnerable to climate shocks. The case for the former option seems compelling under the current climate, and will become even sounder under the climate of the future. In addition, should international climate finance resources become available in the future for Ethiopia (from the Copenhagen Green Fund or other mechanisms), the government might consider utilizing these resources for enhancing the climate resilience of the road network expansion plans.

ENERGY

Current water resources and Ethiopian topography indicate an overall potential of more than 30,000 megawatts in economically viable hydropower generation capacity. The GTP approach is to focus on "the development of water and wind energy options to fulfill the energy demand of the country," with targets for hydropower of 6,000 to 8,000 MW in additional generation capacity. The hydropower analyses of this report (conducted at the monthly scale, which is adequate for sector-wide planning purposes, although not for plant-level design and operation), provides support, from a climate change perspective, to the GTP targets. The projects likely to go online in the next 5 years have very low risk of being impacted by climate change.

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

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

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

MEDIUM TO LONG TERM

As Ethiopia looks into the next stages of development—starting with preparation of the next growth plan, which will follow the GTP 2011–15)—it might want to evaluate more closely the implications of climate change for its overall policies and infrastructure development programs. Early planning for the more severe climate impacts of mid-century is desirable, so as to avoid locking the country into a climate-vulnerable development trajectory, particularly when it comes to economic processes with a high degree of inertia, or investment decisions concerning infrastructures with a long life span.

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

MACROECONOMIC MANAGEMENT

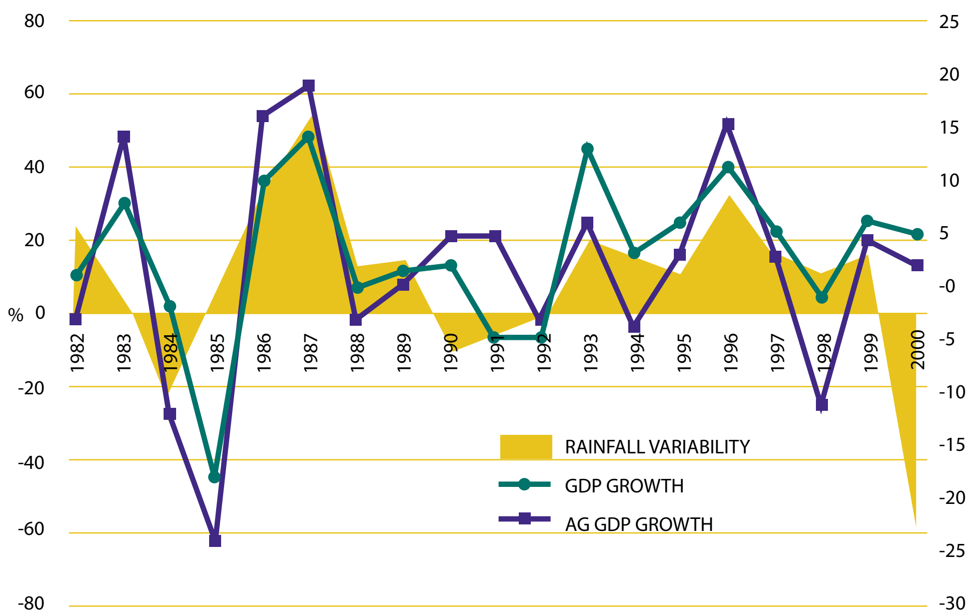
Historically the Ethiopian economy has been vulnerable to climate fluctuations (Figure 7). The analysis of this report shows that climate variability will increase under all scenarios. Since agriculture (the economy's most climate sensitive sector) is likely to remain for some time one of Ethiopia's main engines of growth, climate-induced shocks will continue to be a threat to macroeconomic stability, because of the impacts on income, employment, fiscal revenues, capital formation, the drain on government expenditure, aid flows to support disaster relief, and so on.

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

PROMOTE DIVERSIFICATION ACROSS SECTORS OF INCOME AND EMPLOYMENT

In the longer term, however, accelerated diversification of income and employment sources away from climate-sensitive sectors such as agriculture

FIGURE 7 **ECONOMIC GROWTH AND CLIMATE**



Source: De Jong, The World Bank (2005) is likely to become increasingly important under a more erratic climate. It be should explored in closer detail, particularly because it holds promise to be a cost-effective way to eliminate residual welfare damage caused by climate change.

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

EVALUATE THE CLIMATE RESILIENCE OF LARGE INFRASTRUCTURE PROJECTS

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

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

PROACTIVELY ADDRESS CONFLICTS IN WATER USES

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

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

ONE

Introduction

Background

The Economics of Adaptation to Climate Change (EACC) has two specific analytical 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 it.

The EACC study comprises a global track to meet the first study objective and a case study track to meet the second one. The country track comprises 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 data sets that have global coverage. Sectors covered are agriculture, forestry, fisheries, infrastructure, water resources, coastal zones, health, and ecosystem 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 being assessed by sector, but only for the major economic sectors in each case study country. Differently from the global analysis, though, 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 CGE modeling are being used to integrate the sector level analyses and to identify cross-sectoral effects, such as relative price changes.

Scope and Limitations

The purpose of this study is to assist the government of Ethiopia in its efforts to understand the potential economic impacts of climate change and to develop sound policies and investments in response to such impacts. Adaptation options and their costs are estimated and compared with the costs of inaction. The analysis of impacts and adaptation focuses on three sectors considered: agriculture, road infrastructure, and hydropower. In addition, an evaluation of the economywide repercussions of the sector-wise impacts is also included.

The study methodology and a first set of results were discussed at a workshop with government officials and other stakeholders in Addis Ababa in November 2009. This report presents a set of findings that take into account comments and suggestions made at the meeting, particularly on the definition of a development baseline consistent with the government's priorities and plans. This report also incorporates new work on livestock, irrigation, road infrastructure, and tradeoffs in water use between hydropower and irrigation.

The study does not have the ambition to cover the full range of impacts that climate change might have on Ethiopia's economic and social development. Given resources and time constraints, it focused on three sectors (agriculture, roads, and hydropower) that play a strategic role in the country's current economic structure and in its future development prospects. However, it is important to recognize that climate change might have important impacts in other areas not covered by this report; for example, the provision of ecosystem services (e.g. by forests or wetlands), or the effects of climate change on human health. As a result, the estimates of impacts are likely to be a conservative, lower-bound approximation of the fuller spectrum of effects that climate change might bring about. The analysis has been conducted at the subnational level (the five agro-ecological regions discussed in chapter 3), but further spatial disaggregation would be desirable for future finer-level analysis on specific sectors such as agriculture.

In addition, the report's scope is limited in terms of the adaptation options considered. The analysis focused on a relatively limited numbers of options in each of the three sectors considered. The choice was guided by availability of data, and by the possibility of utilizing straightforward and broadly accepted methodologies. More work would be required to evaluate a fuller range of adaptation options. This would best be done through follow-up studies undertaken at the level of individual sectors, rather than at the multisectoral, economywide level of the present study.

The report is structured as follows. Background information related to climate vulnerability specific to Ethiopia is provided in chapter 2. Methods used to assess the economics of adaptation are described in chapter 3. Estimated impacts of climate change are presented in chapter 4. Adaptation options, including economywide costs, are outlined in chapter 5, and conclusions are provided in chapter 6.

TWO

Country Background

Basic Features

With around 75 million inhabitants, Ethiopia is the second most populous country in Sub-Sahararan Africa (SSA). Despite rapid economic growth over the past five years, per capita income—$255 in 2006/07 at current prices—remains well below the region's average. The 2006/07 share of agriculture in GDP is 46 percent, while industry accounts for 13 percent and services for 41 percent (CSA 2008). The main export commodity is coffee with a share of 35.7 percent in total merchandise exports in 2006/07, followed by oil seeds (15.8 percent), gold (8.2 percent), chat (7.8 percent), leather and leather goods (7.5 percent), and pulses (5.9 percent) (IMF 2008). Ethiopia is a net importer of wheat; petrol, coal, and gas are only imported.

Current Growth and Poverty Reduction Policies

The Ethiopian government prepared and adopted three successive poverty reduction strategy programs. The first was the Sustainable Development and Poverty Reduction Program (SDPRP). that covered three years from 2000/01 to 2003/04. The second is a five-year (2005–10) guiding strategic framework known as Plan for Accelerated and Sustained Development to End Poverty (PASDEP). The third strategy plan, recently published, is the "Growth and Transformation Planning (GTP) 2011–2015."

Policies related to human development, rural development, food security, and capacity building that were a priority in the SDPRP were augmented under the PASDEP. In addition to these, new strategic directions with emphasis on commercialization of agriculture and an emerging urban agenda are also pursued as a means to mitigate the challenges faced by the agriculture sector and the overall economy.

The government strategy in agriculture emphasizes a major effort to support the intensification of marketable farm products by both small and large farmers. To help jump-start this process, a range of public investments have been identified and are being implemented. The major investments include the construction of farm-to-market roads and area irrigation through multipurpose dams. Other related services include measures to improve land tenure security, reforms to improve the availability of fertilizer and improved seeds, and specialized extension services for differentiated agricultural zones and types of commercial agriculture (Ahmed et al. 2009).

Growth and Transformation Planning (2011–2015), recently issued by the Ministry of Finance and Economic Development, outlines growth strategies planned for the next 5 years. The agricultural sector is identified as a key driver of growth. As this sector is particularly sensitive to climate, there is an opportunity to consider the implications of the EACC findings with respect to the GTP (Chapter 5).

Climate and Vulnerability to Climate Change

Around 45 percent of Ethiopia consists of a high plateau with mountain ranges divided by the East African Rift Valley. Almost 90 percent of the population resides in these highland regions with elevations greater than 1,500m above sea level. The surrounding lowlands (<1,500m) are mostly populated by pastoralists. Ethiopia's varied topography has traditionally been associated with three main climatic zones: (a) the warm, semiarid *Kolla*, <1,500m above sea level; (b) the *Woinadega*, a cool, subhumid temperate zone, 1,500–2,400m above sea level; and (c) the cool and humid *Dega*, mostly >2,400m above sea level. As the population increased and agricultural activities expanded, two more were added at the extreme ends of the nation's climatic conditions: the hot, arid *Bereha*, and the cold and moist *Wurch*.

Ethiopia is heavily dependent on rainfed agriculture. Its geographical location and topography in combination with low adaptive capacity entail a high vulnerability to adverse impacts of climate change. Regional projections of climate models not only predict a substantial rise in mean temperatures over the 21st century, but also suggest an increase in rainfall variability with a rising frequency of both extreme flooding and droughts due to global warming. The agricultural sector also affects performance in other sectors of the economy. Hence, there is a strong observable link between climate change variations and overall economic performance.

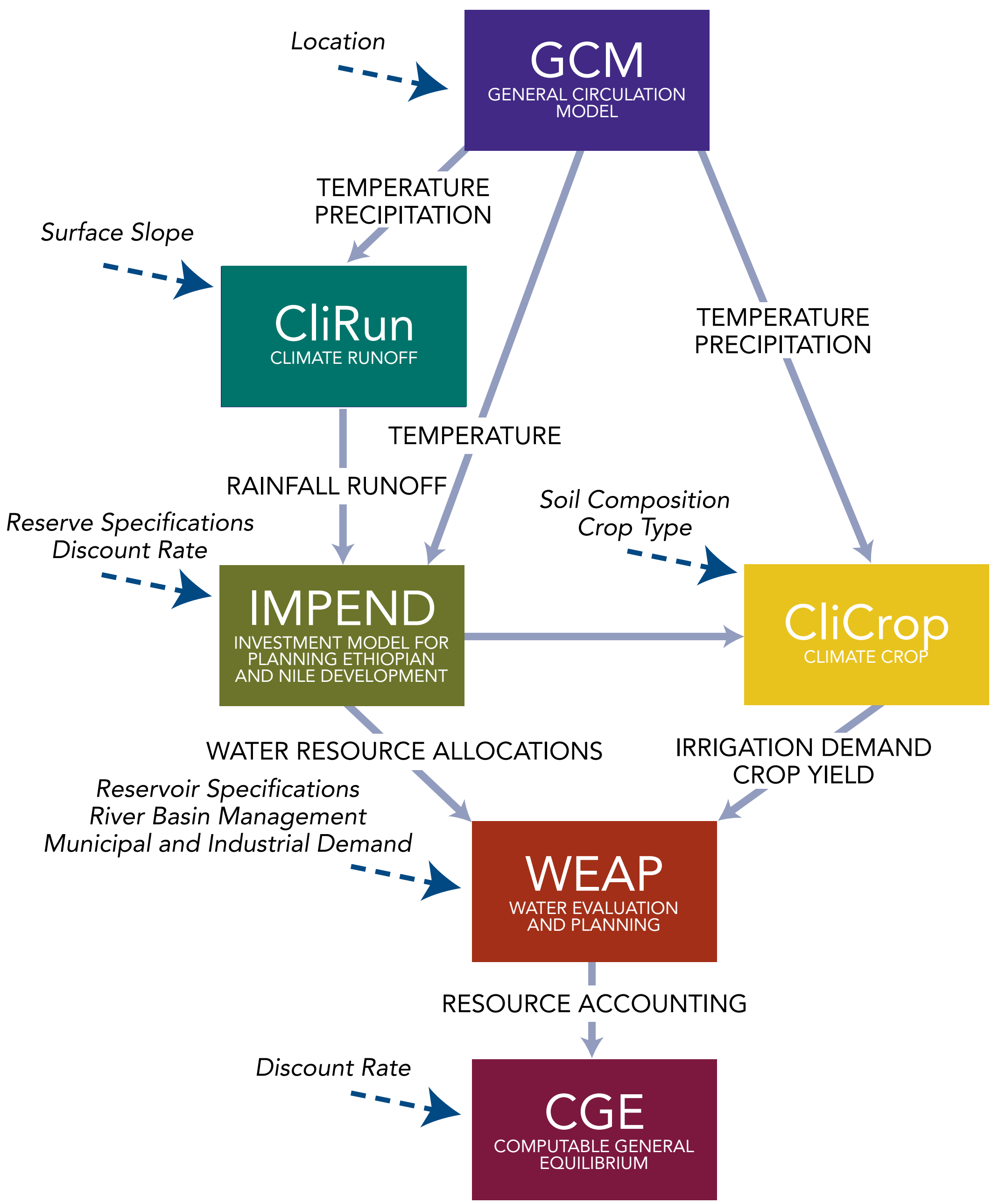
Ethiopia is historically prone to extreme weather events. Rainfall in Ethiopia is highly erratic, and most rain falls intensively, often as convective storms, with very high rainfall intensity and extreme spatial and temporal variability. Since the early 1980s, the country has suffered seven major droughts, five of which led to famines in addition to dozens of local droughts (Diao and Pratt 2007). Survey data show that between 1999 and 2004 more than half of all households in the country experienced at least one major drought shock (UNDP 2007). Major floods occurred in different parts of the country in 1988, 1993, 1994, 1995, 1996, and 2006 (ICPAC 2007).

It is important to highlight that climate change is projected to take place over the course of the next century. In accordance with the approach followed by the broader EACC study, this report will only consider the implications of climate change to 2050 (by decadal increment), even though climate change is expected to be most severe toward the end of the century. The long time frame considered—40 years into the future—means that dynamic processes are important. Two distinct approaches to the analysis were used: quantitative modeling for biophysical and economic assessments, and participatory social analysis.

Modeling Approach

The economywide modeling component of the EACC Ethiopia case study involves linking a dynamic multisectoral and multiregional computable general equilibrium model (CGE) with a range of sectoral climate change impact models that generate quantitative estimates of effects on water systems, agriculture, hydro-energy, and road transport infrastructure (Figure 8).

FIGURE 8 **FLOW CHART OF MODEL SEQUENCING**



Global circulation models (GCMs) lie at the beginning of the modeling chain. These models take as inputs quantities of greenhouse gases emitted and produce climate outcomes through time and across space as a function of these emissions and initial conditions. A series of hydrological and crop models are the next elements in the chain. These models take climate outcomes and convert them to natural outcomes on the ground. Outcomes of particular interest are crop yields, which temperature and rainfall can influence substantially, and hydrological flow within river basins, including the incidence of floods.

The flow of information through the integrated river basin and water resource model is generally linear, as shown above in Figure 8. Climate data is entered into CliRun and CliCrop in order to produce streamflow runoff estimates and crop irrigation demand estimates.

CliRun is a two-layer, one-dimensional infiltration and runoff estimation tool that uses historic runoff as a means to estimate soil characteristics. A 0.5° by 0.5° historic global runoff database generated by the Global Runoff Data Center (GRDC) and measured historic runoff is used to calibrate CliRun. CliCrop is a generic crop model described in chapter 2. Inflows calculated using CliRun are passed to IMPEND, where storage capacity and irrigation flows are optimized to maximize net benefits. The outputs from IMPEND, along with the irrigation demands estimated from CliCrop, 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 socioeconomics of the river basins being modeled.

Finally, this information is passed to the CGE, 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 is an iterative process depending on the scenario and will be completed in the next phase of work. Reservoir flow calculated in WEAP may change previous inputs into IMPEND, thus requiring the net benefits to be recalculated and their implications re-modeled in WEAP. The following subsections describe the sector models CliCrop, a road algorithm, IMPEND, and CGE.

Approach to Climate Model Uncertainty

Historic and future climate inputs specific to Ethiopia and its river basins—such as monthly temperature and precipitation—are used to drive the river basin and water resource model and crop models outlined below. Historic inputs have been gathered using data from the Climate Research Unit (CRU) on global monthly precipitation and temperature. Information on future climate has been taken from four general circulation models (GCMs), forced with different CO_2 emission scenarios to represent the total possible variability in precipitation.

There were four climate change scenarios used for this analysis. The scenarios were selected to span the range of possible climatic change as measured by the Climate Moisture Index (CMI). The CMI is an aggregate measure of annual water availability. It provides for an integrated measure of the impact of climate change on soil moisture and runoff from changes in both temperature and precipitation. Since CMI is an annual measure, it does not account for seasonal changes and the potential for increased flooding due to changes in daily and monthly scale precipitation processes in the midst of annually drier climate. Two scenarios, the Dry1 and Wet1, come from the EACC global track (Box 1). They are the wettest and driest scenarios measuring the changes in CMI over all the land area of the globe. These scenarios were examined to provide for linkage and comparison of the EACC global and country-study tracks.

BOX 1 CLIMATE SCENARIOS IN THE GLOBAL AND ETHIOPIA TRACK OF THE EACC

In the EACC global track study, two models—the National Center for Atmospheric Research (NCAR) CCSM3 and Commonwealth Scientific and Industrial Research Organization (CSIRO) Mk3.0 models—with SRES A2 emission forcings were used to model climate change for the analysis of most sectors. These models capture a full spread of model predictions to represent inherent uncertainty, and they report specific climate variables—minimum and maximum temperature changes—needed for sector analyses. Though the model predictions do not diverge much for projected temperature increases by 2050—both projecting increases of approximately 2°C above pre-industrial levels—they vary substantially for precipitation changes. Among the models reporting minimum and maximum temperature changes, NCAR was the wettest scenario and CSIRO the driest scenario globally based on the climate moisture index (CMI).

In line with the global track, the climate projections from these two GCMs are used to generate the "global wet" and "global dry" scenarios for the Ethiopia country-track study, referred to as Wet1 and Dry1. In addition, the climate projections from the two GCM/SRES combinations with the lowest and highest climate moisture index for Ethiopia were used to generate "Ethiopia dry" and "Ethiopia wet" scenarios. Precipitation and temperature data acquired from these simulations are used to estimate the availability of water at a sub-basin scale. Historical climate data for each basin have been gathered using available precipitation and temperature data when available, along with the Climate Research Unit's 0.5° by 0.5° global historical precipitation and temperature database.

For Ethiopia both of the test scenarios show modest temperature increase and very small changes in annual precipitation. Dry2 and Wet2 are the extremes scenarios of CMI change evaluated only over the area of Ethiopia (Table 3). Over Ethiopia, the Dry2 scenario shows reductions in average annual rainfall over 2045–55 greater than 15 percent. The Wet2 scenario show increases in average annual rainfall close to 25 percent over most of the rest of the country.

TABLE 3 GCM SCENARIOS FOR ETHIOPIA COUNTRY TRACK STUDY

Scenario	*GCM*	*SRES*	*CMI Deviation* (%)*
Wet 1: Global Wet	ncar_ccsm3_0	A2	10
Dry 1: Global Dry	csiro_mk3_0	A2	-5
Wet 2: Ethiopia Wet	ncar_pcm1	A1b	+23
Dry 2: Ethiopia Dry	ipsl_cm4	B1	-15

Note: *The Climate Moisture Index (CMI) depends on average annual precipitation and average annual potential evapotranspiration (PET). If PET is greater than precipitation, the climate is considered to be dry, whereas if precipitation is greater than PET, the climate is moist. Calculated as CMI = (P/PET)-1 {when PET>P} and CMI = 1-(PET/P) {when P>PET}, a CMI of –1 is very arid and a CMI of +1 is very humid. As a ratio of two depth measurements, CMI is dimensionless. Average annual PET is a parameter that reflects the amount of water lost via evaporation or transpiration (water consumed by vegetation) during a typical year for a given area if sufficient water were available at all times. Average annual evapotranspiration (ET) is a measure of the amount of water lost to the atmosphere from the surface of soils and plants through the combined processes of evaporation and transpiration during the year (measured in mm/yr). Evapotranspiration, which is both connected to and limited by the physical environment, is a measure that quantifies the available water in a region. Potential evapotranspiration is a calculated parameter that represents the maximum rate of ET possible for an area completely covered by vegetation with adequate moisture available at all times. PET is dependent on several variables, including temperature, humidity, solar radiation, and wind velocity. If ample water is available, ET should be equal to PET.

INTERPRETING CLIMATE SCENARIOS

IPCC reports that while in terms of annual precipitation in Ethiopia, some climate models indicate increases and some decreases, all models suggest increases in precipitation intensity at the daily and weekly scale (Figure 9). This implies more flooding even in scenarios that suggest more drought. Both increased flooding and increased drought are projected by the same scenarios.

Another important aspect of the IPCC climate change scenarios is that they are generated by dynamic models that are transient over the century. While temperature mostly increases monotonically, precipitation does not. Figure 10 shows a set of climate change precipitation projections averaged over East Africa. These show that there is a great deal of variability from year to year. Some scenarios even switch from increasing to decreasing precipitation, or from decreasing to increasing, over different periods of the 21^{st} Century. These changes can lead to climate change impacts that vary by decade within a less transient multi-decadal trend of reduction or increase in precipitation.

Crop Model Description

CliCrop is a generic crop model used to calculate the effect of variations in CO^2 daily precipitation patterns caused by climate change on crop yields and irrigation water demand. The model was developed in response to the available crop models that 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 IPCC GCMs predict that total annual precipitation will decrease in Africa, but rain will be more intense

FIGURE 9 CGM PROJECTION ON DAILY PRECIPITATION INTENSITY

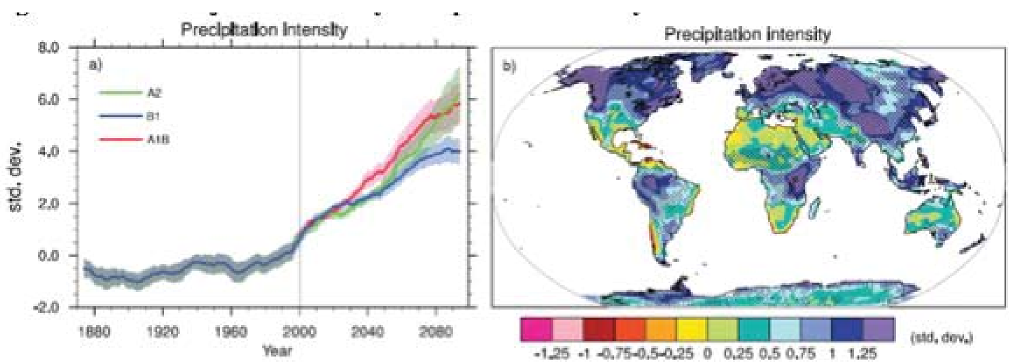
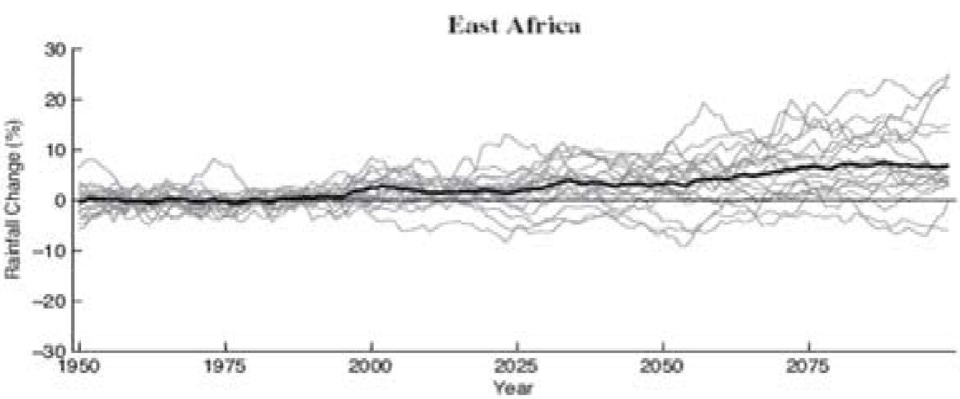


FIGURE 10 PRECIPITATION CHANGES FOR IPCC A1B SCENARIO



and therefore less frequent. Currently 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 it was developed to study effects of agriculture on a global or continent scale, it is a generic crop model. CliCrop can be used at a variety of scales, from field level to agroecological zone. It was developed to measure climate change impacts on water stress and examine field-level adaptation options, including mulching and water harvesting.

The inputs into CliCrop are CO^2 concentration, 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 weather inputs into CliCrop for future scenarios are extracted directly from the four GCMs referred to above. The daily distributions of the precipitation and temperature are derived from the NASA POWER data set for both the baseline and the future scenarios. All of the soil parameters required are extracted from the FAO soils database.

The output of CliCrop is used as input to the computable general equilibrium model (CGE) as shocks/stressors caused by the predicted weather changes from the GCMs. The CGE model includes details about Ethiopia's agricultural crop and livestock commodities, as well as capital, land, and labor inputs. The CGE model is used to study and evaluate impacts of climate change adaption strategies in the agriculture sector and consequently in the other sectors of the economy. The output of CliCrop will also be used in the WEAP model used to calculate the changes in irrigation demand on the reservoir water supply.

Livestock Model Description

This analysis evaluates the effect of changing climate conditions on livestock productivity, relying on a hybrid approach that has two components: a "biophysical" component that considers the effect of temperature on expected livestock incomes, and a "feed" component that incorporates the effect of changing availability of livestock feed. (Ideally, a livestock process model would be available that was capable of explicitly analyzing the effect of changing climate conditions on livestock productivity, and the resulting adaptive responses of livestock farmers. Because no such model is publicly available, this analysis relies on the hybrid approach described above.) The biophysical component relies on the results of a structural Ricardian model of African livestock developed by Seo and Mendelsohn (2006).[1] This model measures the interaction between temperature and livestock and considers the adaptive responses of farmers by evaluating which species are selected, the number of animals per farm, and the net revenue per animal under changes in climate.

The current analysis transfers the findings from Seo and Mendelsohn (2006) to the Ethiopia-specific context. The feed component of the hybrid model uses the outputs of CliCrop to identify how climate change may affect the yields of millet, a primary source of livestock feed in Ethiopia. To evaluate the overall effects of climate change on livestock productivity, the biophysical and feed components are combined to form vectors of changes in expected livestock productivity under the baseline and four climate scenarios between 2001 and 2050. Details of the livestock modeling approach are presented in Annex 8.

1 The Ricardian approach examines how crop production varies in regions of different climates and then infers the effect of climate from these differences (Mendelsohn et al. 1994). The approach explicitly embeds farm adaptations as found in the pooled (time series and cross-sectional) data. Using these data, it is possible to forecast how climate changes affect profits and production in future years.

BIOPHYSICAL COMPONENT

Although the direct effects of heat stress on livestock have not been studied extensively, warming is expected to alter the feed intake, mortality, growth, reproduction, maintenance, and production of animals. Collectively, these effects are expected to have a negative impact on livestock productivity (Thornton et al. 2009). Below, the approach and findings of the Seo and Mendelsohn (2006) study are reviewed, and the transfer methodology is explained.

Seo and Mendelsohn rely on a survey of over 5,000 livestock farmers in ten African countries, one of which was Ethiopia. In this data set, the variation in livestock productivity and expected incomes in different regions demonstrates a clear relationship to regional climate, which provides a mechanism (i.e., through spatial analogue) to statistically analyze how climate change may affect livestock incomes across Africa.[2] The authors develop a three-equation farm-level model. The first equation predicts the probability of selecting each livestock type as the primary animal for the farm, the second predicts the net income of each animal, and the final equation predicts the number of animals on each farm. Farm net revenues are the sum product of these three outputs; that is, the probability of selecting each type of animal multiplied by the number of animals and then the expected income per animal, summed across animal types.

SM uses this model to evaluate fixed changes in temperature of 2.5°C and 5.0°C from the baseline. The resulting predicted changes in the probability of selecting an animal, expected income per animal, and the total number of animals under these changing climate conditions are presented in Tables 4 through 6.

In all three tables, beef cattle and chickens are more sensitive to changes in climate than dairy cattle, goats, and sheep. In prior studies, beef cattle have been found to experience increases in mortality, reduced reproduction and feed intake, and other negative effects as temperatures rise (Adams et al. 1999). Butt et al. (2005) found that small ruminants (such as goats and sheep) are more resilient to rising temperatures than beef cattle. Chickens are particularly vulnerable to climate change because they can only tolerate narrow ranges of temperatures beyond which reproduction and growth are negatively affected. Further, increases in temperature caused by climate change can be exacerbated within enclosed poultry housing systems.

Seo and Mendelsohn (2006) predict that relative to the baseline, the probability of choosing beef cattle and chickens will decline with rising temperatures, but that the probability of selecting dairy cattle, goats, and sheep will increase. Table 5 shows that predicted changes in expected income per animal are most dramatic for beef cattle and chickens, which fall 32 percent and 48 percent, respectively, with an increase of 5.0°C. Finally, Table 6 indicates that rising temperatures reduce the predicted number of beef cattle and chickens on each farm, but will increase the number of other livestock types.

2 Because the raw data from this survey were not available, it was not possible to compare the climatic conditions observed in the Seo and Mendelsohn (2006) survey to the conditions in Ethiopia. If conditions are more attuned to the warmer and more variable climates of western Africa, the impacts estimated here may be overstated.

TABLE 4 PREDICTED CHANGE IN THE PROBABILITY OF SELECTING EACH ANIMAL AS THE PRIMARY ANIMAL TYPE FOR THE FARM (%)

	Beef cattle	*Dairy cattle*	*Goats*	*Sheep*	*Chickens*
Baseline probability	11.8	23.1	23.4	19.4	22.3
Increase temp 2.5C	-1.7	+0.4	+0.8	+3.3	-2.8
Increase temp 5C	-3.8	+2.1	0.0	+8.7	-7.0

TABLE 5 PREDICTED CHANGE IN NET INCOME (US$) PER ANIMAL

	Beef cattle	*Dairy cattle*	*Goats*	*Sheep*	*Chickens*
Baseline income	145.54	132.09	6.49	11.77	1.14
Increase temp 2.5C	-27.80	-3.40	-0.81	-2.55	-0.34
Increase temp 5C	-47.09	-21.36	-0.54	-3.49	-0.55

TABLE 6 PREDICTED CHANGE IN NUMBER OF ANIMALS PER FARM (ANIMALS/HOUSEHOLD)

	Beef cattle	*Dairy cattle*	*Goats*	*Sheep*	*Chickens*
Baseline number	63.47	23.84	15.36	34.05	790.09
Increase temp 2.5C	-9.00	1.84	1.45	0.35	-112.61
Increase temp 5C	-18.96	2.88	2.14	3.20	-183.84

TABLE 7 PREDICTED CHANGE IN EXPECTED INCOME*

	Mean (US$/farm)	*% Change*	*Bootstrap** lower 95% (US$/farm)*	*Bootstrap upper 95% (US$/farm)*
Expected income	3,023			
Increase temp 2.5C	-964	-31.90	-1,077	-722
Increase temp 5C	-2,083	-68.89	-2,452	-1,631

Note: *SM's model does not include any information on livestock prices, only data on per animal net income. As a result, there is no interaction between supply of cattle and market prices in the model. In a model that considered market prices, as livestock numbers fell, prices would likely rise, thus lessening the economic impact of rising temperatures in the model..

** Because effects on income are the product of three separate statistical processes, SM were unable to estimate variance parametrically (i.e., from a well-defined probability distribution). Instead, they used bootstrap methods, which involved resampling from the underlying observed data and then re-running their three-stage model to generate an approximating distribution. This approximating distribution provided the 95 percent confidence interval reported here.

Table 5 combines the above effects into predicted changes (within a 95 percent confidence interval) in expected farm-level income. Seo and Mendelsohn predict a reduction in expected income of 32 percent and 69 percent resulting from a 2.5°C and 5°C increase in mean temperatures. Overall, although both the probability of selection and the number of animals per farm increases for certain types of livestock, the negative responses to climate overwhelm these positive effects. In addition to the fact that the predicted change in net income per animal declines universally across animal types, the animal types that are most affected by changes in temperature (beef cattle and chickens) collectively make up over 60 percent of baseline TLUs and are predicted to generate net incomes that are over 40 percent lower with a 2.5°C increase in mean temperatures. For comparison, dairy cattle generate the largest increases in incomes under the 2.5°C rise at only 7 percent.

To generate vectors of projected changes in expected income from livestock within each AEZ, the analysis uses the framework and findings of Seo and Mendelsohn coupled with country-specific livestock data and climate projections. Details of this transfer are in Annex 8.

FEED COMPONENT

The feed component of the model reflects the availability of feed for livestock under changing climate conditions. Rather than transferring the results of a study, the feed vectors are ratios of the projected millet yields from 2001 to 2050 under the baseline and four climate change scenarios within each AEZ, relative to the mean millet yields under the baseline scenario (25 vectors in total). As a result, the feed ratio can be greater or less than one. The millet yield projections are developed using CliCrop, which produces projections of both irrigated and rainfed yields for the 2001 to 2050 period; this analysis uses the rainfed millet yields.

COMBINING THE BIOPHYSICAL AND FEED COMPONENTS

Next, the vectors from the biophysical and feed components are combined in a weighted average where each vector is given equal weight; that is, a simple average. If additional information becomes available on the relative importance of these two factors in determining livestock productivity, these weights could be adjusted accordingly. The final product is 25 vectors—sets of five AEZ vectors for the baseline and each of the four climate scenarios—that consider both the biophysical and feed effects of climate on livestock productivity. The findings of the livestock analysis are presented in the livestock results in chapter 4.

Drought Model Description

Periodic drought in Ethiopia causes severe reductions in food availability, causing government expenditures on food aid and emergency drought relief to swell during these periods. In recent years, the Ethiopian government has maintained records of expenditures on vulnerability and food security (VFS), which have typically increased extreme droughts (e.g., 1999–2000 and 2003–04).[3] Using a reduced-form statistical model, this analysis estimates the relationship between climate drivers and Ethiopian VFS expenditures, and develops nationwide projections of those expenditures from 2001 to 2050 under the base and four climate scenarios.[4]

The reduced form statistical model relies on historical expenditure data on VFS, historical climate data in drought-prone regions, and a dummy variable reflecting a significant increase in VFS funding from 2001/02 forward because of a federal special purpose grant for food security (World Bank 2008). The latter variable is included in the statistical formulation to explain this large surge in expenditures on VFS. Detailed information related to the drought model is contained in Annex 9.

3 The original data is reported by Ethiopian calendar year, which extends from September 11th to September 10th on the Gregorian calendar (e.g., September 11, 1997 to September 10, 1998 on the Gregorian calendar is 1990 on the Ethiopian calendar). All dates in this analysis are reported in Gregorian terms.

4 A reduced form statistical model is a model that identifies statistical relationships between a dependent variable and one or more independent variables. In the present model, these independent variables are used to explain variations in VFS expenditures. Because this drought model uses observed historical data, the results of this analysis indicate correlation between the dependent and independent variables, but not causation.

Road Transport Model Description

The stressor-response methodology used in this report is based on the concept that exogenous factors, or stressors, have a direct affect on and subsequent response by infrastructure materials used in roads.[5] In the context of climate change and infrastructure in this section, the exogenous factors are the individual results of climate 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 is going to have a specific quantitative impact on the life span of an unpaved road, based on the change in precipitation. (The quantitative estimates presented here, as well as the analysis of the related policy implications, consolidate the findings of COWI (2009)).

Variations across infrastructure type in the relationships between climate and life span 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; for example, 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; for example, 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 was combined with historical data

5 The impact figures presented here are conservative, lower-bound estimates of actual climate change damage. See COWI (2010) for additional analysis.

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; (1) impacts on new construction costs, and (2) 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 rehabilitating the asset, to changes in climate expected to occur over the asset's life span. Maintenance cost effects are those maintenance costs—either increases or decreases—that are anticipated to be incurred due to climate change to achieve the road's 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 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.

Determining impacts. The dose-response relationship between climate change and the cost of maintaining road networks is a central concern for climate change adaptation (Table 6). 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. The former of these can be considered the direct impact and necessary response to climate change. The latter is the optional adaptation that can be done to minimize increased maintenance costs.

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

TABLE 8 DOSE-RESPONSE DESCRIPTIONS FOR MAINTENANCE COSTS

Road Type	*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% change in maximum of monthly maximum precipitation projected during life span.	Not estimated. Impact likely to be minimal.

design of the asphalt mix. Using this approach, the cost increase for the annual maintenance based on dose-response values is based on the concept of infrastructure life-span decrements. 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 (Box 2).

BOX 2 MODELING IMPACTS ON PAVED AND UNPAVED ROADS

PAVED ROADS

Modeling paved roads involves two basic steps as seen in Equation 1 below: (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%)(current maintenance cost) to avoid decreasing the current design life span.

$$MT_{ERB} = (L_{ERB})(C_{ERB}) \qquad \text{(Equation 1)}$$

where
MT_{ERB}: Change in maintenance costs for existing paved roads associated with a unit change in climate stress
L_{ERB}: Potential 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 (LERB), we assume that such a reduction is equal to the percent change in climate stress, scaled for the stressor's effect on maintenance costs (Equation 2).

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

where
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)

UNPAVED ROAD CALCULATIONS (DIRECT RESPONSE METHODOLOGY)

The change in unpaved road maintenance costs associated with a unit change in climate stress is estimated as a fixed percentage of baseline maintenance costs. In general terms, this approach is summarized by Equation 3.

$$MT_{URR} = M \times B_{URR} \qquad \text{(Equation 3)}$$

where
MT_{URR}: Change in maintenance costs for unpaved roads associated with a unit change in climate stress
M: Cost multiplier
B_{URR}: Baseline maintenance costs

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°C change in maximum annual temperature for existing paved roads (FDOT 2009a; FEMA1998; Miradi 2004; Oregon DOT 2009; Washington DOT 2009).

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 (*SMT*). For paved roads, precipitation-related maintenance represents 4 percent of maintenance costs and temperature-related maintenance represents 36 percent (Miradi 2004).

After estimating the potential reduction in life span associated with a given climate stressor, we estimate the costs of avoiding this reduction in life span. To estimate these costs, we assume that the change in maintenance costs would be approximately equal to the product of (1) the potential percent reduction in life span (LERB), and (2) the base construction costs of the asset. Therefore, if we project a 10 percent potential reduction in life span, we estimate the change in maintenance costs as 10 percent of base construction costs. We estimate base construction costs for a primary paved road at $500,000 per km.

Unpaved road maintenance. Maintenance of unpaved roads is primarily focused on the need to reseal the road every five years to preserve a usable driving surface and reduce the impact of erosion from precipitation. To estimate dose-response values for unpaved road maintenance costs, we use a more direct approach for estimating the cost impact of changes in climate stressors. The need for this approach is based on two factors; (1) maintenance tasks for unpaved roads are related closely to the initial construction tasks, and (2) the reduced life span of an unpaved road has established a norm in construction estimating that maintenance is based on initial construction costs as a standard estimating procedure. Given these two factors, we directly relate changes in maintenance costs to specific changes in climate or infrastructure design requirements using a direct response methodology (Box 2).

The stressor-response relationship discussed in Box 2 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 indicates 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, we assume a maintenance cost increase of $7.70 per km.

Flood Cost Model for Road Infrastructure

FLOODING COST IMPACTS

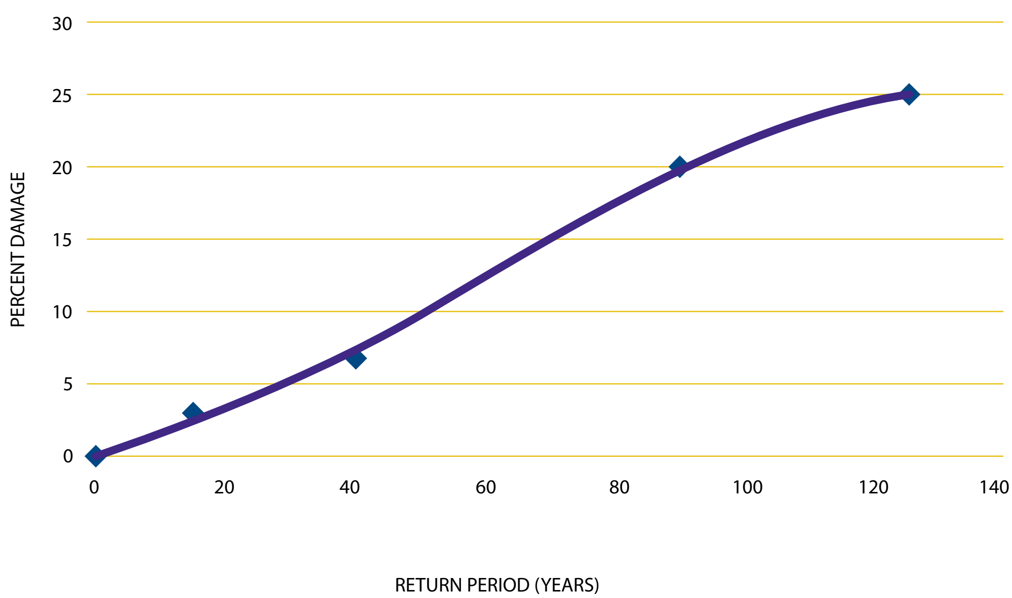
The development of annual cost estimates for the flooding impacts from climate change combines life-cycle concerns, climate impacts and resistance, and cost estimates. Specifically, the cost of climate change impacts on roads must be examined from the design phase through the maintenance phase and through the rehabilitation phase. This life-cycle perspective incorporates the complete spectrum of costs that climate change imparts on the road infrastructure. This section outlines the overall methodology and describes the output generated by this life-cycle perspective, which is used as input to the CGE models.

DAMAGE IMPACTS

Road and highway flood losses were calculated based on monthly runoff estimates generated from CliRun simulations. While road and highway damages actually occur under flooding conditions over a range of time scales (hourly, daily, weekly), only monthly GCM data were available for the time frame required for the EACC study. By using the monthly data to estimate damages, the underlying implication is that the distribution of damages resulting from sub-monthly precipitation follows the monthly rainfall distribution. While this assumption is not likely to be strictly accurate, neither is it likely to introduce strongly biased errors. Given the constraints on data required for the CGE analysis (annual series of damages from 2010 to 2050), this was the only feasible option given the availability of GCM output.

A custom damage function was used to generate loss estimates based on the return period of the precipitation intensities. The damage function given below in Figure 4 is a general damage function for flooding impacts on roads, based on assumed reasonable design standards and engineering judgment. Climate change will have an effect on the curve in that the frequency and intensity of floods may change; for example, what originally was a 70-year flood may occur more frequently, such as a 50-year flood. This will translate to damage becoming more severe on a more frequent basis.

FIGURE 11 **FLOOD DAMAGE RELATIONSHIP**



LIFE-CYCLE CONCERNS

The first component of the flooding methodology translates information on floods into actual kilometers of road that will be damaged. Flood modeling generates information to calculate the percentage of roads anticipated to be damaged in each climate region, based on the intensity and recurrence of the floods as well as the corresponding damage curve. These percentages are provided in a time series from 2010 through 2050. For example the damage calculator may return that in a specific climate zone, in 2025, that .12 percent of the roads will be damaged. This provides the basic input for the system to determine the specific number of roads that will be damaged in a specific year.

The determination of how many kilometers will be damaged is dependent on two factors; whether the roads are paved or unpaved, and how many roads have had adaptations applied to them. In terms of the former, the road inventory is used to determine the number of primary, secondary, and tertiary roads that exist in each region. Additionally, the inventory is used to determine the number of roads that are paved and unpaved within those classifications. From the combination of the damage projection for the specific zone and the inventory for that zone, the total number of potential damaged roads is determined. This is illustrated by the following formula.

$$PDR = (\sum PR * DE) + (\sum UR * DE)$$
$$PDR = (\sum PR * DE) + (\sum UR * DE)$$

Where: PDR = Potential Damaged Roads
PR = Paved Roads
DE = Damage Estimate
UR = Unpaved Roads

The overall total is modified by one of two factors. For paved roads, the potential number is reduced if the roads have had adaptation measures applied to them during the most recent repaving operations. These measures—which include increased drainage, increased road thickness, or a change in asphalt mix—are applied at the end of a 20-year design life span, which then climate-proofs the roads and provides resistance to additional flooding levels induced by climate change. For example, if 1,000 kilometers have the potential to be damaged, but 200 kilometers have been upgraded previously, then 800 kilometers are considered the actual pool from which the damage calculation will be applied.

For unpaved roads, the potential number of damaged roads is reduced by the number of roads that have been damaged and then had an adaptation approach applied over the previous five years of its anticipated design life span prior to re-grading. Adaptations for this group of roads include increasing the thickness of the gravel and applying a sealer to reduce the amount of erosion due to flooding. In the non-adaptation scenario, it is assumed that no adaptation policies have been applied and all roads in the region remain as potential roads that are susceptible to flooding.

IMPEND Model Description

Hydropower simulation was done using a hydropower planning model developed for Ethiopia, the IMPEND model (*Investment Model for Planning Ethiopian Nile Development*) (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, as well as reservoir attributes such as the surface area of each reservoir, design head, and peak energy output. Output includes a time series of energy generation and associated project costs.

The IMPEND simulation required estimates of monthly flow and net evaporation from the hydrologic model CliRun. The CliRun model was used to estimate flow into the hydropower generation facilities for the 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 baseline; operating assumptions, surface areas of the reservoirs, etc. were all held constant. Only influent flow changed.

Given the time scale utilized (monthly time-steps), the modeling does capture seasonal peaking but not daily or hourly peaking, an important aspect of hydropower design and operation. The analysis therefore does not purport to inform project-level decisions, but rather to estimate (a) climate change impacts on annual power production up to 2050, as an input to an annual economy-wide economic model; and (b) the cost to restore hydropower generation to levels attainable in the no-climate-change scenario by constructing additional hydropower capacity.

WEAP Model Description

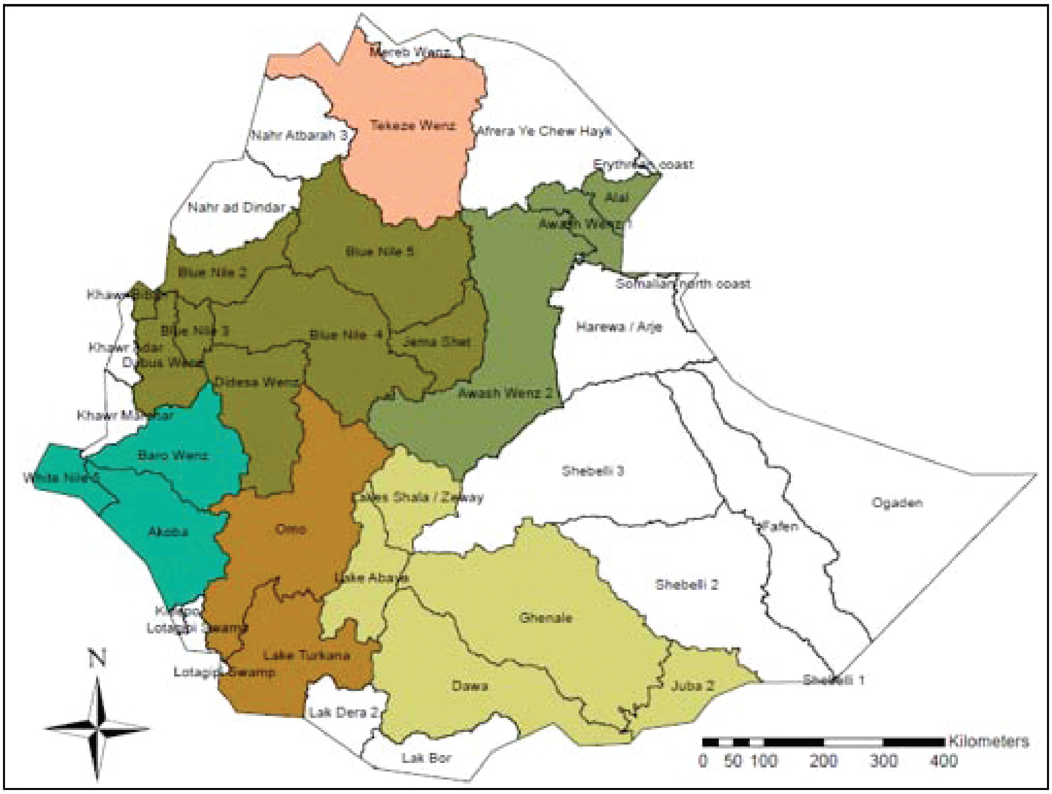
A water planning model is used to evaluate the potential interactions between growing municipal and industrial (M&I) water use, irrigation, and hydropower demands under climate change. The model evaluates these intersectoral effects between 2001 and 2050, and generates time series of impacts to irrigated agricultural yields and hydropower generation under each of the climate scenarios. These time series are used as perturbations to irrigation yields and hydropower generation estimates in the CGE under each of the climate scenarios.

This analysis consists of modeling surface water availability(runoff), reservoir storage, hydropower, and major demands in Ethiopia in order to investigate intersectoral conflicts between water demands. In particular, the study focuses on projected interactions between climate-driven changes in water availability and growing demand for water in the hydropower and irrigation sectors. The analysis projects perturbations, or "shocks," to hydropower production and irrigated crop yields resulting from these conflicts from 2001 to 2050 across Ethiopia. These questions are addressed using the water evaluation And planning (WEAP) tool (Sieber and Purkey 2007), which is a software tool for integrated water resources planning. WEAP provides a mathematical representation of the river basins encompassing the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, existing as well as potential major schemes, and their various demands for water. More information on the WEAP tool is provided in Annexes 5 and 6.

Computations are performed on a monthly time scale for 50 years for a base-case scenario (i.e., no climate change) and the four climate change scenarios. Each climate change scenario is characterized by unique inflows and growing demand, hydropower, and reservoir storage. Unmanaged inflows are modeled using CLIRUN-II (Strzepek et al. 2008), a hydrologic model used in climate change hydrologic assessments that simulates runoff from a lumped watershed. The output runoff projections from CLIRUN-II are used as the available runoff in WEAP. Municipal and industrial (M&I) and irrigation demands both withdraw water from available runoff, and are projected based on World Bank and in-country sources. Hydropower production is calculated for existing and planned dams based on an expected investment and construction schedule. The withdrawals and hydropower production were validated with historical values.

Twenty-one basins in Ethiopia are expected to have hydropower capacity by 2050. Therefore these basins were used as the basis for hydrologic simulation in CLIRUN-II and WEAP, as shown

FIGURE 12 **ETHIOPIA RIVER BASINS MODELED WITH WEAP**



in the shaded areas in Figure 12. These 21 basins may be aggregated to form six larger basins that have outlets exiting Ethiopia; in the figure, basins of like color form these six larger basins.

Surface water inflows from CLIRUN-II were used as inflows to an aggregated river in each basin modeled in WEAP. At the six-basin level, the outflows from each of the rivers either served as additional inflow to a downstream river, or flowed out of Ethiopia; that is, water supplies and demands are linked between the basins forming the six larger basins. In some basins, an aggregate reservoir was included at the head of the modeled river. The analysis assumes that all demands in a basin would have access to storage regardless of potential constraints on the transmission of water. This approach may overestimate water availability in some cases because all demands may not always have access to water, depending on their distance from the supply. If hydropower is generated in a basin, the reservoir and turbine characteristics are calibrated to ensure that the power produced is validated with historical values. Basins that included storage in 2000 (the base year) include the Akoba, Awash Wenz 2, Blue Nile 4, and Blue Nile 5; by 2010, this list also included the Omo and Tekeze Wenz. Several additional reservoirs are added to the WEAP model between 2010 and 2050, as discussed below. Major demand nodes in the Ethiopia WEAP were for municipal, industrial, and irrigation withdrawals from the aggregated rivers.

In general, the representation of the basin structure is similar to the basin schematic shown in Figure 13, which shows the linkage between supply and demand in the Blue Nile 4, the Blue Nile 5,

FIGURE 13 **EXAMPLE OF BASIN SCHEMATIC WITH SUPPLY AND DEMAND IN WEAP**

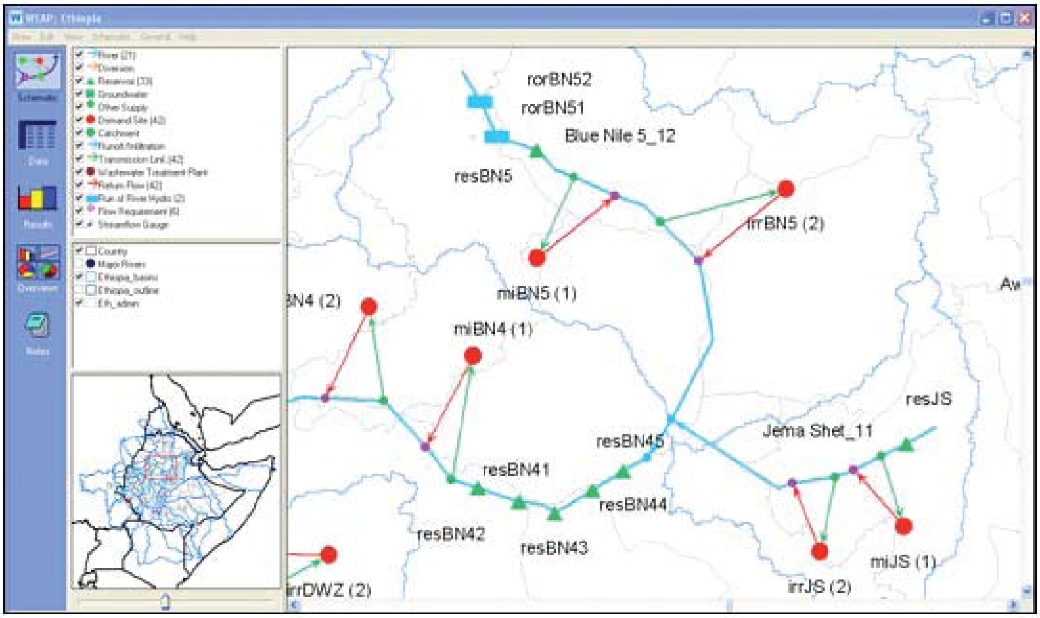
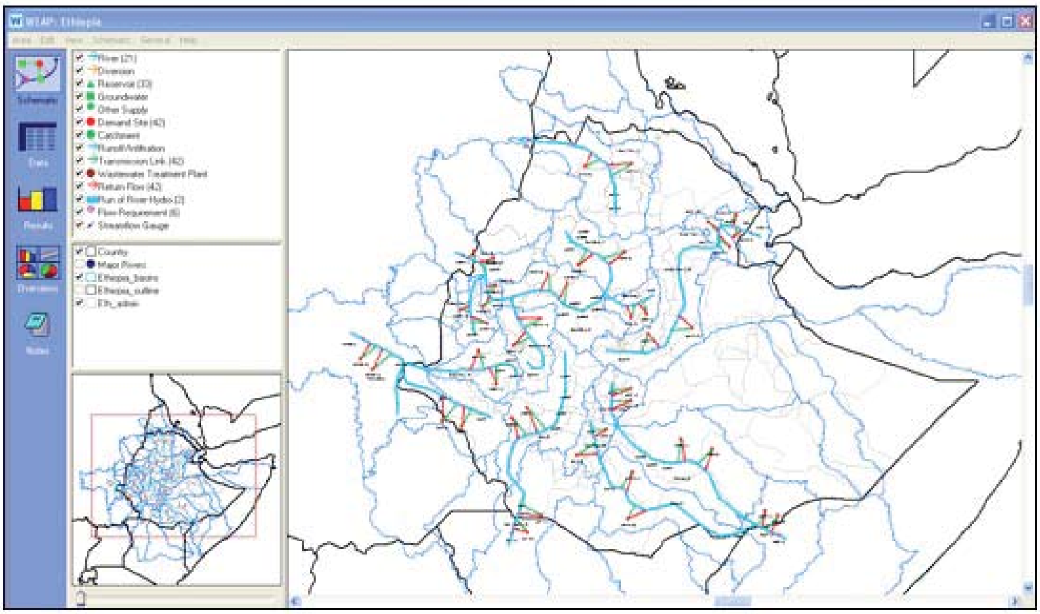


FIGURE 14 **OVERVIEW OF ETHIOPIA WEAP MODEL**



and the Jema Shet basins. In the Blue Nile 5, for example, the inflow data into the basin was supplied by CLIRUN-II and stored in the aggregated reservoir (resBN5). Irrigation and M&I withdraw water for nodes miBN5 and irrBN5. While the reservoir and aggregate demands are physically located within each basin, they are not located to represent any specific reservoir or demand site. Also of note are the two run-of-river hydropower facilities on the Blue Nile 5 (rorBN51 and 2), which produce hydropower but have no storage, and outflows from Jema Shet flow into the Blue Nile 5. The 21 basins have a similar schematic representation, and vary slightly due to individual basin topology. An overview of the entire study area is shown in Figure 14.

CGE Model Description

The economic impact of climate change is simulated using a dynamic computable general equilibrium model (CGE), which is described in Box 3. The model simulates the operation of commodity and factor markets across the economy. Market interactions—with changing prices, supplies, trade, and allocation of factors across production activities—determine how the economy adjusts over time under different scenarios. The CGE model provides a "simulation laboratory" for analyzing the direct and indirect impacts of different climate change and adaptation investment scenarios.

Within the existing structure and subject to macroeconomic constraints, producers in the model maximize profits under constant returns to scale production technologies, with the choice between factors governed by a constant elasticity of substitution (CES) function. Factors are then combined with fixed-share intermediates using a Leontief specification. Under profit maximization, factors are employed such that marginal revenue equals marginal cost based on endogenous relative prices. Substitution possibilities exist between production for domestic and foreign markets. This decision of producers is governed by a constant elasticity of transformation (CET) function that distinguishes

BOX 3 COMPUTABLE GENERAL EQUILIBRIUM MODELS (CGES)

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

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

Dynamic CGE models

The features described above apply to a single-period "static" CGE model. However, because climate change will unfold over decades, the model must be capable of forward-looking growth trajectories. Therefore, the model must be "dynamized" by building in a set of accumulation and updating rules; for example, investment adding to capital stock, labor force growth by skill category, and productivity growth. In addition, expectation formations must be specified. Expectations are a distinguishing feature of macroeconomic models. In our CGE model, a simple set of adaptive expectations rules are chosen so that investment is allocated according to current relative prices under the expectation that climate realization in the upcoming year will be an average of recent experience. A series of dynamic equations "update" various parameters and variables from one year to the next. For the most part, the relationships are straightforward. Growth in the total supply of each labor category and land is specified exogenously. Sector capital stocks are adjusted each year based on investment, net of depreciation. Factor returns adjust so that factor supply equals demand. The model adopts a "putty-clay" formulation, whereby new investment can be directed to any sector in response to differential rates of return, but installed equipment remains immobile; for example, a factory cannot be converted into a railroad. Sector- and factor-specific productivity growth is specified exogenously. Using these simple relationships to update key variables, we can generate a series of growth trajectories, based on different climate scenarios.

between exported and domestic goods, and by doing so, captures any time- or quality-related differences between the two products. Profit maximization drives producers to sell in markets where they can achieve the highest returns. These returns are based on domestic and export prices; the latter is determined by the world price times the exchange rate adjusted for any taxes and subsidies. Under the small-country assumption, Ethiopia faces a perfectly elastic world demand curve for its exports at fixed world prices. The final ratio of exports to domestic goods is determined by the endogenous interaction of the relative prices for these two commodity types.

Substitution possibilities also exist between imported and domestic goods under a CES Armington specification. This takes place both in intermediate and final usage. These elasticities vary across sectors, with lower elasticities reflecting greater differences between domestic and imported goods. Again, under the small-country assumption, Ethiopia faces an infinitely elastic world supply at fixed world prices. The final ratio of imports to domestic goods is determined by the cost-minimizing decision making of domestic agents (firms/ consumers) based on the relative prices of imports and domestic goods (both of which include relevant taxes).[6]

The model distinguishes among various institutions, including enterprises, the government, and five rural and five urban representative household groups in each region. Households and enterprises receive income in payment for the producers' use of their factors of production. Both institutions pay direct taxes (based on fixed tax rates) and save (based on marginal propensities to save). Enterprises pay their remaining incomes to households in the form of dividends. Households, unlike enterprises, use their incomes to consume commodities under a linear expenditure system (LES) of demand. The government receives revenues from activity taxes, sales taxes, direct taxes, and import tariffs, and then makes transfers to households, enterprises, and the rest of the world. The government also purchases commodities in the form of government consumption expenditures, and the remaining income of the government is saved (with budget deficits representing negative savings). All savings from households, enterprises, government, and the rest of the world (foreign savings) are collected in a savings pool from which investment is financed.

The model includes three macroeconomic accounts: government balance, current account, and a savings-investment account. In order to bring about balance in the macro accounts, it is necessary to specify a set of "macroclosure" rules, which provide a mechanism through which balance is achieved. A "balanced" macro closure is assumed such that investment, government demand, and aggregate consumption are fixed shares of total aggregate demand. Savings rates are assumed to adjust to finance investment. Implicit in this macro closure is that government policy is assumed to be designed to share the burden of any fall in aggregate demand equally across the demand aggregates: consumption, investment, and government. For the current account, a flexible exchange rate adjusts in order to maintain a fixed level of foreign savings (i.e., the external balance is held fixed in foreign currency terms). Finally, in the government account, the fiscal deficit is endogenous, with government demand a fixed share of aggregate demand and all tax rates held constant, so that government income depends on the level of economic activity—the tax base. Labor is assumed to be mobile across sectors and fully employed. Under the full employment closure, for example, expanding biofuels production implies reduced use of labor elsewhere in the economy. The assumption of full employment is consistent with widespread evidence that, while relatively few people have formal sector jobs, the large majority of working-age people engage

6 For both the CES and the CET functions, a relatively flexible value of 3.0 was applied for the substitution parameter across all sectors. Qualitative results are robust to the choice of CES and CET parameter values.

in activities that contribute to GDP. The model numeraire is the consumer price index (CPI).

The CGE model of the Ethiopian economy employed for the simulation analysis is calibrated to a social accounting matrix (SAM) for the year 2005/06 (EDRI-IDS, 2009). The SAM provides a detailed representation of the structure of production, demand, international trade, and income distribution. It contains a regional disaggregation of agricultural activities, household income, and household consumption. The five regions distinguished in this database are differentiated by their agroecological characteristics, as summarized in Table 9. The Ethiopia CGE model contains 22 commodity groups and 46 activities, including 35 regionally differentiated agricultural sectors. Fifteen primary factors of production are identified: four types of labor, agricultural land, and livestock capital in each of the five agroecological zones, and nonagricultural capital employed in industry and the service sector.

TABLE 9 FIVE AGROECOLOGICAL ZONES

SAM Region	*Temperature and Moisture Regime*
Zone 1	Humid lowlands, moisture reliable
Zone 2	Moisture-sufficient highlands, cereals-based
Zone 3	Moisture-sufficient highlands, enset-based*
Zone 4	Drought-prone (highlands)
Zone 5	Pastoralist (arid lowland plains)

Note: *Enset is a root crop.

On the household side, the SAM-based model identifies 14 distinct household groups comprising "poor" and "non-poor" rural households residing in each of the five regional zones, as well as poor and non-poor households distinguished by big and small urban settlements.

Social Analysis Approach

To complement the economic studies undertaken within the EACC study in Ethiopia, a "social component" was developed that used a bottom-up perspective to vulnerability assessment and identification of adaptation investment options. The social component views vulnerability as encompassing both physical and socioeconomic elements. It adopts IPCC definitions of vulnerability as comprising physical exposure, socioeconomic sensitivity, and adaptive capacity components (including levels of skills, institutional "thickness," and degree of market integration).

The vulnerability assessment included a literature review; identification of select "hotspots," representing both physically exposed and socioeconomically vulnerable areas from across the country; and fieldwork in these areas, including focus group discussions and a survey of 294 households. The identification of an adaptation options element comprised a series of four participatory scenario development (PSD) workshops at local/regional and national levels in both highland and lowland areas 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.

Key Assumptions and Limitations

One of the strengths of the EACC study is its use of mathematical tools, which impose intellectual discipline. Examples of this discipline are the use of a well-defined baseline and the requirement under CGE models that the national income accounting identities balance at the end of each year. This mathematical approach is indicated when the objective of the exercise includes quantitative and monetary impact evaluation of costs and benefits. Apart from providing estimates of both, the models indicate the relative importance of some factors vis-à-vis others, and also the effects of changing certain variables onto others. This is important for concretely supporting the decision-making process. By making a choice for quantitative rigor, however, all the well-known limitations of using econometric and other mathematical models apply.

UNCERTAINTY

Uncertainty complicates the analysis of adaptation to climate change in three different ways. First, for most countries there is no consensus whether future climate will be wetter or drier, or the degree to which future storms will be stronger. The second major uncertainty concerns economic growth. As the global results made clear, the more rapid economic growth, the more assets are at risk, but also the better prepared is a country to absorb and defend against climate-induced changes in productivity and adverse climate events. Finally, technological change over the next 50 years will affect adaptation in currently unknowable ways. These issues are discussed below.

Climate uncertainty. As indicated earlier, this study uses four climate models to bracket uncertainty on future climate outcomes. However there is a wider number of climate models available, and thus many other climate outcomes are possible. Of the 26 climate projections available for the A2 SRES, an assessment of adaptation costs was possible only with 2 for the global track, and 2–4 for the country studies.

Growth uncertainty. A key contribution of this study is to separate the costs of adaptation from those of development by defining a development baseline. The study specifies as a comparator "base run" a future development path for Ethiopia that is consistent with forecasts of growth in population, labor force, aggregate investment, productivity, and hence GDP per capita. The base run also yields the structure of production and degree of urbanization, which, along with income, largely drive the structure of demand and required investment in infrastructure.

Technological uncertainty. Most parts of the study do not allow for the unknowable effects of innovation and technical change on adaptation costs. In effect, these costs are based on what is known today rather than what might be possible in 20–40 years. Sustained growth in per capita GDP for the world economy rests on technical change, which is likely to reduce the real costs of adaptation over time.

INSTITUTIONS

The EACC study deliberately never intended to include institutional, political, and cultural factors in the analyses of adaptation costs. As examples, many adaptive measures are best implemented through effective collective action at the community level. Soft adaptation measures—such as early warning systems, community preparedness programs, watershed management, urban and rural zoning, and water pricing—generally rely on effective institutions supported by collective action. Because of the desire to produce quantitative results, and the availability of models to do so, both the global and country studies tended to focus on physical adaptation measures (sometimes referred to as "hard adaptation"), which basically require an engineering response. Country-level studies have explored numerous soft options, but again, hard numbers tend to crowd out important concepts: the difficulty of assigning costs and benefits to good institutions and good public policy has led country teams to focus most intently on hard options. Furthermore, in some cases discussions of future investment might be less politically contentious than discussions of possible institutional reforms—especially in sensitive areas such as water and utility pricing, property rights, and zoning and land-use policies.

Any type of outside assistance to bring about institutional reform in developing countries needs to build on changes that have internal sources and support. There are no magic recipes for dealing with the institutional aspects of adaptation. We observe that certain countries manage to cope with extreme events better than others, and we can describe the mechanics of their actions, but the incentives and mechanisms to make it happen has to come from internal concerns and conviction. This is not a limitation of the study itself, simply recognition of what we do or do not know.

MODELING

Most of the results of this study are based on biophysical, engineering, and economic models. These models use mathematical techniques to represent physical and economic processes. The more the phenomena being simulated are generated by deterministic physical processes, the better performance of the models. As phenomena become increasingly influenced by uncertainty or by human behavior and institutional change, the ability to simulate weakens.

Efficiency in adaptation can be explored either through extremely complex inter-temporal and cross-sectoral optimization (for which models capable of policy analysis do not exist), or through comparing the results of a wide range of alternative investment programs, including those that implement projects at differing points in the future. This study explores a limited number of adaptation investment strategies consistent with the stated development strategy being pursued by Ethiopia. As climate change impacts become more clearly defined in the future, further exploration of strategic options is a highly recommended follow-up activity.

The second issue is the integration of the social analyses with the economic models. The original intent of the EACC was to translate the very rich information coming out of field work in economic terms, so that different adaptation actions indicated by the local populations could somehow appear in the models as explicit adaptation alternatives. The two difficulties were that (1) a greater level of effort would be required to obtain the necessary economic information as part of the field work, and (2) the level of aggregation of the models—whether national or global—would not accommodate the integration of these very specific local measures. Nonetheless, it was possible, as registered in the social analyses of the countries, to observe the consistency of the adaptation measures proposed at the two different levels. Specific economic analyses of adaptation measures at the local level would be an important exercise to be pursued in future work.

One final important qualification must be made to the overall limitations of the EACC: while uncertainty is pervasive when dealing with climate change, the basic lesson is no different from any other area of economic policy—do not act on fixed assumptions about the future, build flexibility into both policies and hardware. No study, however careful and detailed, can remove this uncertainty.

THREE

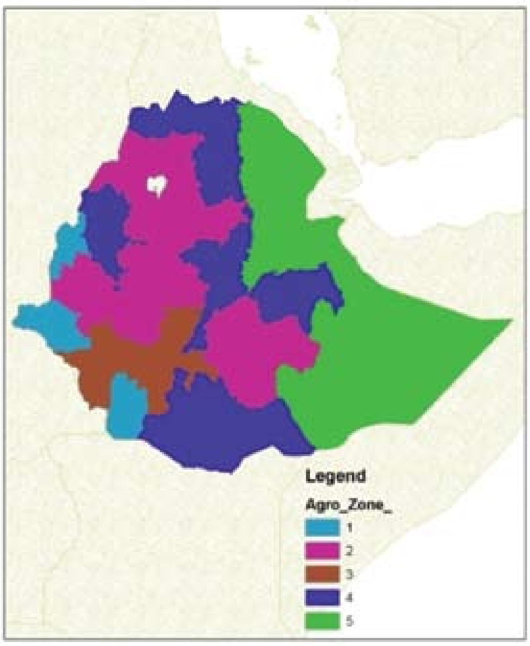
Impacts

Agriculture

SECTOR BACKGROUND

In 2006/07, agricultural production generated around 46 percent of Ethiopia's gross domestic product and employed 80 percent of the working population. According to Deressa (2006), Ethiopia has about 16.4 million hectares of arable land (14.6 percent of its total land area), of which about 8 million hectares are currently used for crop production.

FIGURE 15 AGROECOLOGICAL ZONES IN ETHIOPIA



The country is divided into five agroecological zones (Figure 15). Around 45 percent of the country consists of a high plateau comprising zones 2 to 4 with mountain ranges divided by the East African Rift Valley. Almost 90 percent of the population resides in these highland regions (1,500m above sea level). Within the highlands, zones 2 and 3 generally have sufficient moisture for, respectively, the cultivation of cereals and enset (a root crop), whereas zone 4 is prone to droughts. The arid lowlands in the east of the country—zone 5—are mostly populated by pastoralists.

The agricultural sector is dominated by mixed rainfed small-scale farming based on traditional technologies. Small-scale subsistence farming (about 8 million peasant households) accounts for 95 percent of the total area under crops and more than 90 percent of the total agricultural output. Most food crops (94 percent) and coffee (98 percent) are produced by small-scale farmers, while the remainder is generated by private and state commercial farms. Production technologies are predominantly characterized by the use of ox-drawn wooden ploughs with steel pikes and other traditional farm implements, minimal application of fertilizer and pesticides due to high input prices in the presence of credit constraints[7] and weak extension services, and low use of improved seeds (Deressa 2006).

By the end of the 2005/06 growing season, only 13 percent of the potentially irrigable land area was irrigated. A typical farming household in the semi-arid areas owns just a small portion of land (generally less than one hectare) for crop and livestock (cattle, goats, sheep, poultry, donkeys) production. In addition to these constraints, the country continues to experience persistent drought episodes because of its prominent location in the Sahel region, characterized by erratic rainfall and unpredictable climatic variability. Factors contributing to the low productivity of the agricultural sector—beside droughts and floods—include declining farm sizes due to population growth; land degradation due to inappropriate use of land such as cultivation of steep slopes, overcultivation and overgrazing; tenure insecurity; weak agricultural research and extension services; lack of agricultural marketing; an inadequate transport network; low use of fertilizers, improved seeds, and pesticides; poor nutrition of livestock; low levels of veterinary care; and livestock diseases.

Zones 2 and 4 comprise the major agricultural production zone. These regions face both water shortages and waterlogging throughout the growing season because they are primarily rainfed. Portions of these regions are able to accommodate multiple crops due to climate conditions. Parts of these regions and many others are suitable for irrigation-based multi-cropping.

The eastern arid regions of zone 5 are dominated by a grassland-based livestock production. Very limited rainfall in this area leads to a very vulnerable livestock sector.

A large proportion of the farm output is consumed at home as household consumption. As recently as 2001/02, the Central Statistical Agency's (CSA) agriculture census estimated that farmers consumed at home about 63 percent of their total output, and that less than 30 percent was in fact marketed.

IMPACTS ON CROPS

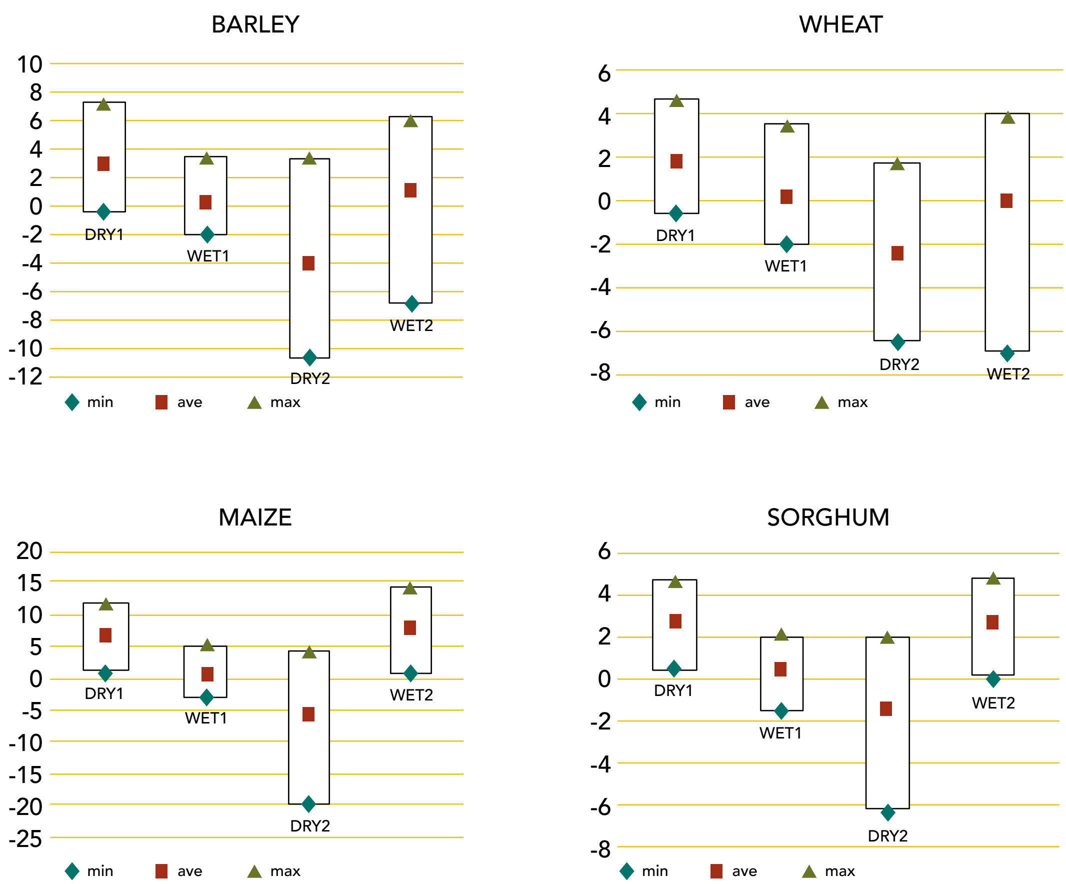
With the use of CliCrop, the changes in CO^2 concentration, precipitation, and temperature from the four GCMs are used to estimate the changes in production (yield) each year for the major crops. The yield effects reflect the reductions in yield due to either the lack of available water, or due to the overabundance of water that causes waterlogging. Regional and temporal trends over the four scenarios are depicted below in Figure 16.

CO^2 fertilization is included in the analysis but does not make a significant difference. Current research is suggesting much smaller CO^2 fertilization than initially thought. Additionally, new research shows that under higher CO^2 levels, ozone will also be present and that has a negative impact on crop yields.

Climate impacts are significant, but variable over regions and crop type. The impact of these trends tends to grow stronger in time. The Dry2 scenario is the most damaging scenario due to the frequent occurrence of droughts. The impacts of climate on yields are first-order effects that trigger direct and indirect economic impacts—such as reductions in income, employment, savings and investments. These impacts are captured in the CGE analysis as described in chapter 4.

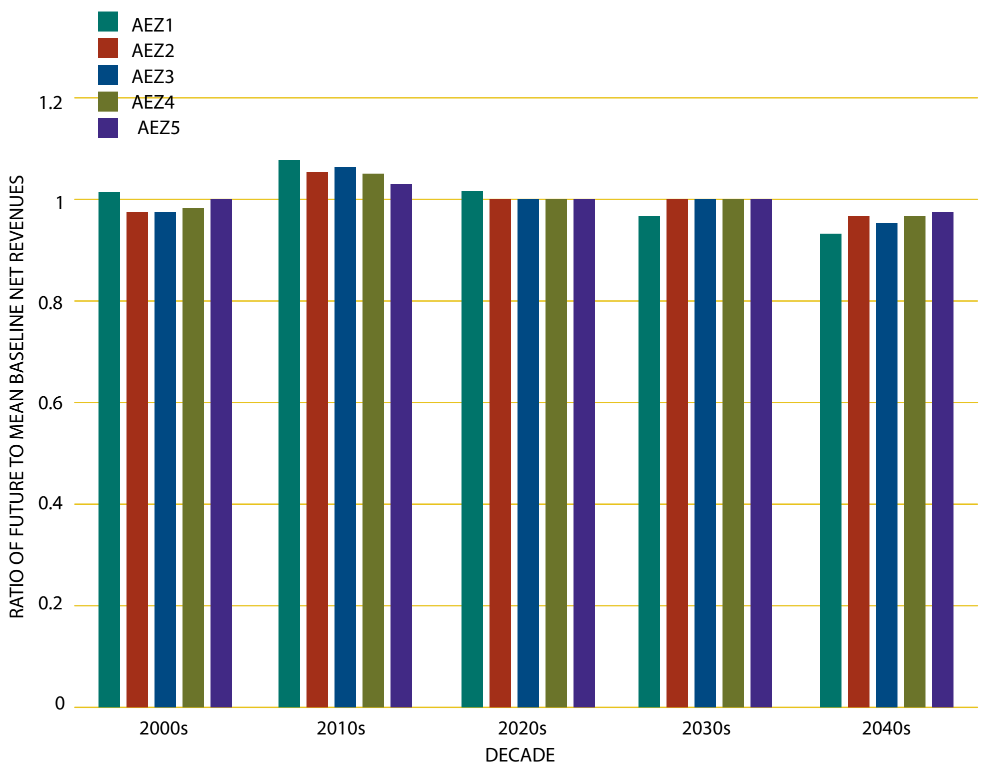
7 Using a nationally representative data set, Croppenstedt, Derneke and Meschi (2003) identify credit constraints and low value-cost ratios due to high procurement and distribution costs as major hurdles to the adoption and intensity of fertilizer use in Ethiopia.

FIGURE 16 RANGE OF PERCENT YIELD DEVIATIONS FROM NO-CC BASE (2006–2050) FOR SELECTED CROPS



Note: The effects of climate change on the different crops are weighted averages across regions, using the regions' shares in crop total production as weights. Baseline yields include a technology growth component reflecting historical trends.

FIGURE 17 BIOPHYSICAL COMPONENT: RATIO OF FUTURE LIVESTOCK EXPECTED INCOMES TO EXPECTED INCOMES UNDER MEAN BASELINE CONDITIONS, ETHIOPIA BASE SCENARIO, 2001–50



IMPACTS ON LIVESTOCK

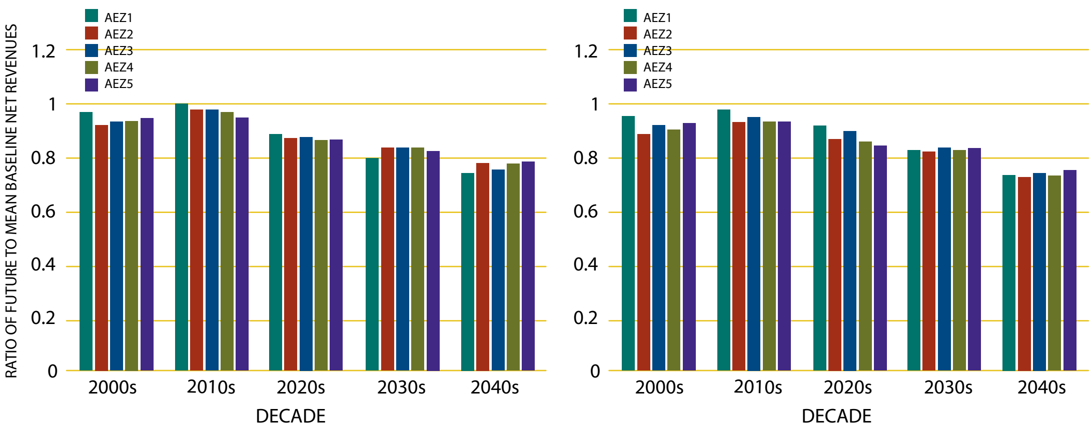
Based on the steps outlined in the methodology section above, the analysis developed two sets of time series that collectively make up the livestock impact vectors. Each of these sets of time series and the combined final livestock productivity vectors are described below.

Biophysical results. The first is the biophysical component, which is a unitless time series of future livestock net revenues relative to mean baseline conditions; that is, mean baseline climate conditions would produce a value of one. Figure 17 presents the biophysical ratios for AEZs under the base scenario from 2001 to 2050. Note that there are fluctuations above and below mean baseline conditions as temperatures fluctuate from year to year.

Figure 18 presents the vectors of ratios for the Ethiopia dry (on right) and wet (on left) scenarios, and Figure 19 presents results under the global dry (on right) and wet (on left) scenarios. In all scenarios, the projected impacts on livestock incomes are severe by 2050. Under the Ethiopia wet and the two global scenarios, income in each AEZ falls to 70 to 80 percent of baseline levels. Under the more pronounced temperature effects of the dry scenario, livestock incomes fall to roughly 60 percent of mean baseline levels, although in AEZ 1 they reach a low of roughly 55 percent. Generally, these effects do not vary significantly across AEZs.

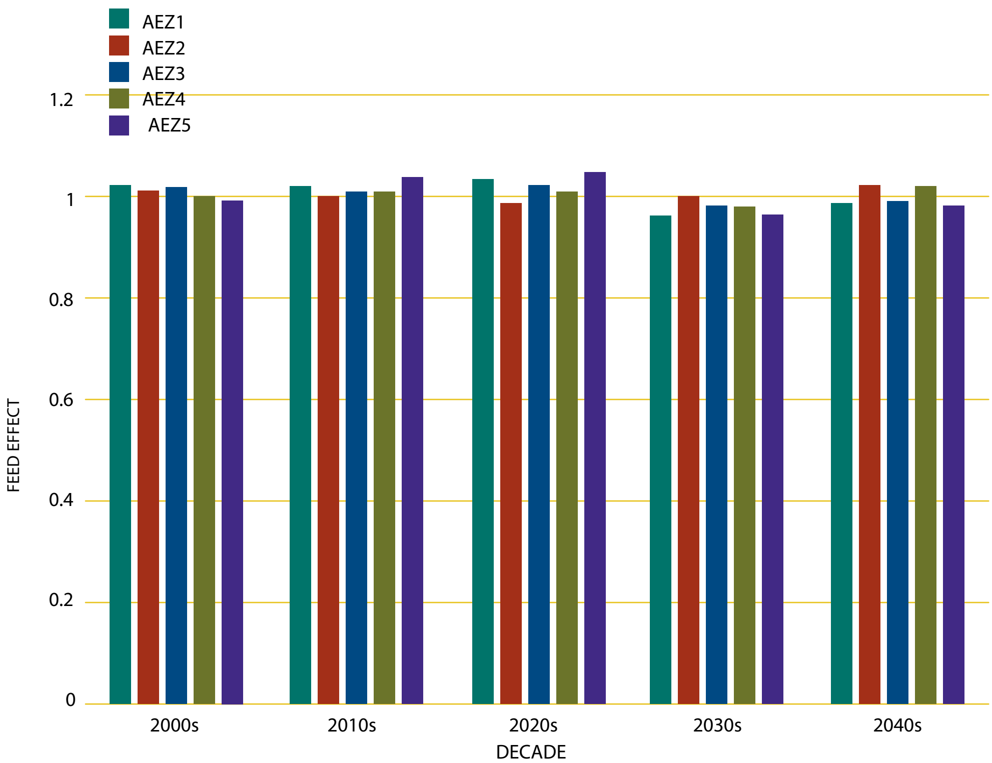
FIGURE 18 BIOPHYSICAL COMPONENT: RATIO OF FUTURE LIVESTOCK NET REVENUES TO NET REVENUES UNDER MEAN BASELINE CONDITIONS, ETHIOPIA DRY (ON LEFT) AND WET (ON RIGHT) SCENARIOS, 2001–50

FIGURE 19 BIOPHYSICAL COMPONENT: RATIO OF FUTURE LIVESTOCK NET REVENUES TO NET REVENUES UNDER MEAN BASELINE CONDITIONS, GLOBAL DRY (ON LEFT) AND WET (ON RIGHT) SCENARIOS, 2001–50



Feed results. Next is the feed component, which is a unitless time series of projected millet yields relative to mean baseline yields generated by CliCrop. The feed ratios for AEZs under the base scenario from 2001 to 2050 are presented in Figure 13. Notice that feed ratios vary much more widely across AEZs than the biophysical ratios.

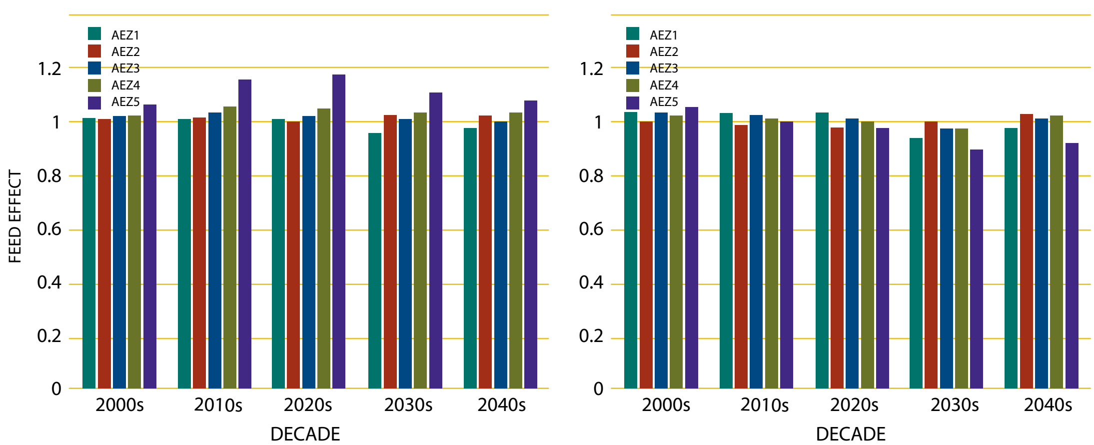
FIGURE 20 FEED COMPONENT: RATIO OF MILLET YIELDS TO MEAN BASELINE YIELDS, ETHIOPIA BASE SCENARIO, 2001–50



The vectors of ratios for the Ethiopia dry (on left) and wet (on right) scenarios are presented in Figure 21, and Figure 22 presents results under the global dry (on left) and wet (on right) scenarios. The projected impacts on yields differ considerably between the four scenarios and across the five AEZs. Under the Ethiopia scenarios, yields tend to respond more positively under the wet scenario than the dry scenario, particularly in AEZ 5, which has yield ratios up to 20 percent higher than mean baseline levels. Results are mixed in the global scenarios, with AEZ 5 showing a positive yield response in the dry relative to wet scenario, but others (such as AEZ 1) showing the opposite relationship.

FIGURE 21 FEED COMPONENT: RATIO OF MILLET YIELDS TO MEAN BASELINE YIELDS, ETHIOPIA DRY (ON LEFT) AND WET (ON RIGHT) SCENARIOS, 2001–50

FIGURE 22 FEED COMPONENT: RATIO OF MILLET YIELDS TO MEAN BASELINE YIELDS, GLOBAL DRY (ON LEFT) AND WET (ON RIGHT) SCENARIOS, 2001–50



Combined results. Each of the 25 pairs of biophysical and feed vectors for the AEZs and scenarios are averaged to produce the vectors presented in Figures 23 through 25 for 2001 to 2050. These hybrid vectors represent a ratio of livestock productivity under each of the scenarios relative to productivity under mean baseline climatic conditions. The combined vectors for the baseline scenario are presented in Figure 23.

FIGURE 23 COMBINED COMPONENTS: MEAN OF BIOPHYSICAL AND FEED VECTORS, ETHIOPIA BASE SCENARIO, 2001–50

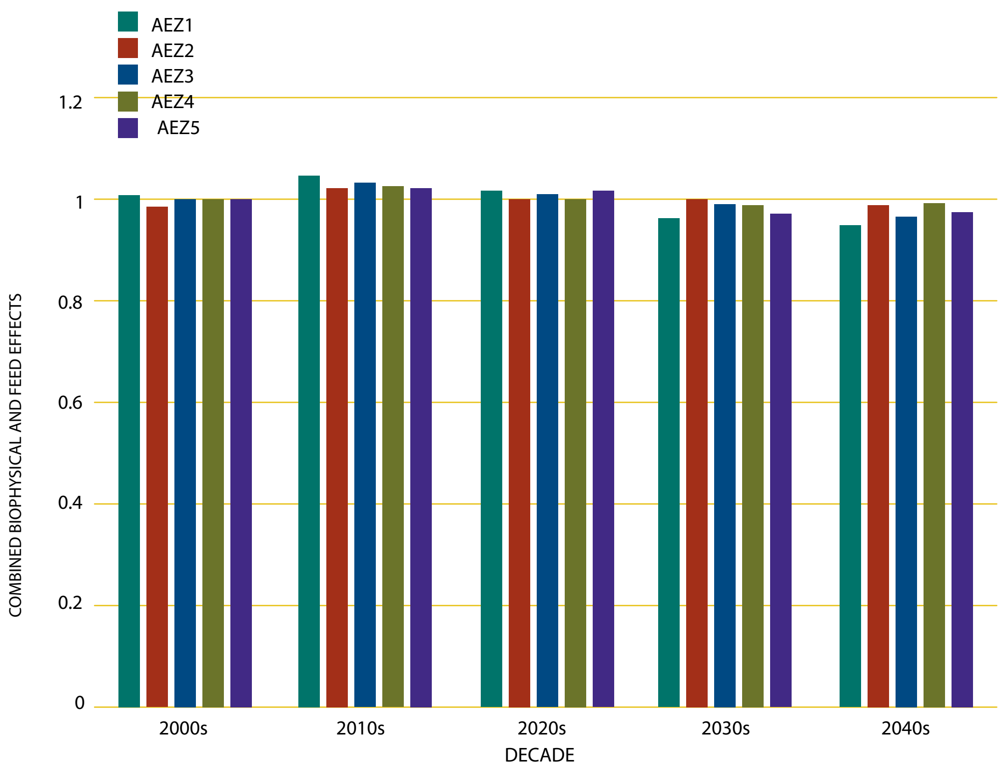


Figure 24 presents the vectors of combined ratios for the Ethiopia dry (on left) and wet (on right) scenarios, and Figure 25 presents the results under the global dry (on left) and wet (on right) scenarios. Livestock productivity is affected most severely under the Ethiopia dry scenario, which shows the ratio falling to a low value of approximately 0.70 in AEZ 1, or a 30 percent decline in productivity. Under each of the scenarios, there is a downward trend in productivity over the 2001 to 2050 period.

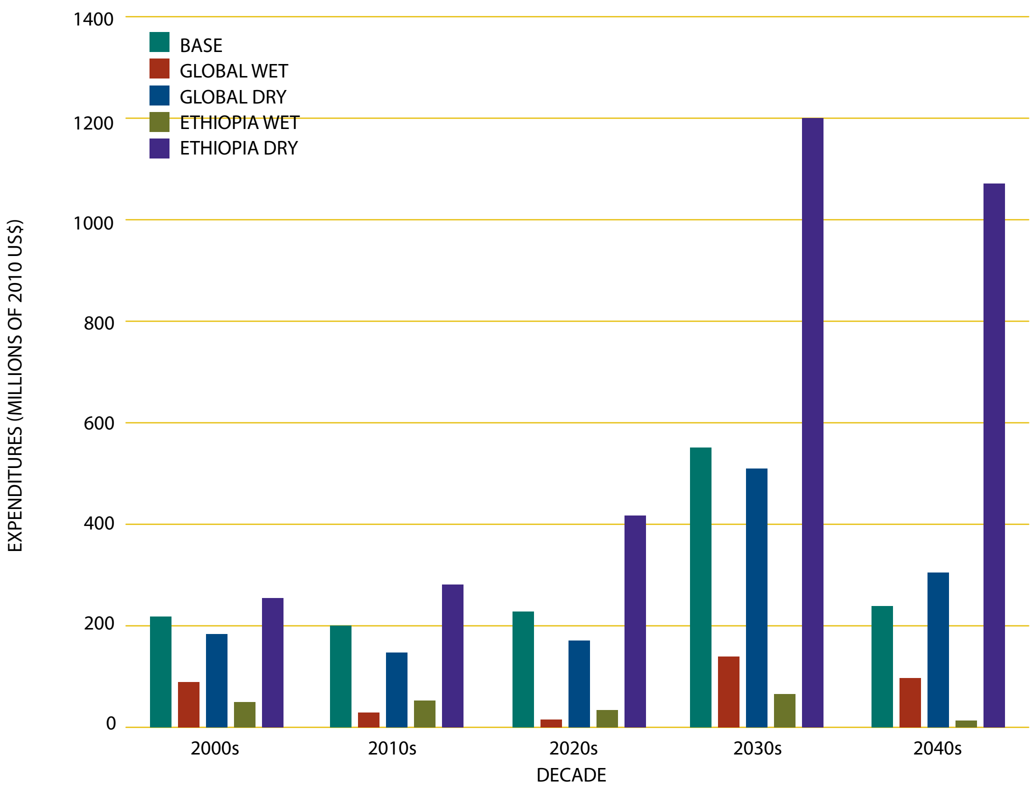
FIGURE 24 COMBINED COMPONENTS: MEAN OF BIOPHYSICAL AND FEED VECTORS, ETHIOPIA DRY (ON LEFT) AND WET (ON RIGHT) SCENARIOS, 2001–50

FIGURE 25 COMBINED COMPONENTS: MEAN OF BIOPHYSICAL AND FEED VECTORS, GLOBAL DRY (ON LEFT) AND WET (ON RIGHT) SCENARIOS, 2001–50

Drought Expenditures

The average annual projected expenditure on droughts by decade under the baseline and four climate scenarios is presented in Figure26. These vary from a low of $7.3 million annually under the Ethiopia wet scenario in the 2040s to a high of $1.2 billion in the Ethiopia dry scenario in the 2030s. This compares to an average annual recurrent drought expenditure between 1997/98 and 2005/06 of roughly $696 million and a maximum annual expenditure of $1.8 billion (see Annex 9).

FIGURE 26 MEAN ANNUAL PROJECTED ETHIOPIAN GOVERNMENT EXPENDITURES IN THE 2000S THROUGH 2040S (MILLIONS OF 2010 $)



Road Transport

The road transport sector is impacted by climate change in two areas; standard maintenance and flood-induced maintenance. The former represents costs that are incurred due to precipitation and/or temperature changes that occur during the life span of the road. These changes represent differences in the average climate conditions that exist for the road and thus change the conditions under which the road is intended to perform on an everyday basis. The latter represents changes in extreme events and the costs associated with repairing the roads from those extreme events.

ROAD TRANSPORT BACKGROUND

Ethiopia's strategy for the road sector stated that the total road length in the country was 56,113 km as of April 2006. Unpaved roads represent about 85 percent of the total road length (47,612), while paved roads represent the remaining 15 percent (Table 10).

TABLE 10 BASE CLASSIFIED AND URBAN ROAD NETWORKS, 2006 (KM)

Class	Unpaved	Paved	Total
Primary	1,155	3,490	4,625
Secondary	24,869	2,443	27,282
Tertiary	21,588	1,047	22,635
Subtotal Classified			**54,613**
Urban		**1,500**	**1,500**
Grand total	**47,612**	**8,480**	**56,113**

Source: Ethiopia Ministry of Transport

Table 11 provides estimates of unit maintenance costs for the existing road network.

ROAD TRANSPORT IMPACTS

The stressor equations introduced earlier provide the basis for determining the impact of climate change on the maintenance of paved and unpaved roads. Based on the road inventory in Ethiopia, it is estimated that maintenance on paved roads that is directly attributable to climate change ranges from \$5 million to \$13 million per year depending on the climate model used for the projection. As illustrated in Table 12 and Figures 27 and 28, maintenance costs on paved roads are the highest in the first decades as climate change impacts are realized on existing road inventory that is 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 \$2 million and \$14 million per year depending on the climate model used. In contrast to the paved roads that see reductions in maintenance costs due to enhanced design standards, the unpaved roads continue to see maintenance costs that are dependent 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 \$15 million and \$31 million per year depending on the climate model used. These numbers are on the lower bound of what may be expected due to the key assumptions that (1) regular maintenance is implemented on the roads so that compounding damage effects do not occur; (2) the effects do not include flooding damage, which is a major factor for road damage as seen in the next section; and (3) adaptation to paved roads is completed when roads are repaved. If any of these assumptions fails to materialize, then the costs could be significantly higher.

TABLE 11 UNIT MAINTENANCE COST RATES (US$)

Type of Maintenance	Transitability	Routine		Periodic		Rehabilitation	
Road Class	**Un-paved**	**Un-paved**	**Paved**	**Un-paved**	**Paved**	**Un-paved**	**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

Note: Values in US$ per km, per year for transitability and routine.
Source: Data obtained from World Bank projects in-country and in region.

FIGURE 27 AVERAGE DECADE COSTS FOR EACH OF THE FOUR GCMS FOR MAINTAINING GRAVEL AND EARTH ROADS DUE TO CLIMATE CHANGE INCREASE IN PRECIPITATION

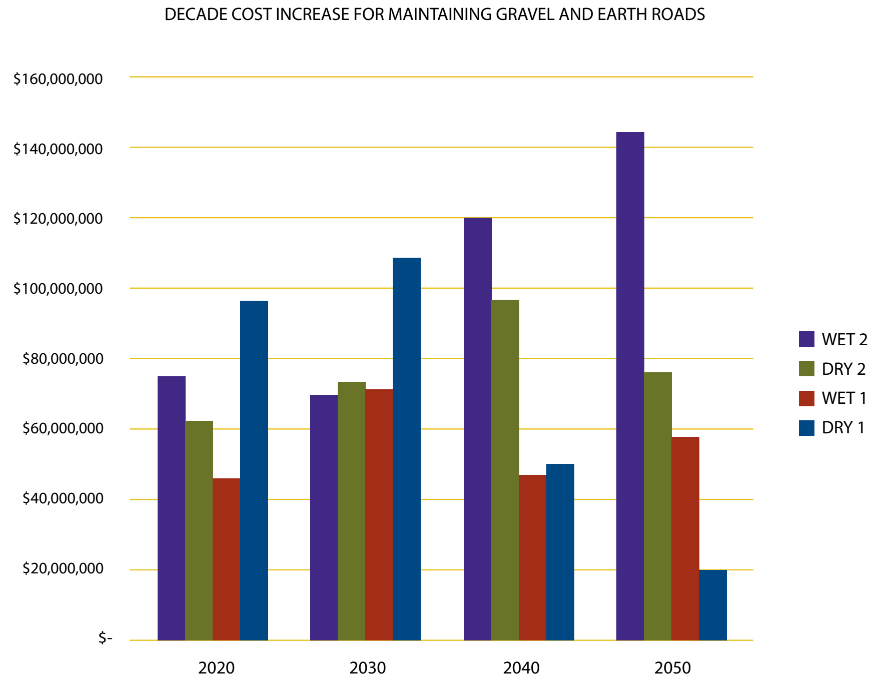


FIGURE 28 AVERAGE DECADE COSTS FOR EACH OF THE FOUR GCMS FOR MAINTAINING PAVED ROADS DUE TO CLIMATE CHANGE INCREASE IN PRECIPITATION AND TEMPERATURE

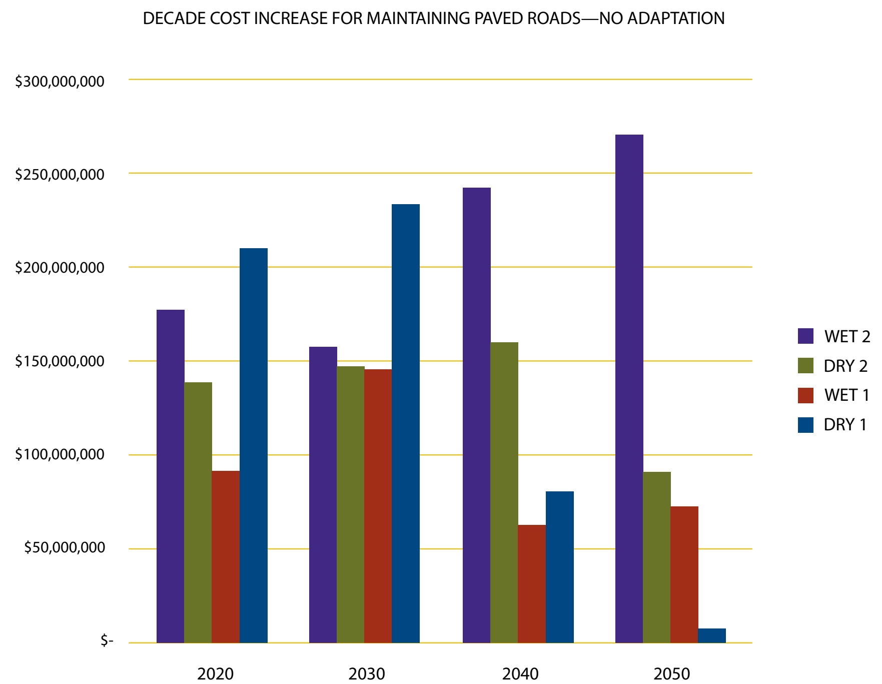


TABLE 12 CUMULATIVE CLIMATE CHANGE IMPACT ON PAVED AND UNPAVED ROADS BASED ON INCREASED MAINTENANCE COSTS FOR THE FOUR CLIMATE GCMS (US$ MILLION)

	Wet 2	*Dry 2*	*Wet 1*	*Dry 1*
Cumulative cost increase for maintaining paved roads	$849.2	$538.4	$371.8	$531.7
Cumulative cost increase for maintaining gravel and earth roads	$408.8	$308.7	$221.7	$273.8
Total cumulative maintenance costs from climate change (paved and unpaved roads)	**$1,258.0**	**$847.1**	**$593.5**	**$805.5**

FLOODING COSTS

Flooding costs for the road sector focus on the need to maintain roads after a flooding event. The methodology—introduced later in the section on economywide impacts—is utilized to illustrate the costs that flooding will impose on the road sector. The focus of the flooding analysis is to determine the maintenance costs required to repair the roads to functioning order. For this focus, a combination of the COWI report on making transport climate resilient and previous work conducted by the research team for the U.S. Federal Highway Administration—together with actual numbers obtained from local transport ministries—is used as a basis for maintenance costs. Specifically, these efforts yield a cost for maintenance based on original construction costs.

Primary roads have a 15 percent maintenance cost, while 29 percent and 35 percent are used for secondary and tertiary roads respectively to obtain a cost per kilometer for maintenance. The primary roads number is lower due to the roads being built to a higher standard at original construction. For unpaved roads, we use these same sources to estimate maintenance costs. However, unpaved roads differ in that they are based on the severity of the flood rather than the road type, since the impact focuses on the road surface rather than the road base or the type of pavement, as is the case for paved roads. Therefore, the gravel and dirt surfaces on these roads will erode based on the amount of floodwater rather than the type of road that is constructed. Given this relationship to water rather than construction materials, the impact percentage

TABLE 13 TIME-SERIES INPUTS TO CGE MODEL FOR TRANSPORT COSTS

Vector	*Definition*
1. Base Maintenance costs derived from historic flood data	This is the base yearly maintenance costs that would be anticipated from historic floods.
2. The total percentage of road capital loss for both paved & unpaved roads, using a weighted average over the country based on road density	This is the projected capital road loss percentage from the historic storm levels. This is the # of damaged road kilometers / number of total kilometers. This number is weighted over the climate zones to reflect the relative amount of roads contained in that zone.
3. Total maintenance costs for existing paved and unpaved roads WITH NO ADAPTATION	This is the projected cost for maintenance of the roads due to climate-change-induced flooding if no adaptation were put in place.
4. Total road capital % loss due to climate change—paved & unpaved—weighted each region based on total kms	This is the projected capital road loss percentage from the projected climate-change-induced storms over and above the historic levels. This is the # of damaged road kilometers / number of total kilometers. This number is weighted over the climate zones to reflect relative amount of roads contained in that zone.

FIGURE 29 BASE MAINTENANCE COSTS TO REPAIR FLOOD DAMAGE BASED ON PROJECTED FLOODS FROM HISTORIC CLIMATE PATTERNS

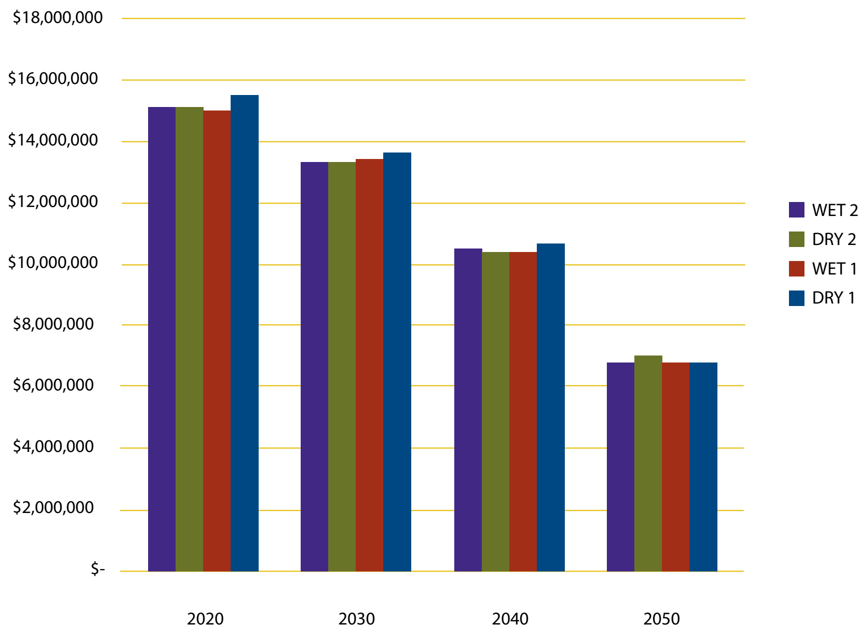


FIGURE 30 TOTAL ROAD CAPITAL % LOSS BASED ON HISTORIC PROJECTED FLOOD EVENTS

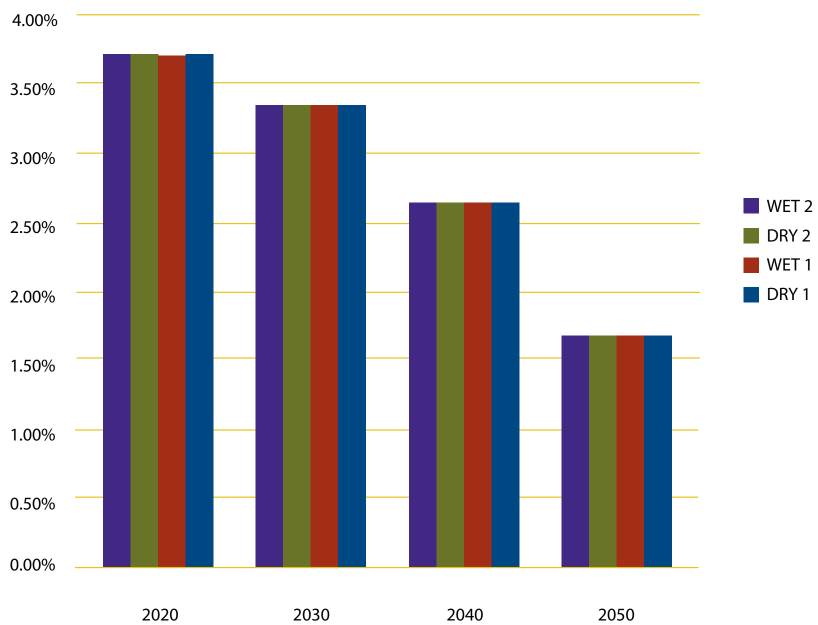
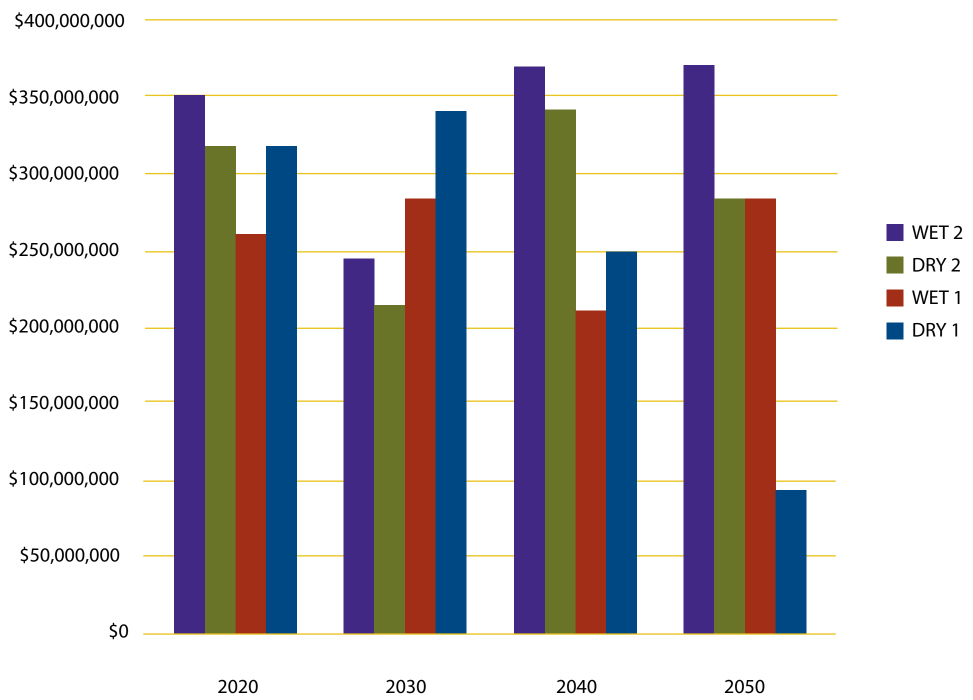


FIGURE 31 ANNUAL AVERAGE MAINTENANCE COST FOR EXISTING PAVED AND UNPAVED ROADS PER DECADE WITH NO ADAPTATION



for unpaved roads does not vary according to whether they are primary, secondary, or tertiary roads. Therefore, an 11 percent maintenance ratio is used for maintenance costs for all categories of unpaved roads. This ratio indicates that maintenance cost for flood repairs is equal to 11 percent of the construction cost each time a flood event occurs. It is assumed that the repairs can be completed in a single year.

Using these maintenance ratios for the non-adaptation scenario, the potential roads are then multiplied by the cost per kilometer to obtain a total maintenance rate required for that particular year in the time series. The application of this process to the time series of damages results in a time series of maintenance costs. The flooding analysis results in the generation of the cost vectors reported in Table 13 , which are used as input for the CGE modeling.

For each vector, the data conveyed from the cost module are divided among the three road types—primary, secondary, and tertiary. The vectors combine the climate zones together since the CGE models do not divide the economywide analysis into separate zones. An example of each vector is supplied as follows.

TABLE 14 **SUMMARY OF IMPACTS COSTS ON ROADS (US$ MILLION, ANNUAL AVERAGE)**

	Wet 2	*Dry 2*	*Wet 1*	*Dry 1*
Impacts on regular maintenance	31.45	21.12	14.84	20.14
Flood impacts	340.86	296.92	265.7	257.73
Total impacts costs	**372.31**	**318.04**	**280.54**	**277.87**

Hydropower

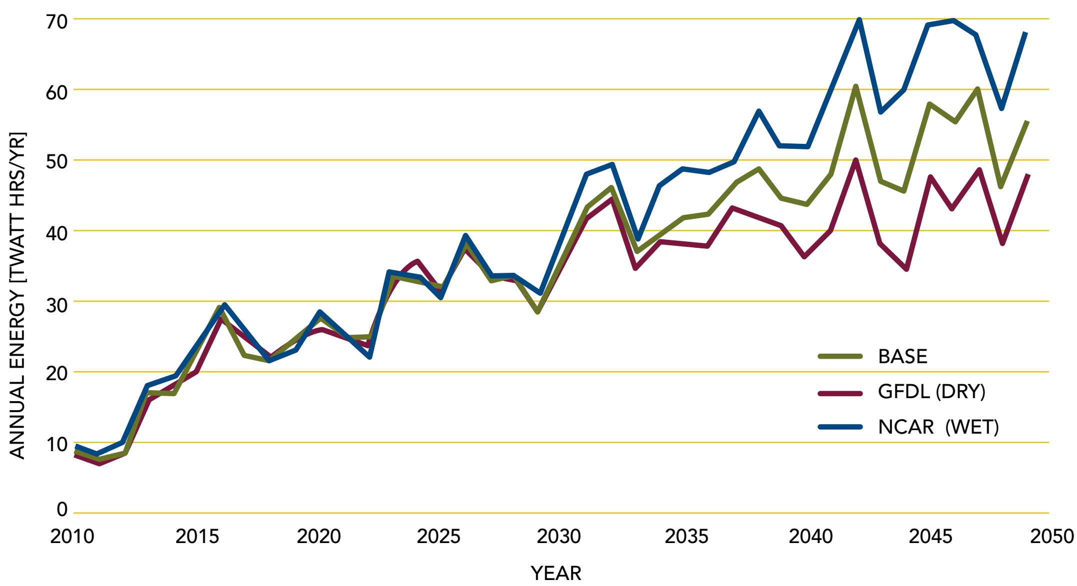
HYDROPOWER BACKGROUND

Associated with water resource use is the generation of energy by constructing renewable hydroelectricity generating dams. Current generation capacity is approximately 2,000 MW, of which 95 percent is generated from hydroelectric generators. Presently, five additional hydroelectric dams and one wind farm are under construction. When finalized, they are expected to increase power

TABLE 15 **PLANNED POWER GENERATION PROJECTS INCLUDED IN THE ANALYSIS**

Plant	*Year of Completion & Online*	*2010 value ($Million)*
Fixed (started)		
Wind - Ashegoba	2011	259
Gilgel Gibe III	2013	1730
Tendaho Geothermal (near Djibouti)	2013	305
Planned		
Gilgel Gibe IV	2014	2,930
Halele Werabesa	2014	725
Chemoga-Yeda	2014	318
Geba I & II	2016	593
Genale III	2018	362
Genale IV	2018	456
Tekeze II	2020	694
Karadobi	2023	2,411
Border	2026	1,741
Mendaia	2030	2,990
Baro	2034	914
Aleltu	2038	1,444
Didessa	2038	523
Dabus	2042	1,805
Birbir	2042	1,199
Tams	2046	1,805

FIGURE 32 HYDROPOWER GENERATION UNDER TWO CHANGE SCENARIOS, 2008–50



Source: IMPEND – CliRun Simulations

supply to a total of 3,270 MW and provide access to 50 percent of the total number of households in the country. Moreover, the hydroelectric generating dams are also expected to regulate water flows, control floods, and channel water for irrigation purposes. The government's plan for the expansion of hydropower generation capacity is summarized in Table 15.

HYDROPOWER IMPACTS

The IMPEND model analysis provided an estimate of the potential change in hydropower generation capability for the plants, under the above investment schedule in Table 15 using a monthly modeling of streamflow and energy generation. The results of this comparison between the base, Ethiopian dry, and Ethiopian wet scenarios are shown in Figure 32. The economywide implications of these alternative hydroenergy paths are explored in chapter 4.

As the figure shows, climate change does not change the variability of hydropower generation but impacts the mean annual energy generation. The wet scenario produces more hydropower than the base and the dry scenario produces less than the base. However, the deviations from the base only start after 23 years because initially there is so little installed hydro capacity that changes in flows have no impact. This is an important result as it shows that Ethiopia has a chance to gain or lose from climate, but these impacts have a threshold and then increase nonlinearly with the size of the hydropower development. This suggests a careful risk-based approach to hydropower investments after 2030, which accounts for close to half the value of the projects listed in Table 15.

RESULTS OF THE WEAP ANALYSIS

The water evaluation and planning (WEAP) analysis first establishes the baseline (i.e., no climate change) projections through 2050 for key water demands, including municipal and industrial (M&I), hydropower, and irrigation (described above). Next, it analyzes baseline competition among water end-users given baseline water availability; that is, competition for water that would take place even in the absence of climate change. Specifically, the impacts of the competition are measured in terms of reduced hydropower production and irrigated crop yields relative to maximum potential generation and yields. In addition, the analysis evaluates the effects of these rising demands on flows from Ethiopia into other countries. Finally, the analysis incorporates the runoff under the climate change scenarios to see if competition among end-users intensifies and/or changes, as well as how flows from Ethiopia are affected.

FIGURE 33 TOTAL HYDROPOWER PRODUCTION IN THE 21 ETHIOPIA RIVER BASINS, ASSUMING GROWING M&I DEMANDS AND IRRIGATION TO 3.7 MILLION HA, 2001–50

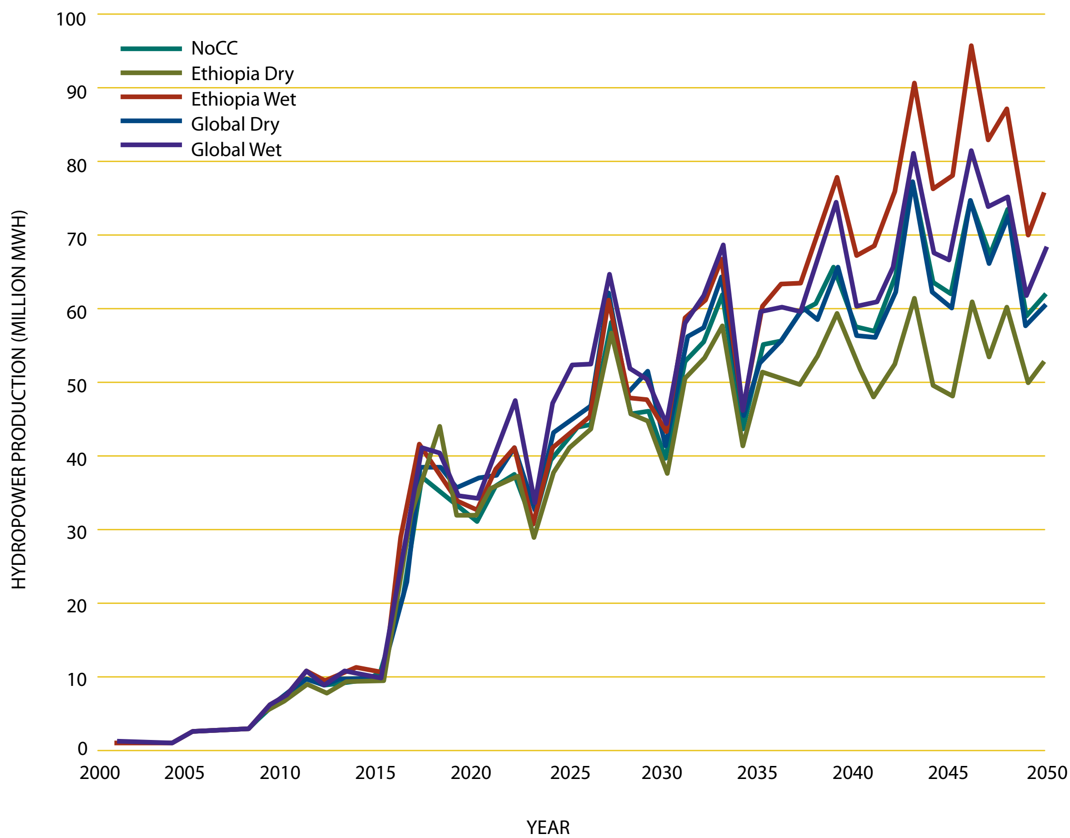
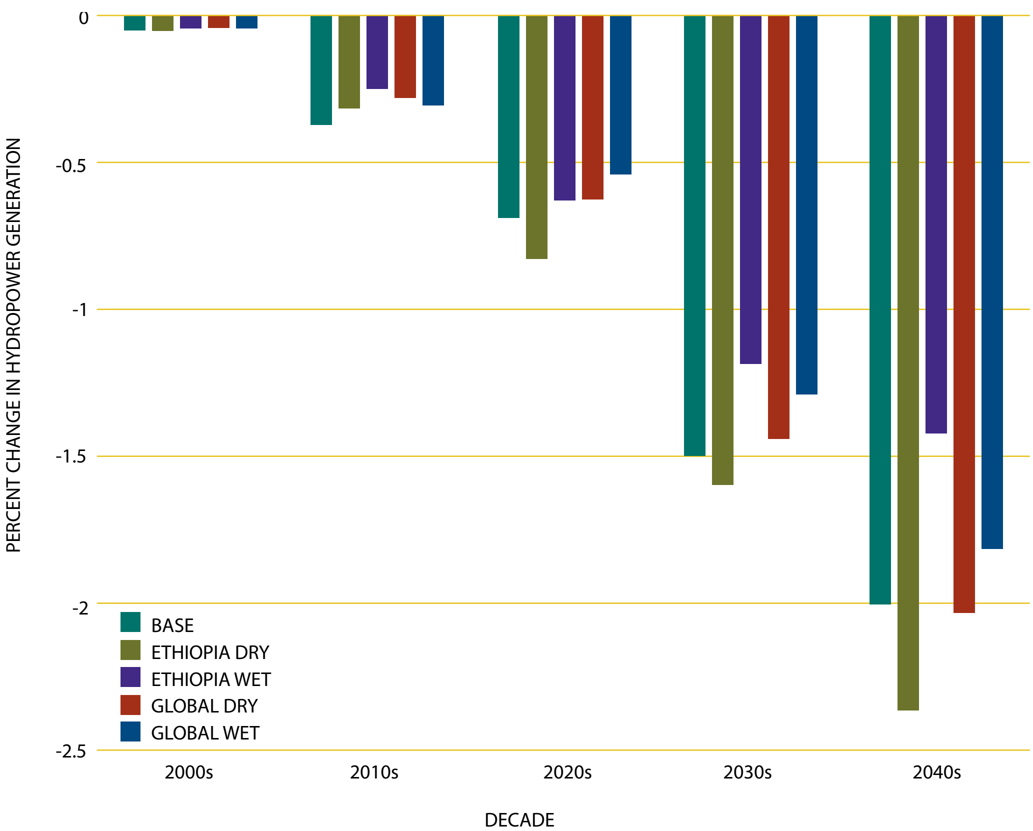


FIGURE 34 MEAN DECADAL CHANGES IN HYDROPOWER PRODUCTION GIVEN INCREASING M&I AND IRRIGATION DEMANDS, RELATIVE TO A NO-DEMAND SCENARIO



The hydropower and irrigation results are used to produce adjustments in the hydropower and crop impact results generated by IMPEND and the crop models under both baseline and climate change. Both of the other models consider climate change effects but no intersectoral effects.

The analytical scenario assumes increasing M&I demands, increasing irrigation to 3.7 million ha by 2050, full expansion of hydropower to levels outlined by the Ministry of Water Resources' Water Sector Development Plan (MWR 2002),), and no transboundary flow requirements.[8] The results and assumptions of the analysis of competition under both baseline and climate change are described for hydropower, irrigation, and unmanaged flows below.

Intersectoral effects on hydropower production. The IMPEND model was used to evaluate the potential impacts of climate change on energy

8 This analysis was unable to evaluate the water resources implications of the existing Nile Basin treaty, so does not impose transboundary flow requirements. Instead, the analysis evaluates the implications of rising Ethiopian demand for water on transboundary flow.

production in Ethiopia. For comparison purposes, the total hydropower output in megawatt-hours (MWH) shown in Figure 33 is produced under the baseline and four climate scenarios. Baseline hydropower production over the 50-year period is 1.89 billion MWH; as expected, under the Ethiopia wet scenario outputs are highest (13.6 percent higher than baseline), and under the Ethiopia dry scenario outputs are lowest (8.7 percent lower than baseline). The two global scenarios hover much more closely to the baseline (dry is 2.2 percent higher and wet is 9.3 percent higher than baseline). These closely reflect the runoff projections presented in Annex 7.

Figure 34 presents the mean decadal reductions in hydropower production given increased M&I and irrigation demands through 2050 (described below).[9] These changes are evaluated under the baseline and four climate change scenarios (i.e., five bars per decade in Figure 34.) relative to hydropower production under a hypothetical scenario where Ethiopia has no extractive water demands (i.e., no M&I or irrigation). Note that the baseline scenario includes growth in the M&I and irrigation sectors but no changes in climate, whereas the hypothetical "no demand" scenario (which mirrors the scenario used in the IMPEND analysis) includes no changes in demand or climate.

Changes in hydropower production occur because the higher-priority downstream irrigation and M&I demands affect the reservoir water release schedules and thus cause suboptimal production conditions. For example, if irrigation demand causes water to be released in May rather than stored to increase hydraulic head, overall power production can decline.

9 To evaluate the worst-case outcome for hydropower, this scenario assumes that municipal and industrial demands have the first priority, followed by irrigation, then hydropower.

The maximum effect is under the Ethiopia dry scenario, where an average decadal effect for the 2040s reaches -2.5 percent. The findings of the analysis in terms of total volume of power produced (Million of MWH) are presented in Table 16.

TABLE 16 TOTAL HYDROPOWER PRODUCTION UNDER DIFFERENT DEMAND AND CLIMATE SCENARIOS (MILLION MWH, 2010–40)

Demand scenario	*Baseline (no climate change)*	*Wet 2*	*Dry 2*
No competing demand to be met	1,884	2,136	1,722
Demand for M/I to be met	1,881	2,133	1,718
Demand for M/I and for irrigation to be met	1,858	2,113	1,696

Changes in irrigation water availability and crop yields. Intersectoral water conflicts will also impact the availability of water for irrigation, which will decrease crop yields in irrigated areas. Based on communications with the Ministry of Water Resources, irrigated agriculture will expand considerably by 2050, from 1.6 percent to 35 percent (3.7 million ha) of the approximately 10 million ha of agricultural land in Ethiopia (total agricultural area is assumed to remain relatively constant). WEAP generates unmet demand estimates based on a balancing of demands in the system. These unmet irrigation demands (all M&I demands are met because it has top priority) are produced for each basin and summed across basins to generate percent reductions in irrigation water availability between 2001 and 2050 under the baseline and each of the climate scenarios. Table 17 illustrates these unmet irrigation water demands, which rise to an annual average of up to 965 million m^3 under the Ethiopia dry scenario in the 2040s.

FIGURE 35 MEAN DECADAL CHANGES IN CROP YIELDS GIVEN INCREASING M&I AND IRRIGATION DEMANDS

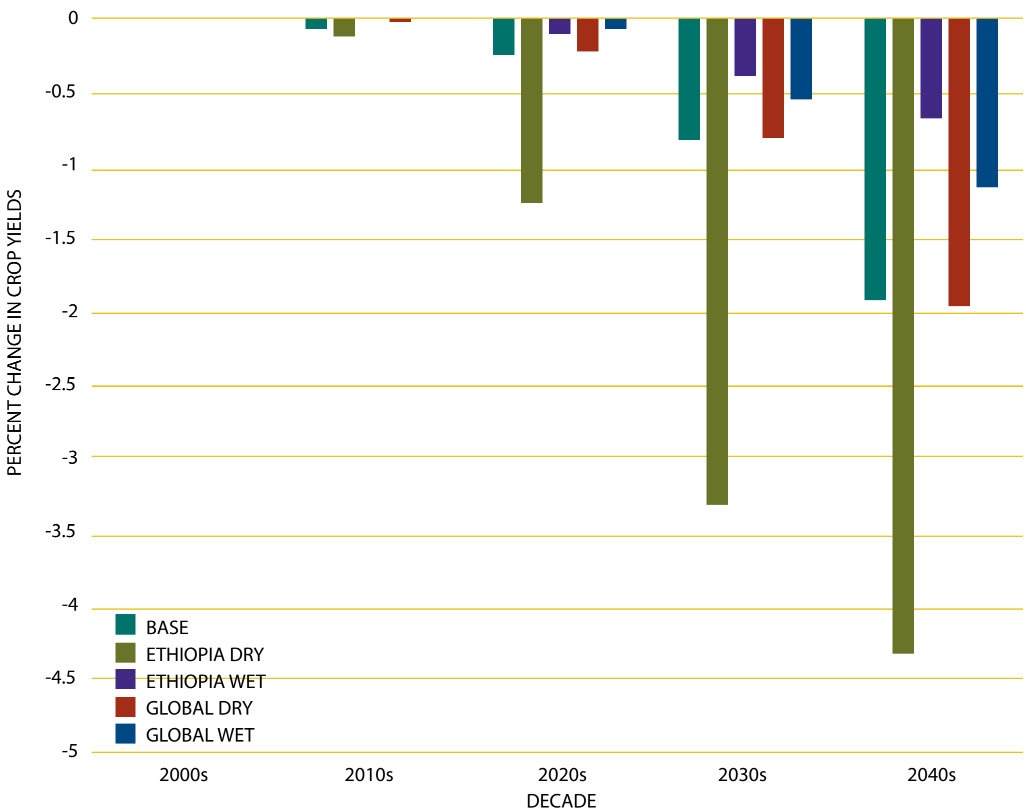


TABLE 17 UNMET DEMAND FOR IRRIGATION (MILLION M3, ANNUAL AVERAGE BY DECADE)

Scenario	*2010*	*2020*	*2030*	*2040*
Baseline	3.98	23.0	135	443
Wet 2	0.00	9.63	61.9	160
Dry 2	8.33	122	496	965

The unmet water demands can also be converted to changes in crop yields. Because farmers can adapt to restrictions on water and because the relationship between water and yield is nonlinear, this analysis assumes that each percentage reduction in irrigation water availability results in a one-half percent reduction in yields (i.e., a 10 percent reduction in water availability generates a 5 percent yield reduction). Based on this assumption, the resulting decadal reductions in yield are presented in Figure 35. Note that impacts on yield under the Ethiopia dry scenario are most severe at an average loss of approximately 4.4 percent in the 2040s (i.e., unmet irrigation water demands of 8.8 percent). The maximum annual loss in crop yield between 2001 and 2050 is also under the dry scenario at approximately 9 percent in 2049 (i.e., unmet irrigation demands of 18 percent). Under the scenario where 4.1 million hectares are irrigated by 2050 instead of 3.7 million, the maximum annual yield reduction is approximately 10 percent, also in 2049.

Vulnerability: A Participatory Analysis

To complement the numerical simulation of biophysical sector performance, a participatory analysis was also performed. Vulnerability was found to stem from a number of factors. These included elements of physical location/ hazard-proneness; economic geography/ regional development levels; socioeconomic status; and social differentiation, including ethnicity and gender.

Physical Geography. Physical location and hazard-proneness greatly affect household vulnerability, as in the drought-prone lowlands, which are chronically exposed to low rainfall. Just as asset depletion occurs in a chronic form at the household level, at the area level too, repeated hazard events can reduce a region's adaptive capacity.

Economic Geography. Vulnerability can also arise from the existing livelihood systems and policy regimes governing these systems. For example, single-sector pastoral livelihoods, which are dependent on natural resources and therefore vulnerable to climate change, are also being threatened by state policies regarding nonfarm external investment in the area that reduces land access for pastoralists.

Socioeconomic status. Poverty status (including low physical, financial, and human capital asset levels) lead to extreme vulnerability of households. Common factors here include high dependency ratios in the household, reliance on one livelihood, and low education levels. Cluster analysis of 294 households revealed that small poor farmers were in the worst position in the field sites, with young agropastoralists also vulnerable.

Crucially, the perception of households' wealth status by others (i.e., their "fallback position") affects the degree to which they can access private social protection measures organized at village level through their socially constructed "entitlements" to these measures. Analysis shows that private-measure benefits accrue largely to wealthier households facing crises (given they are likely to offer future reciprocal assistance). Specifically, at the household level, low levels of entitlements to resources means that households are more vulnerable to climate and other shocks. Cluster analysis of household survey responses found that informal village social assistance institutions tended to benefit large, landowning farmers (52 percent of these large farmers accessed the social assistance institutions, compared to an average access rate for all income groups of 34 percent). This finding points to the likelihood of inequity in collective social protection mechanisms through community institutions such as *idir* and *kire* (informal insurance organizations), *jiggie* and *debbo* (labor sharing organizations), and *iqub* (informal rotating savings associations).

This finding underlines the importance of ensuring public social protection transfers are also available to households, with transparent targeting processes, as now being undertaken by the Productive Safety Nets Program (PSNP) in Ethiopia. Such programs help smooth household consumption, and through NRM-targeted public works, help build area resilience, but may also thereby help households take on more of the necessary risk needed to diversify successfully through long-term adaptation measures in which more vulnerable households are unable to invest (for example, education).

Social differentiation, including gender. Impacts of physical hazards have differential effects on diverse groups. Social vulnerability factors identified in the Ethiopia study included ethnic status, migration status, presence of social conflict, and female-headed household status. Vulnerable groups identified through community discussions included asset-poor households, the expanding group of rural landless; the urban poor living in flood-prone areas of cities, and the elderly and the sick due to their limited adaptive capacity. Women and children left behind as male adults migrate for employment during drought-related production failures were identified as vulnerable during and after extreme events. Other vulnerable groups identified included communities living on already-degraded lands, and pastoral communities who face severe conflicts over access to land.

Gender.: There is also a relationship between household wealth/ livelihood composition/ asset ownership/ education levels, and female-headed household status. In sum, a quarter of households from the "small, poor farm" category were female-headed, in contrast to other, better-off household categories where female-headed households comprised just 5-7% of the total. Migration appeared to be of the "pull" factor, undertaken by those households cultivating more land.

Gendered norms and division of labor disproportionately harm women in resource-constrained environments such as those experiencing drought. In Birko-Debele *kebele* in South Wollo, Amhara region in the midlands of Ethiopia, a male farmer stated that women suffer most from food shortages at the household level, saying :

"When I realize that there is not enough food in the house, I go out to the nearby town or to my friends [to eat]. The woman cannot go out because the children will be waiting on her to get some food. In such cases, it is common that she cooks the little she has in the house and gives to her children and puts some aside for the husband, and goes hungry herself. As a result, the women get sick easily."

There is a strong gender division of labor regarding particular adaptation strategies and who decides about whether to undertake them. According to the survey, men decide on agriculture and livestock sales, use of savings, and all pastoralist practices. Men often tend to also decide seed selection, planting dates, and tillage practices, while women control decisions regarding handicraft production, household consumption, and charcoal and timber sales; that is, the less common/ dominant and less remunerative strategies.

Area asset status, including social capital and infrastructure. Social capital is an important input to adaptive capacity of both households and areas.

At the area level, social capital matters. Ethnic differences underlying diverse production systems can also exacerbate conflict over natural resources. Afar pastoralists' mobility has been restricted in Fentalle district in the Oromia region of eastern Ethiopia, leading to recurrent conflicts with neighboring agricultural communities (including in-migrant highlanders) over resource access and land rights. The violence in the area over these issues was presented as currently posing as much of a threat to pastoralist livelihoods as physical exposure factors of recurrent droughts, erratic rainfall, floods, and the growth of invasive bush species that destroy the rangelands.

Without good governance in the natural resource management sector (including at the local level), conflicts over natural resources will increase in climate-stressed environments. Water management at the local level poses a particular governance challenge. Fentalle district in the pastoralist area receives rainfall from the highland region, but the water does not move across the area due to the dikes in Gola that have been built to protect the local sugar estate. This local water governance issue further inflames tensions in an area where the pastoralists have already lost land to the commercial sugar estates.

Infrastructure assets also matter to reduce sensitivity and improve adaptive capacity. In highland Ethiopia, for example, livelihood diversification was said by workshop respondents to be constrained by a number of missing linkages such as poor road and telecommunication infrastructure, poor market information, and weak credit systems.

Economywide Impacts

BACKGROUND

The Ethiopia CGE model contains 22 commodity groups and 46 activities, including 35 regionally differentiated agricultural sectors. Agriculture and food processing (AgFood) account for 42 percent of gross production value and generate around 50 percent of Ethiopia's GDP at factor cost in 2005/06. AgFood imports account for only 8.4 percent of Ethiopia's total import bill, and the share of AgFood imports in domestic AgFood demand is also fairly low (5.3 percent). The only agricultural commodity with a large share of imports in domestic demand is wheat. Teff, maize, barley, sorghum, and enset are all virtually nontraded goods. On the other hand, agriculture makes a significant contribution to Ethiopia's total export revenue. Agricultural exports, which consist primarily of coffee and oilseeds, account for nearly 80 percent of agricultural exports. Agriculture represents 63 percent of total household consumption, including non-marketed home production for own home consumption, with a far higher share for rural poor households. Regionally, zone 2 produces nearly 50 percent of Ethiopia's total agricultural output and has the largest production share in all agricultural commodities except enset, while zone 1's contribution is marginal. Ninety-six percent of zone 5's agricultural output value is livestock production, and livestock accounts for 31 percent of Ethiopia's total agricultural gross production value.

BASELINE

The CGE model provides a simulation laboratory that allows us to estimate the economic impacts of climate change by doing controlled experiments, comparing the results of various scenarios. In order to use the model to estimate costs imposed on Ethiopia by global warming, we start by specifying a "baseline" path to 2050 that reflects development trends, policies, and priorities in the absence of climate change, but incorporating a historical pattern of climate shocks. The baseline is not a forecast, but instead 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.

Within the CGE model, the decisions of consumers, producers, and investors change in response to changes in economic conditions driven by different sets of climate outcomes, as do market outcomes. The model allows a degree of endogenous adaptation within periods, with changes in labor allocation across sectors and crops in response to shocks. In agriculture, land cannot be reallocated across crops within a period in response to climate shocks—cropping decisions are assumed to be made in the beginning of the period, before the realization of climate shocks are imposed. Between periods, land and capital can shift in response to changes in the economic environment.

In the baseline, underlying rates of productivity growth, world prices, foreign aid inflows, tax rates, and government investment policies are imposed exogenously. In the climate change scenarios, climate shocks affect various parameters and exogenous variables, as described below. By comparing results from the baseline path with those from the CC scenarios, the CGE model provides an estimate of the economywide impact of climate change.

Because comparisons are made with specific changes imposed and everything else held constant, the interesting results—the differences in outcomes between an experiment and the baseline—are generally insensitive to changes in the assumptions underlying the baseline. Results are generally more sensitive to the trajectory of baseline variables that are also policy variables. In the adaptation section, potential strategic options for adapting to climate change are presented. For

TABLE 18 SCENARIOS

Name	*GCM*	*CMI (%)*	*Description*
Base	Historical Climate		Historical climate shocks
Wet2	Ncar_ccsm3_0-sresa1b	23	Very wet CC shocks for Ethiopia
Wet1	Ncar_ccsm3_0-sresa2	10	Global wet CC shocks
Dry1	Csiro_mk3_0-sresa2	-5	Global dry CC shocks
Dry2	Gfdl_cm2_1-sresa1b	-15	Very dry CC shocks for Ethiopia
Wet2A	Ncar_ccsm3_0-sresa1b	23	Very wet CC shocks, with adaptation
Wet1A	Ncar_ccsm3_0-sresa2	10	Wet CC shocks, with adaptation
Dry1A	Csiro_mk3_0-sresa2	-5	Dry CC shocks, with adaptation
Dry2A	Gfdl_cm2_1-sresa1b	-15	Very dry CC shocks, with adaptation
Wet2AC	Ncar_ccsm3_0-sresa1b	23	Very wet CC shocks, with adaptation and costs
Wet1AC	Ncar_ccsm3_0-sresa2	10	Wet CC shocks, with adaptation and costs
Dry1AC	Csiro_mk3_0-sresa2	-5	Dry CC shocks, with adaptation and costs
Dry2AC	Gfdl_cm2_1-sresa1b	-15	Very dry CC shocks, with adaptation and costs

Notes: GCM=Global Climate Model. GCM scenarios are from Strzepek et al. (2008).
CMI=Crop moisture index change. "Adaptation" is the set of adaptation investment projects described in the text.

example, increasing irrigation is an important adaptation investment options. If the baseline plan were to expand irrigation to the limits of land or water availability, then there would be little policy space for expanded irrigation in the adaptation scenarios.

In defining the baseline, policy documents as well as sectoral planning documents were very helpful in establishing the expected path of sector development, and these plans were largely incorporated in the baseline. In some cases, such as road investment, the time horizon of the plan did not extend to 2050, so we had to extrapolate the existing plan. In the case of dams and hydropower, existing plans extend to the end of the period (2050).

The scenarios considered in this report are described in Table 18. There is a "Base" scenario, which provides the baseline with historical climate shocks, using monthly historical data from the past fifty years, extended over the future period. To recapitulate from earlier sections, there are four climate change (CC) scenarios based on output from various global climate models (GCMs): Ethiopia very wet (Wet2), globally wet (Wet1), globally dry (Dry1), and Ethiopia very dry (Dry2). The wet1 and dry1 scenarios are based on separate GCMs that yield global wet and global dry scenarios, and use the same GCM models across the case studies. The country very wet and country very dry scenarios are country-specific, using GCMs that yielded very dry and very wet scenarios for each country.

In the scenarios with a suffix "A," a program of adaptation investments are included, but with no explicit costs. These scenarios provide an upper bound of potential gains from adaption. The scenarios with a suffix "AC" include costs of the various adaptation investment programs. In this section, we report results for the shock scenarios. Adaptation scenarios will be considered later.

In the CGE model, the climate scenarios involve shocks to (1) agricultural productivity by crop and region, (2) hydroelectric power production, and (3) flood damage by region to roads, crop yields, and livestock.

ECONOMIC IMPACTS

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

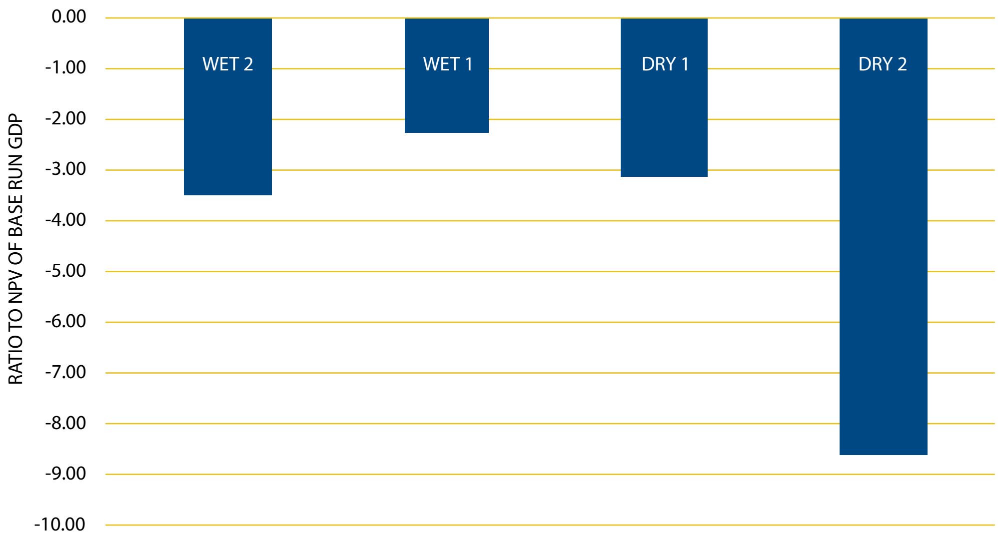
1. ***Productivity changes in dry-land agriculture.*** The influence of climate variables on agricultural productivity is obtained from the crop models (CliCrop) using the crop moisture index (CMI) generated by the GCM on a daily basis. The CGE model determines how much land, labor, capital, and intermediate inputs are allocated to a crop, as well as an estimated level of production under the assumption of normal climatic conditions. CliCrop determines deviations from this level as a consequence of realized climate. The resource allocations determined in the CGE and the deviations obtained from CliCrop jointly determine the level of production. Livestock production is estimated separately from CliCrop, as described in chapter 4.

2. ***Water availability.*** There are three principal sources of demand for water: municipal needs, hydroelectric power, and irrigation. The river basin models described earlier track water availability under alternative climates. Available water is allocated according to a hierarchy of use. First, municipal demand is satisfied. Second, flow is used to generate hydropower from available dams. Third, flow is used to irrigate cropland. The river basin models pass their results to hydroelectric power planning models, which estimate power output given available flow, and are affected by CC shocks and construction of dams over time. In addition, these models assess the implications of construction of more or fewer dams for electricity output and flow further downstream. Finally, crop models determine the maximum potential area that could be irrigated given available water flow. The CGE model incorporates directly the fluctuations in hydropower production due to variation in river flow, which are exogenous in the model.

3. ***Road 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.*** Extreme and damaging events such as floods and extended droughts may become more frequent under climate change, and are an output of the GCMs. The simulations presented below take flood damage to crops, livestock, and road infrastructure into account. "Extreme events" refers to extreme monthly streamflow events, not daily-scale flooding. The extreme events are obtained by rainfall runoff modeling using the monthly climate data from CGMs. Floods affect crop yields directly and also indirectly through damage to the transport sector that increases agricultural costs. Flood damage to roads affects the capital stock in the transport sector (differently for paved and unpaved roads), raising transport costs. In estimating flood impacts, we have drawn on data on the road system in Ethiopia that distinguish primary, secondary, and tertiary roads and the transportation model outlined earlier that estimates the impact of floods on these different types of roads.

FIGURE 36 WELFARE LOSS FROM CC SCENARIOS



Note: Difference in net present value (NPV) of total absorption (defined as GDP plus imports, minus exports) from the base run as a percent of NPV of base GDP. All figures are calculated over the 2010–50 time horizon

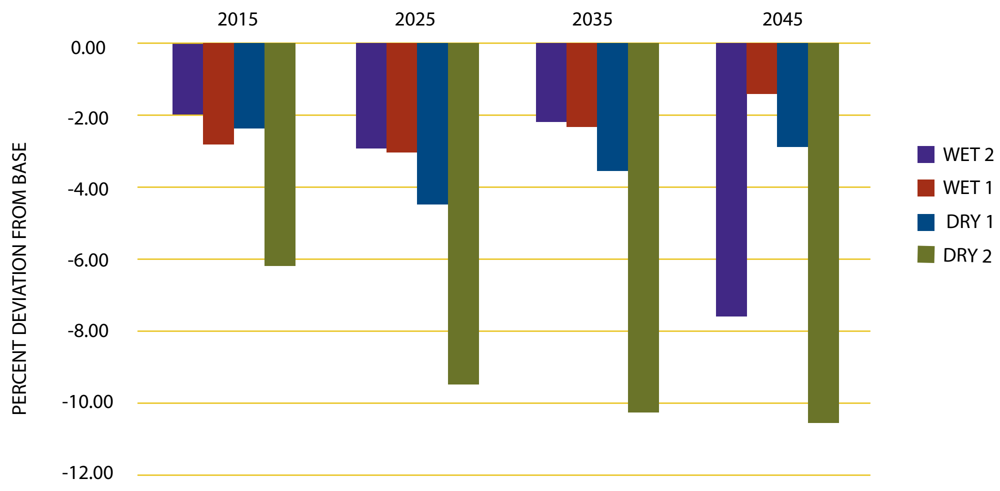
Other potential impacts are recognized but not explicitly considered. For example, climate change may alter the incidence of malaria in parts of Ethiopia, with potential implications for the pattern of economic activity and rates of economic growth. Health-related implications are not considered at this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

Economic development is very much about the accumulation of factors of production such as physical capital and human capital, and growth in technology. These factors, combined with the necessary institutional frameworks to make them productive, determine the material wellbeing of a country. The dynamic CGE model captures these accumulation processes, which largely drive growth. 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 results in less infrastructure capital both now and in the future. Extreme events can destroy infrastructure capital, which can only be replaced by additional investment over time. Generally, even small differences in rates of accumulation can lead to large differences in economic outcomes over long time periods. The CGE model employed is well-positioned to capture these effects. The key findings of the CGE analysis are summarized below.

Climate change has significant negative impacts on welfare. The Dry2 and Wet2 scenarios are the most damaging in net present value (NPV) terms (Figure 36), with the Dry2 having the largest negative impact.

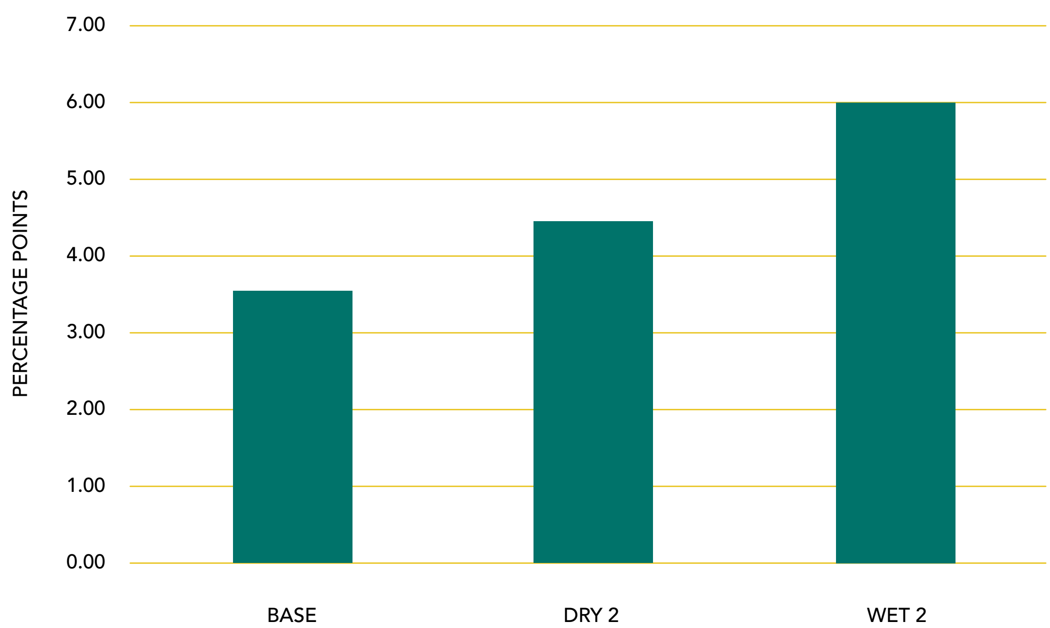
The Wet2 scenario is especially damaging in the final decade due to extreme floods, with GDP loss of nearly 8 percent compared to the base.

FIGURE 37 DEVIATION OF GDP FROM BASE SCENARIO



Note: 10-year average centered on year.

FIGURE 38 STANDARD DEVIATION OF AGRICULTURAL YEAR-TO-YEAR GROWTH RATES



Note: Standard deviation (SD) of annual growth rates of agricultural GDP for the different scenarios over the entire period.

The damage from the wet scenarios is concentrated in the latter years, while the damage from the dry scenarios is larger and is spread more evenly over the period. Under the Dry2 scenario, by 2050 GDP is projected to be some 10 percent smaller than in the no-climate change baseline (Figure 37).

Climate change increases variability in agriculture income. The variance in yields seems to increase with time, and the shocks become more negative, which is consistent with the view that the CC shocks will become more intense and damaging over time, as demonstrated in Figure 38.

The wet scenarios tend to be better for crop yields than dry scenarios, but floods are damaging, especially in the final decade (Figure 39).

The impacts of CC shocks differ greatly across regions for different scenarios**.** In zone 5, agriculture is almost exclusively based on livestock, and is very sensitive to water availability and temperature. (Figures 40 and 41).

The impacts of the shocks on electricity generation are significant. However, when we account for the construction of new dams, the supply of electricity grows faster than domestic demand and there are significant exports within a few

FIGURE 39 AGRICULTURAL GDP, DEVIATION FROM BASE

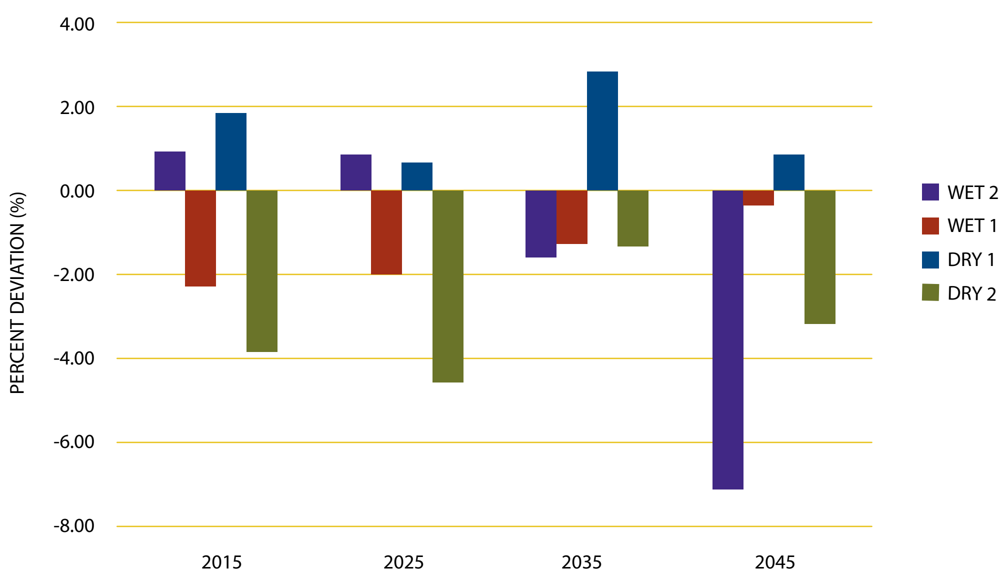
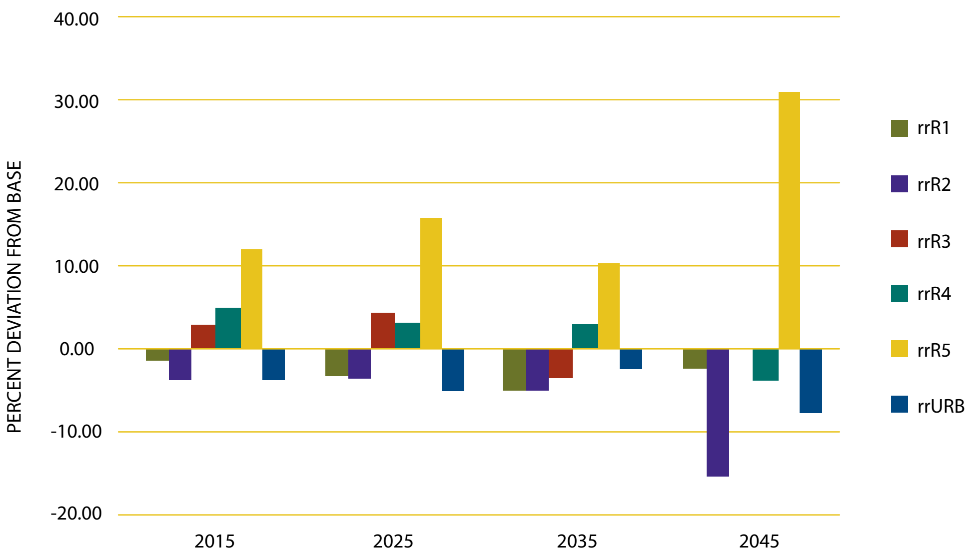
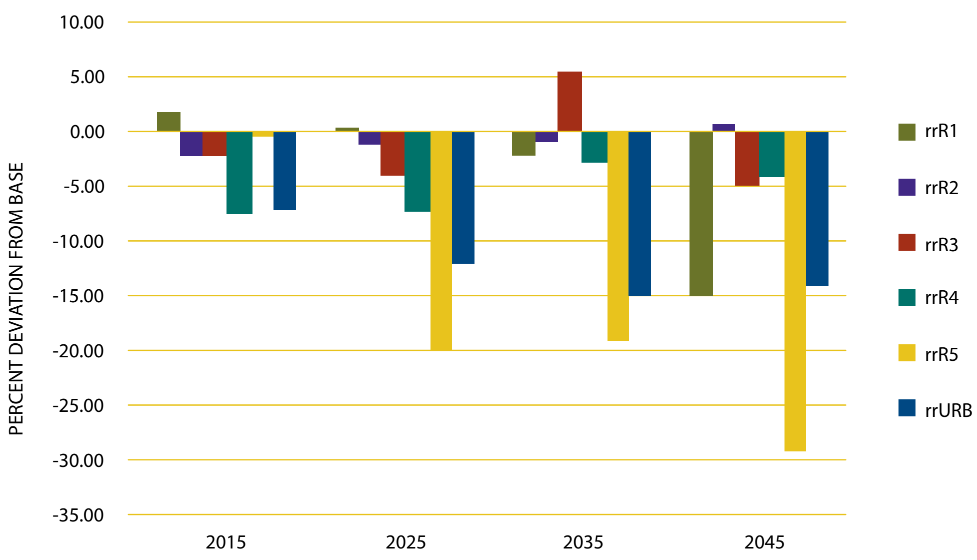


FIGURE 40 REGIONAL GDP, DEVIATION FROM BASE, WET2



Note: Regions R1 to R5 and Urban.

FIGURE 41 REGIONAL GDP, DEVIATION FROM BASE, DRY2



Note: Regions R1 to R5 and Urban.

FIGURE 42 EXPORT SHARE OF ELECTRICITY PRODUCTION

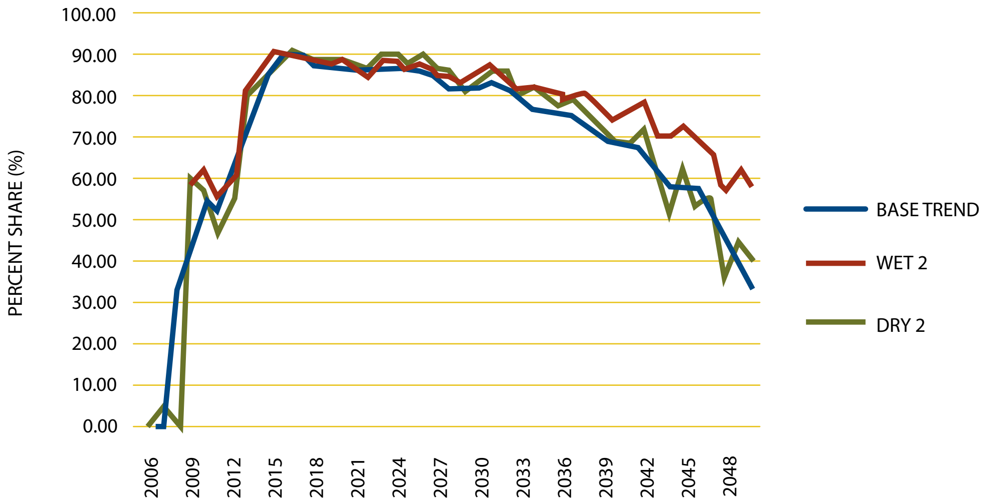


TABLE 19 STATISTICS ON YEAR-TO-YEAR GROWTH RATES (%) OF HOUSEHOLD CONSUMPTION

Scenario	*Household type*	*Mean*	*SD*	*Min*	*Max*
Base	Poor	5.29	1.82	2.01	8.97
Base	Non-Poor	5.57	1.78	0.61	9.25
Wet2	Poor	5.18	3.37	-4.50	12.77
Wet2	Non-Poor	5.44	3.23	-4.19	12.61
Dry2	Poor	5.09	2.50	-0.65	11.65
Dry2	Non-Poor	5.34	2.43	0.65	11.03

Note: Statistics on year-to-year growth rates over the entire period.
Mean=simple mean of year-to-year growth rates; SD=standard deviation; Min=minimum; Max=maximum

years. The CC shock scenarios lead to large variations in exports, but in no scenario is there a significant shortage or price rise in the domestic market (Figure 42).

Climate change impacts tend to hurt the poor more. Table 19 provides statistics on the year-to-year growth rates of household consumption for poor and non-poor households for the Dry2 and Wet2 scenarios. In general, the poor suffer slightly less in terms of means, but have to adjust to more variability in income and hence aggregate consumption than non-poor households.

FOUR

Adaptation Options

This chapter identifies a set of adaptation measures in agriculture, roads, and hydropower. The following adaptation options are considered:

- Increase irrigated area
- Increase research and development for agriculture
- Modify plans for expansion of hydroelectric power; build more or fewer dams
- Build climate-resistant road infrastructure; for example, increase the capacity of roads and bridges to withstand greater heat and precipitation.

By and large, these options are identified by taking as given certain sector development objectives—for example, the road network expansion plan, or the target production of electricity from hydropower—and defining ways to achieve those objectives even under varying climate conditions. Generally, however, adaptation might also involve changing sector development plans, or promoting a different allocation of resources across sectors. An illustrative investigation of this different line of reasoning is summarized below.

Agriculture

Taking into account the government's recent development activities in the sector (Box 4), as well as the significant (and yet largely untapped) potential for irrigation growth (Table 20), this report proposes a "portfolio strategy" approach to adaptation in agriculture. Such an approach combines (a) programs in research and development (R&D) and farm management practices, aimed primarily at boosting yields in rainfed areas; and (b) investments in irrigation and drainage infrastructure. The proposed approach is consistent with the EACC "global track" analysis (Nelson et al. 2009), which analyzed R&D and irrigation/drainage as a direct adaptation strategy; and the expansion of rural roads as an indirect strategy. In the case of Ethiopia, adaptation in the road sector is discussed in the next section.

BOX 4 GOVERNMENT ACTIVITIES IN THE AGRICULTURE SECTOR

Recent government activities to accelerate the development of the agriculture sector have focused on promoting better integration into market networks of both small and large farmers. This is being pursued through construction of farm-to-market roads, increases in drainage to address waterlogging and salinization, and increases in irrigation area, including by means of multipurpose dams. In addition, the government has been supporting reforms to improve the availability of fertilizer and improved seeds, and specialized extension services for differentiated agricultural zones and types of commercial agriculture.

The government is actively promoting irrigation, which has large expansion potential, but remains largely untapped. In terms of small-scale irrigation, schemes are being supported—such as such as river diversion, micro-dam construction, and groundwater abstraction for supplementary and double cropping—through provision of technical and material support for expansion and improved water use efficiency. Efforts are also being made to strengthen water harvesting, encourage the adoption of technologies for supplementary irrigation, and to promote low-cost manual, mechanical, and electrical water lifting mechanisms, as well as mini-drip irrigation methods and family drip-kits. In addition, medium- and large-scale irrigation projects are also being promoted (Ahmed, Arndt, Robinson and Willenbockel 2009).

The two pillars of the adaptation approach analyzed here (R&D and irrigation/ drainage) are meant to capture key aspects of a strategy capable of tackling the essential features of the climate of the future—that is, an increase in temperature, which is common to all scenarios—and changes in precipitation patterns (in varying directions and magnitudes, depending on the climate change scenarios).

Under all scenarios, temperature increases, with negative impacts on crops yields. Investment in R&D is thus intended to maintain the technology-induced productivity growth in the agricultural sector at the base, no-climate-change rate, by developing new crop varieties optimized for the changed climate. In each scenario an initial period of extensive R&D activities over the first 10 years was assumed to allow time to learn what direction climate change was taking for Ethiopia. This would allow infrastructure designs to minimize the risk of "regrets" associated with the selection of the "wrong" adaptation response.

TABLE 20 EXISTING IRRIGATION SCHEMES (2005/06) AND IRRIGATION POTENTIAL

Irrigation activity	*Area (000 hectares)*
Small-scale irrigation implemented (including traditional & modern)	
2004/05	306.70
2005/06	242.84
Total—end of 2005/06	549.54
Medium & large-scale irrigation implemented	61.06
Private implemented	5.41
Total irrigation potential	4,250.00

Source: Ahmed, Arndt, Robinson and Willenbockel (2009).

In all four adaption scenarios the baseline irrigation development plan of 3.7 million hectares by 2050 is increased gradually to 4.1 million hectares by 2050. The level of irrigation infrastructure is matched to the magnitude of climate-change-induced irrigation deficit. Note that it is possible to have increases in irrigation deficit even in wet scenarios. As warming increases, crops demand an amount of water greater than the increases in precipitation during the growing season. Changes in precipitation intensity and seasonality call for increased installation of drainage systems, especially in wet scenarios.

The order of magnitude of investments in agricultural adaptation was determined taking into account the opportunity cost of diverting resources from other sectors. Using CGE modeling, an average annual cost of about $70 million was assessed by expert judgment to be in a reasonable range so as to avoid an excessive drain on economywide growth.[10]

Irrigation infrastructure is installed on 400,000 hectares for all scenarios. For the Wet2 scenario, the design was for only stream diversion for supplemental irrigation For the Wet1, again only stream diversions were considered, but for a greater amount of supplemental irrigation. For Dry1, the designs included water harvesting and small-scale storage reservoirs. For Dry2, small, medium, and large-scale irrigation systems were part of the adaptation design, with correspondingly different levels of cost per hectare.

Drainage infrastructure was installed on 1.4 million, 1 million, 0.9 million, and 0.4 million hectares for the Wet2, Wet1, Dry1, and Dry2 scenarios respectively. The distribution of the costs between the adaptation components is listed in Table 21.

TABLE 21 SUMMARY OF ADAPTATION COSTS IN AGRICULTURE (ANNUAL AVERAGE 2010–50, US$ MILLION)

Cost Elements of the Adaptation Scenario	*Wet 2*	*Wet 1*	*Dry 1*	*Dry 2*
Irrigation Costs	16.00	30.00	32.00	50.00
Drainage Costs	36.78	23.79	21.17	7.50
R&D, Farm and Watershed Mgt	16.84	17.14	16.93	10.34
Total	69.63	70.93	70.10	67.84

10 In an economy-wide CGE analysis, after each climate shock the model reallocates inputs to activities and products so as to maximize profits. In certain cases, even after adaptation, marginal returns to inputs may be higher in sectors other than agriculture, so the baseline, no-climate-change level of production may not be attained in the scenarios with climate change.

While the adaptation strategy analyzed here addresses key aspects of sector vulnerability, it is admittedly defined in relatively coarse terms, given the aggregate level of analysis of this report. Future work will be needed to spell out in further detail individual components (and costs) of a more comprehensive adaptation strategy for agriculture, such as for example, specific technologies for livestock, soil, or water management; changes in planting dates, crop varieties, and cultivars; enhancement of large irrigation schemes; development of small irrigation projects and associated reservoirs in water-short areas; on-farm water harvesting projects; and installation of agricultural tile drainage in waterlogged areas.

Road Transport

The adaptation approach recommended for Ethiopia in the road sector is to adopt a "design strategy" approach that emphasizes enhanced design standards for roads and bridges such that these new designs consider the risk of increased climate change stressors. These design strategies encourage building infrastructure with enhanced materials and technologies that are able to withstand the increased climate stressors.

BOX 5 DESIGN STRATEGY ADAPTATION FOR PAVED AND UNPAVED ROADS

Paved roads. The design strategy 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°C maximum temperature increase for paved roads (Blacklidge Emulsions 2009; Whitestone Research 2008). The general dose-response relationship for paved roads is expressed as follows:

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

Where $C_{P,BHP}$ = change in construction costs associated with a climate stressor
B_{BHP} = base construction costs for paved roads.

We assume a construction cost of $500,000 per kilometer (km) for a new paved road in Ethiopia, which represents the average cost per km of constructing a 2-lane collector road in rural areas based on in-country data, and $117,700 per km for re-paving a road (World Bank 2009; 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, if it is estimated that precipitation will increase 11 cm over the next 20 years and temperature will increase 4°C, then 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, $8,000 per km, is required to adapt to the projected change in climate.

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.

$$C_{URBT} = M \times B_{URBT} \qquad \text{(Equation 5)}$$

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.

In this approach, when the road is re-paved at the end of its 20-year life span, it is repaved according to a design standard that compensates for the change in climate. Specifically, a road should be designed so that it can withstand the stress of increased precipitation or temperatures that will occur over its planned 20-year life span. In this manner, no increase in maintenance costs will be incurred due to the road being overbuilt at the beginning to meet any increased climate-based damages that may have been required maintenance during its life span.

The quantitative analysis of the potential total adaptation costs for Ethiopia utilizing the design strategy approach is illustrated in Table 20. In addition to the enhanced design strategy for paved roads, the costs assume that unpaved roads are regraded and re-sealed at five-year intervals, increasing maintenance costs as required in-between the five-year cycles. These costs are additional to regular maintenance or construction costs.

TABLE 22 SUMMARY OF ADAPTATION COSTS FOR ROADS (ANNUAL AVERAGE 2010–50, US$ MILLION)

	Wet 2	Dry 2	Wet 1	Dry 1
Cost increase for new paved roads	2.1	1.9	1.69	1.93
Cost increase for maintaining paved roads	4.1	3.5	2.26	4.98
Cost increase for maintaining gravel and earth roads	10.2	7.7	5.54	6.85
Total	16.5	13.1	9.5	13.8
Total (Cumulative total for entire period 2010–50)	658.4	524.4	379.8	550.4

As illustrated, the costs of adaptation compared to the potential impacts that result from no adaptation make it an imperative to spend a minimal amount up-front to avoid significant costs later due to no action. The cost-benefit from this expense becomes greater as time progresses due to the fact that each climate scenario indicates that over time, climate change impacts will increase. The longer adaptation is delayed, the greater the expense that must be incurred doing reactive maintenance.

The climate impacts analysis on road infrastructure used engineering data from the United States and Ethiopia. Unpaved roads in the United States and Ethiopia face similar engineering threats from climate, and impacts and costs have been vetted against a companion study on climate change impacts on transportation in Ethiopia. The magnitude of the undiscounted costs appear too high compared to current road investment and maintenance, because by 2040 the number of kilometers of road is projected to be many times the current network and extreme events from climate change are projected to become much more frequent and severe. This results in a multiplicative increase in impacts exhibiting, very large impacts at mid-century.

Additionally, much of the planned road expansion is with unpaved roads. Unpaved roads are very susceptible to intense precipitation events and local flooding damage. Both of these conditions are projected by climate models to increase under all GHG emission scenarios and are being reflected in the large impacts and adaptation costs at mid-21st century.

Adaptation to flooding. Similar to the process used for examining flooding under a maintenance-only scenario, the adaptation scenario utilizes a focus of multiplying a cost-per-kilometer factor times the actual pool of roads that may be damaged. The difference in this process is that the rate per kilometer includes adaptation costs and strategies that when implemented will protect the road from additional damage caused by climate-change-induced flooding. The basis for this approach for paved roads is derived from the report on making transport climate resilient (COWI 2009), where investigations were made to make roads climate resilient and climate proof. As introduced earlier, the adaptation approach assumes that the extra costs are used to improve drainage, road characteristics, and pavements to enhance flooding resilience.

The outcome of this research was the development of specific cost ratios for the adaptation process. For paved roads, the percentage increase for adapting to climate change is applied equally to all categories of roads. Specifically, an 11 percent increase in base construction cost is applied for adaptation charges.[11] This cost increase is added to all roads that are being re-paved at the end of their design life cycle when it is anticipated that a flood will occur in the projected life span that exceeds a minimum flood threshold. For this study, the projected flood must exceed a 20-year flood event, since this is the standard level of design that a road would incorporate in current design standards. If the projected floods exceed this level, then the adaptation cost is included in the rehabilitation costs. These roads are then considered to be resilient to a climate induced 1-in-50-year flood for their design life span, which is traditionally the greatest level of flooding that a road is designed to withstand under normal design conditions. Additional design and adaptation criteria would be required to make the road fully resilient to a revised 1-in-100-year flood.

Similarly, unpaved roads use the same approach, except since unpaved roads are on a 5-year design cycle rather than a 20-year design cycle, the adaptation process is incorporated on a more frequent basis. Other than this factor, the process is the same. For unpaved roads, the adaptation increase factor is 35 percent, which was derived using the same detailed adaptation analysis process as discussed previously for paved roads. The cost of this adaptation is a higher ratio than paved roads due to the actions that are necessary to make unpaved roads resilient to flooding. Similar to paved roads, the adaptation cost is applied to unpaved roads whenever the anticipated flood exceeds the design flood.

The conclusion of the flooding cost process is the generation of the adaptation cost vectors that are used as input for the CGE modeling. For this output, the flooding cost component provides an adaptation vector as follows:

Vector	*Definition*
Total Adaptation Cost for new roads - Paved + Unpaved	This is the total cost of adapting both paved and unpaved roads in a given year to the 1-in-50-year flood.

For each vector, the data conveyed from the cost module is divided among the three road types, primary, secondary, and tertiary. The vectors combine the climate zones together, since the CGE models do not divide the economywide analysis into separate zones. An example of each vector is supplied as follows.

In summary, the greatest adaptation costs for the road sector arise from adaptation to flooding. Combined, the average annual adaptation costs for both maintenance and flooding are in the \$80–\$90 million per year range except for the Wet1 scenario, where the total rises to \$117 million per year. Although these costs appear large, the cost-benefit factor must be taken into account. Specifically, the costs of proactive adaptation remain at only about 20 percent of the costs that will be incurred if no adaptation is put in place and a reactive perspective is put in place.

11 The 11 percent cost is obtained when the individual adaptations of drainage, road base, and road surface treatments are examined, the total cost related to the original design is an 11 percent increase. This number reflects findings by the overall EACC research team and is previously reported in broader terms in the COWI report, Making Transport Climate Resilient (COWI 2009).

FIGURE 43 TOTAL ADAPTATION COST FOR NEW ROADS (AVERAGE ANNUAL COST PER DECADE)

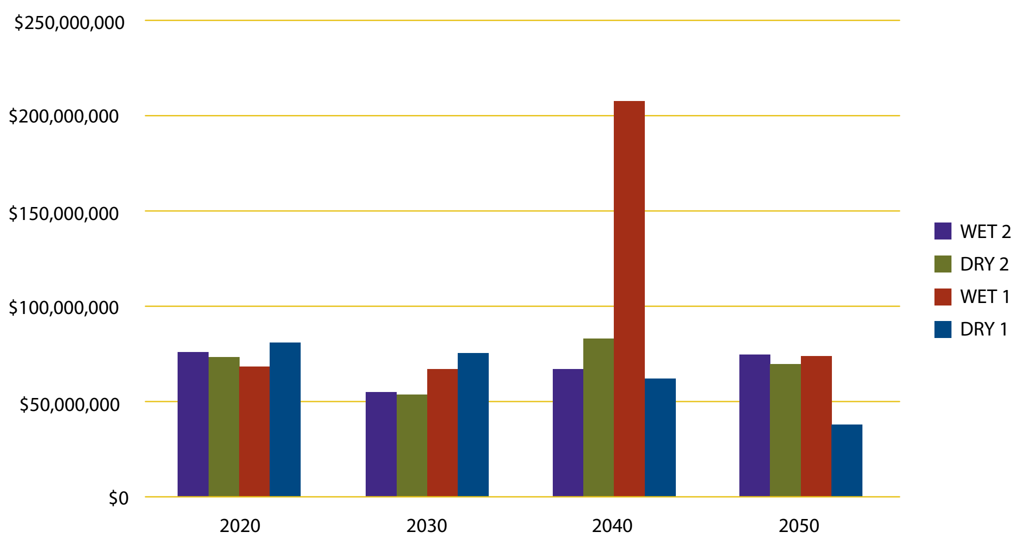


TABLE 23 SUMMARY OF ADAPTATION COSTS IN THE ROAD SECTOR (ANNUAL AVERAGE OVER THE 2010–40 PERIOD, US$ MILLION)

	Wet 2	*Dry 2*	*Wet 1*	*Dry 1*
Road maintenance	16.5	13.1	9.5	13.8
Adaptation to floods	71.92	73.17	107.85	67.76
Total Cost	88.42	86.27	117.35	81.56

ADAPTATION IN A BENEFIT/COST FRAMEWORK

The interventions included in the adaptation analysis—consisting of enhanced design standards, so that roads require less maintenance under ordinary weather conditions and are less vulnerable to floods—are likely to make sense (in a benefit-cost sense) even under current climate. However, financial constraints, which limit access to the required incremental capital at construction stage, make their adoption difficult.

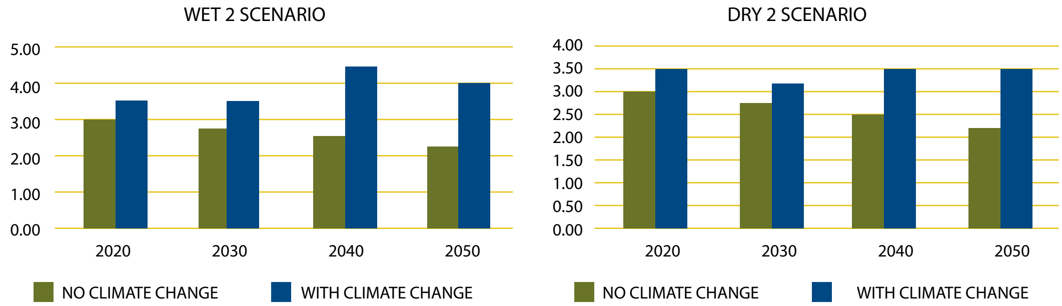
But the case for better standards is further strengthened when one accounts for the climate shocks of the future, which are likely to increase (for the same cost of construction and maintenance) the benefits, in terms of extended life of the network span, and of avoided higher maintenance cost in the future.

A benefit-cost analysis confirms these insights. The benefit/cost ratio of adopting higher design standards is 17 percent to 75 percent higher than in the baseline under the Wet2 scenario, and 16 to 55 percent in the Dry2 scenario (Figure 44). The additional benefit of higher standards become more pronounced in later decades of the time horizon considered on account of the expected higher frequency and/or severity of flood events.

Hydropower

Potential adaptation policy adjustments in the hydroelectric sector include altering the scale and

FIGURE 44 BENEFIT/COST RATIO OF UPGRADING ROAD STANDARDS



timing of planned projects as well as constraining downstream flow and irrigation flow.

Ethiopia is embarked on a very extensive hydropower development program. This program includes major dams on the Blue Nile, Atbara, and Gibe rivers. Some of these dams are planned as cascades of dams in series, and some as dams on parallel rivers. Climate change may result in higher average river flow, so the proposed projects could produce more energy than the base case. Additional economic benefits can be realized—or capital costs can therefore be saved—by building fewer projects.

Drier climate change scenarios result in lower average river flows and thus reduced energy generation from the projects developed under base conditions. Additional dams and power stations can be used to develop greater energy generation potential for the same river flow, as well as developing new dam sites on parallel rivers. The cost of additional capital to keep up with the Ethiopian base-energy generation plan is assumed to be the cost of adaptation in the energy sector. In some cases fossil fuel (CO_2-emitting) power stations could be built at a lower cost, but due to mitigation targets and high fuel cost this option was removed as an adaptation option.

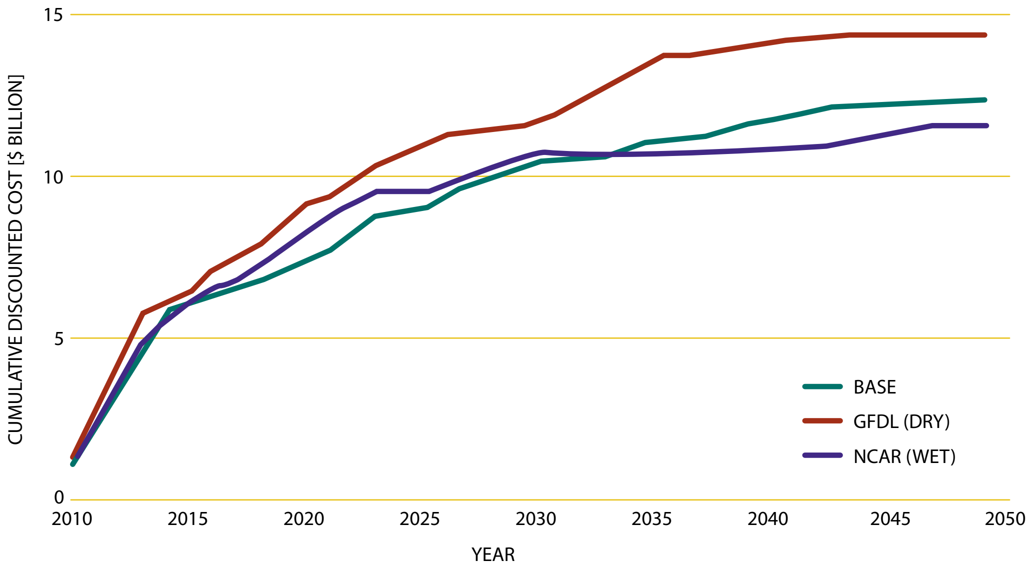
The goal of the adaptation analysis was to return the annual energy generation to base (non-climate change) values. With reduced flows and reservoir levels resulting from a drying climate change scenario, energy generation would be reduced. Since in the base development plan only a portion of all of Ethiopia's potential hydropower is developed, the adaptation strategy is to construct a series of additional hydropower projects to generate the "energy lost" to climate change. The costs for these new plants would be the adaptation costs.

Figure 45 shows the additional cost for the dry scenario and reduced costs for the wet scenario from the base hydropower investment development plan. The additional costs are incurred by bringing on additional power plants sooner than in the base case. The figure shows cumulative discounted costs. The annual undiscounted cost average over the 2010 to 2050 period is estimated at $100 million.

Summary of Sector-Level Adaptation Costs

By summarizing the results of the sector-wise analyses reported above, it is possible to evaluate

FIGURE 45 CUMULATIVE DISCOUNTED COST OF HYDROPOWER FOR TWO CLIMATE CHANGE SCENARIOS



the range of total costs (Table 24) that Ethiopia would need to incur in order to offset climate change impacts on the sectors analyzed. That is, the cost of actions that would need to be undertaken to achieve the sectors' development goals, even in the harsher climate of the future.

Adaptation costs vary considerably, depending on the climate scenarios considered. On an annual average basis, the range is between $158 million to $258 million per year. The highest cost is associated with the Dry2 scenario, which tends to generate damages (and therefore costs to remediate them) in a consistent manner throughout the period considered; whereas under the Wet2 scenario, damages (and adaptation costs) tend to cluster in the final decade.

TABLE 24 SUMMARY OF ADAPTATION COSTS, ALL SECTORS ANALYZED (ANNUAL AVERAGE 2010–50, US$ MILLION)

	Wet 2	*Dry 2*	*Wet 1*	*Dry 1*
Agriculture	69.6	70.9	70.1	67.8
Road transport	88.4	86.3	117.4	81.6
Hydro-power		100.4		25.0
Total annual average	158.0	257.6	187.4	174.4
Cumulative total for entire period (2010-2050)	6,321.9	10,304.0	7,497.9	6,976.2

Adaptation: Economywide Analysis

The sector-based analysis of adaptation reported above is just one part of the whole picture. To get a better representation of efforts needed to adapt, it is necessary to consider the opportunity cost of diverting scarce investment resources from ordinary development objectives to enhancing the economy's resilience to climate change. To exemplify, building stronger roads might entail less resources to build hospital or schools.

To include these indirect effects into the analysis, sector-level adaptation costs are incorporated into the CGE model described in chapter 2. In particular, the economy-wide effects of undertaking the following adaptation strategies are analyzed:

Roads. An expanded investment program in roads is analyzed. Such a program includes increasing the share of paved and hardened roads, as well as "soft" measures such as changes in transportation operation and maintenance, development of new design standards that consider projected climate changes, transfer of relevant transportation technology to stakeholders, and the enhancement of transportation safety measures. The associated adaptation costs were included in the model by converting the annual flows to local currency units (billions of birr) and treating them as a "claim" on gross fixed capital formation (GFCF). In the model, the initial road construction costs are incorporated in GFCF in the base run. These adaption costs are incremental; they essentially increase the road infrastructure investment plan for Ethiopia, increasing the share of paved roads and of "hardened" unpaved roads.

Dams. In this case, adaptation consists of altering the scale and timing of planned dam construction and hydropower projects, as well as constraining downstream flow and irrigation flow. The conflict analysis between hydropower and irrigation is discussed in chapter 3, and was used to develop this adaptation strategy in the CGE model. In the CGE model, the costs of the dams and hydropower investments are assumed to be financed by foreign borrowing. The annual costs are calculated as the interest charges (at 5 percent) on the cumulated debt in each period, which is then assumed to be a foreign exchange outflow in the current account balance. Note that the costs are higher under the "dry" scenarios, reflecting the need for additional investments to manage lower stream flows.

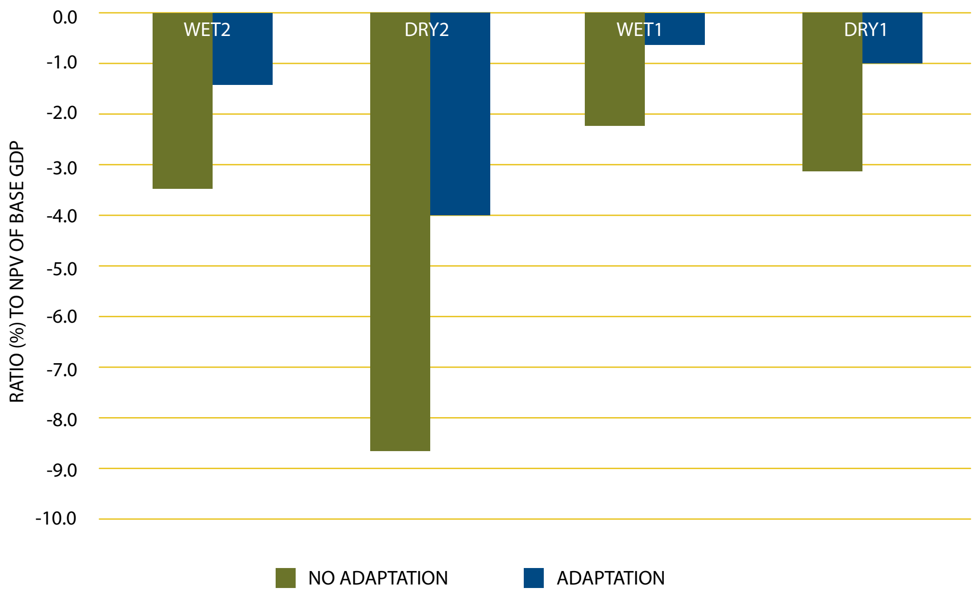
Irrigation. The model incorporates irrigation and water management investments. In the adaptation scenarios, the assumption is that the share of irrigated land and land benefiting from better water management increases over time more than in the base (no CC) scenario. The incremental cost of these investments has been estimated and incorporated in the model. There is also a tradeoff between water used for irrigation and for power generation. In the Dry2 scenario with adaptation, we assume that policy favors irrigation, with some loss of hydropower production and exports as a result.

WELFARE ANALYSIS

Figure 46 presents the effects of adaptation (with costs) on economic well-being—measured here as net present value (NPV)—of differences in total absorption as a ratio of the NPV of GDP for the different climate scenarios. The results indicate that adaptation investments significantly offset—but do not eliminate—the impact of CC shocks and improve welfare in all scenarios.

The ratio between the benefits of the adaptation strategy, and the project-level costs of implementing it ranges between 6 and 10, suggesting that while not fully effective at restoring baseline welfare, the strategy is quite efficient and capable of delivering welfare gains at relatively low cost.

FIGURE 46 NET PRESENT VALUE (NPV) OF ABSORPTION DIFFERENCES



Note: NPV of Absorption, Difference from Base (% of NPV of GDP). Absorption is defined as GDP, plus imports minus exports

Time profile of costs. Figure 47 provides information on the impact of the various scenarios on average GDP for various years (10-year average centered on the reported year).

The Dry2 scenario has a much bigger impact in all periods, while the Wet2 scenario has a dramatic impact in the last decade (with three 100-year floods in that period).

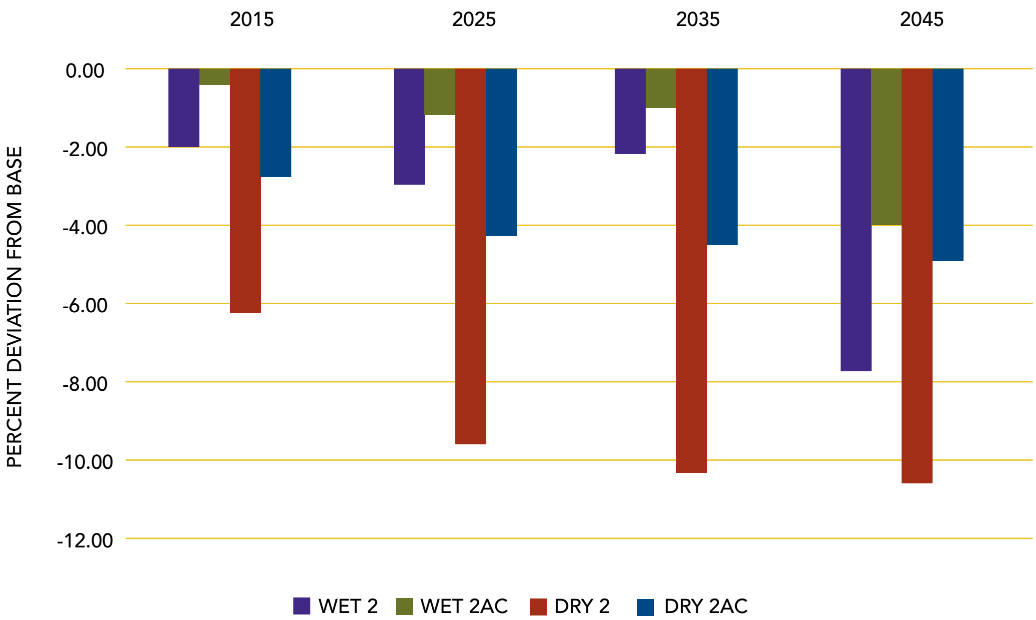
There is some evidence of "regret" adaptation investment, particularly in the case of building costly dams that may not be needed in the Wet scenarios. On the other hand, the gains from improved transport infrastructure are significant. Improved transportation is an essential part of the Ethiopian basic development strategy, and more resilient roads make sense even in the absence of climate change. As discussed in above, the argument is strengthened by introducing climate. In fact, the benefits are likely to be even higher than those considered at the project level because of the indirect, economywide benefits implications of enhanced design standards. A more climate-resilient road network can avoid costly disruptions of communications links and supply chains that increased flood frequency might bring about.

Adaptation investment is also found to have income smoothing benefits: it significantly reduces variability of agriculture GD growth compared to the no adaptation scenario (Figure 48).

ADAPTATION COSTS

We measure adaptation costs in two ways. First, earlier in the chapter, we calculated the direct costs of adaptation investment projects that were considered to be additional to the investment program in the base run. These costs are summarized in Table 24. Below we also provide a general equilibrium measure of direct and indirect adaptation costs. In the general equilibrium approach, the total cost of adaptation investments includes the

FIGURE 47 AVERAGE DEVIATION OF GDP FROM BASE RUN (%)



opportunity cost of the resources diverted from gross fixed capital formation (GFCF). It is measured as the difference between total absorption in the various CC scenarios with costless adaptation and with adaptation costs. This approach uses the CGE model to provide the counterfactual experiments to measure total absorption, first assuming costless adaptation, and then assuming adaptation is costed, based on the sector-wise analysis in chapter 3. The general equilibrium measure includes benefits that are foregone as a result of diverting toward adaptation investment, resources that would be otherwise employed to support Ethiopian development programs. The results are given in Table 25, which shows total direct and indirect adaptation costs in dollars.

In the case of hydropower, as discussed above, we assumed that the costs were funded by foreign borrowing and measured the annual flow of costs as the cost of servicing the accumulated foreign debt, using scarce foreign exchange which would otherwise be available for use in Ethiopia. The effect is to cut absorption, with the cut shared between aggregate consumption, government spending, and investment. Table 26 shows the impact on foreign savings of the servicing costs on foreign debt arising from hydropower investment.

TABLE 25 TOTAL DIRECT AND INDIRECT ADAPTATION COSTS ($ BILLIONS)

	Sum	*NPV*	*Average*
Wet2	100.30	29.31	2.457
Wet1	32.19	8.90	0.79
Dry1	38.71	10.74	0.94
Dry2	115.34	32.72	2.81

Notes: Sum: Sum, 2010 to 2050; NPV: Net Present Value; Average: Annual average

FIGURE 48 STANDARD DEVIATION OF YEAR-TO-YEAR AGRICULTURE GDP GROWTH RATES

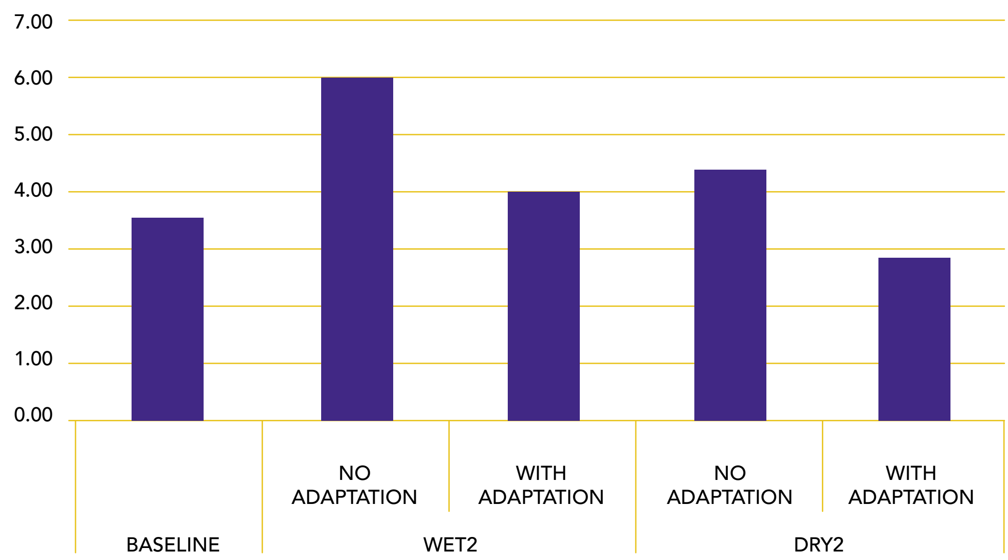


TABLE 26 FOREIGN SAVINGS ($ BILLIONS)

	Sum	*NPV*	*Average*
Base	103.65	$35.29	2.53
Wet2AC	106.23	$35.66	2.59
Dry2AC	98.49	$33.62	2.40
Wet1AC	103.84	$35.20	2.53
Dry1AC	101.68	$34.70	2.48

Notes: Sum, 2010 to 2050; NPV: Net Present Value; Average: Annual average

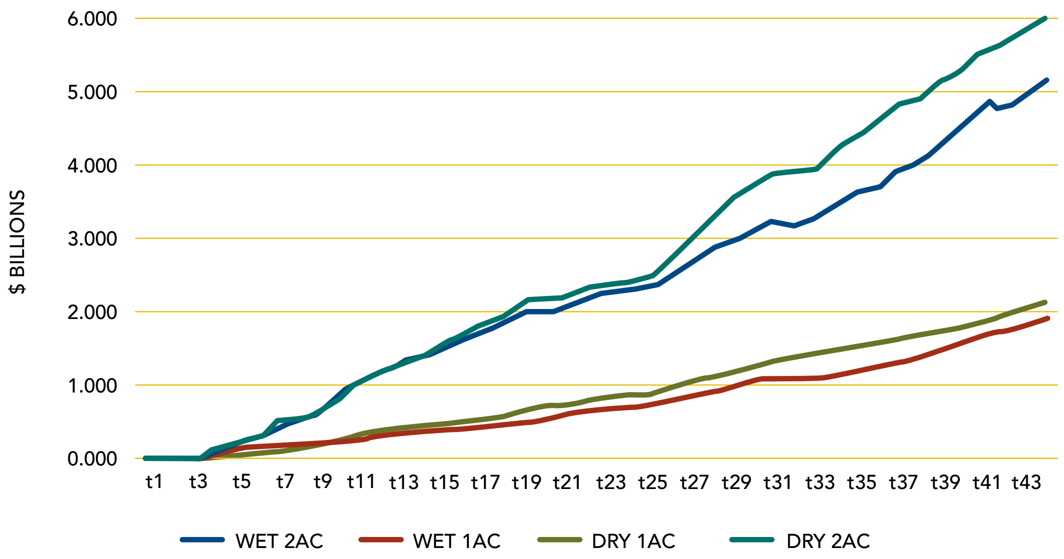
The results shown in Table 25 and Figure 49 indicate that adaption costs in the various scenarios differ a lot. Adaptation in the dry scenarios involves expensive increased investment in dams, irrigation, and hydropower, while adaptation in the wet scenarios involves relatively major investments in improved roads, which is especially evident in the later periods.

Table 26 and Figure 50 show the differences in foreign saving in the adaptation cost scenarios. The Dry2 scenario involves the largest increase in dams and hydropower investment, which results in the largest change in foreign savings as Ethiopia services the increased foreign debt to finance the investment. From Table 23, average annual adaptation costs vary widely and are a large share relative to foreign savings annually.

Figure 50 and Table 26 show the effect of dam/hydropower investment on the current account balance during the period. Note that in the Dry2 scenario, the additional investment costs impose interest charges that significantly reduce foreign saving (the current account balance). By contrast, in the Wet2 scenario, the lower construction costs and hence lower foreign debt lead to increases in foreign savings relative to the base run.

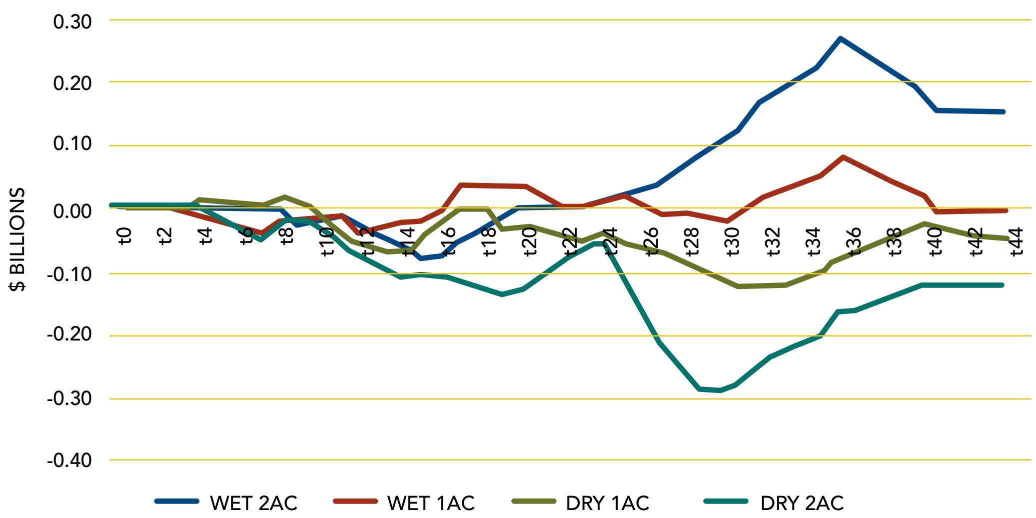
Figures 51 and 52 show the impact of the Wet2 and Dry2 scenarios on annual GFCF. The dry

FIGURE 49 DIRECT AND INDIRECT ADAPTATION COSTS ($ BILLIONS)



Notes: Direct and indirect costs of adaptation projects.

FIGURE 50 FOREIGN SAVING, DIFFERENCES FROM BASE RUN VALUES ($ BILLIONS)



Note: Foreign saving is the current account balance.

scenarios are more damaging to investment overall, while the wet scenarios are most damaging in the latter years, with magnitudes close to those of the dry scenarios. Not surprisingly, costless adaptation is the most beneficial. Costly adaptation always yields higher GFCF in all years compared to the no-adjustment scenario, indicating the success of costly adaptation to generate increased savings and investment.

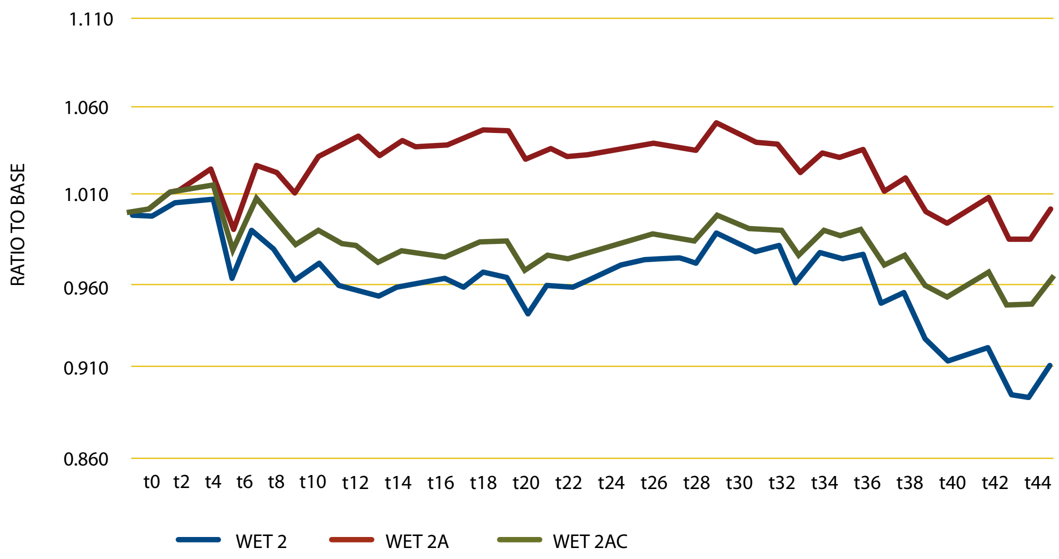
BENEFIT-COST ASSESSMENT

In addition to being able to reduce welfare losses and GDP variability, the adaptation strategy analyzed here appears to be quite sensible in a benefit-cost perspective. Table 27 provides data on the net gains from adaptation and the direct costs of the various adaptation projects assumed to be undertaken in the adaptation scenarios. The net gains are measured using the CGE model and are measured by the difference in total welfare (absorption) between the climate change shock scenario and the same scenario with costly adaptation. This measure is the appropriate measure of direct and indirect benefits that project evaluation manuals seek to approximate by partial equilibrium analysis and shadow pricing.

The values are not discounted because the time sequence of the benefits depends on the sequence of climate change shocks, which represent one draw from a stochastic process. While climate change effects become more pronounced in the latter part of the period, there is no certainty about year-to-year values. The "net gain" from adaptation is a general equilibrium measure, capturing all the direct and indirect benefits. It is the appropriate measure for benefit-cost analysis in project evaluation, which project evaluation manuals seek to approximate by partial equilibrium analysis and shadow pricing. The costs include all adaptation projects undertaken simultaneously, so the benefit-cost ratio measures the ratio of gains to costs for an adaptation investment program, rather than an evaluation of particular projects.

The results are dramatic. The mix of infrastructure projects in the adaptation investment programs (hydropower, irrigation, water management, and roads) yield very high benefit-cost

FIGURE 51 **GFCF, RATIO TO BASE RUN, WET SCENARIOS**



Note: GFCF is Gross Fixed Capital Formation

FIGURE 52 **GFCF, RATIO TO BASE RUN, DRY SCENARIOS**

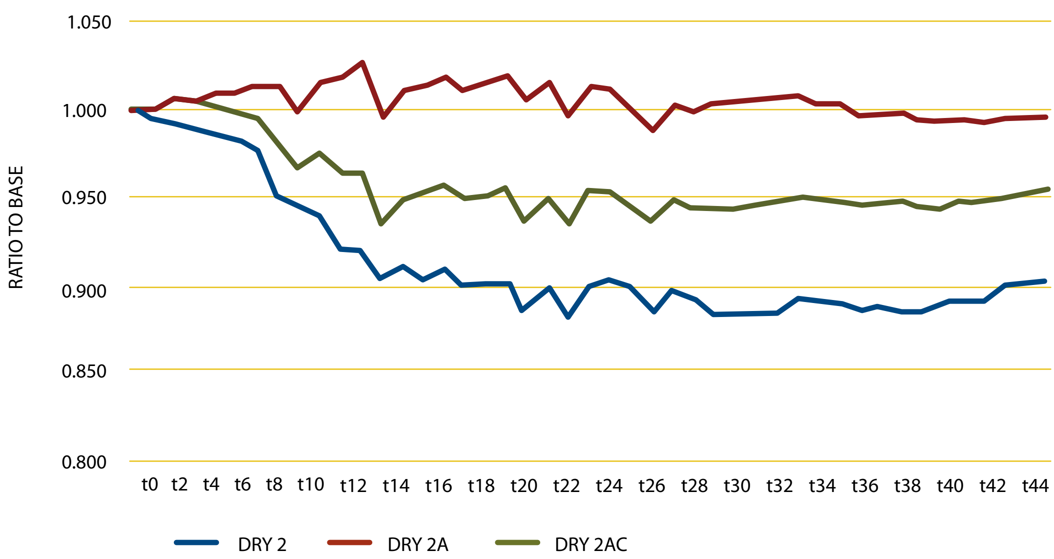


TABLE 27 NET BENEFITS AND ADAPTATION PROJECT COSTS, US$ BILLIONS

Scenarios	Welfare Losses		Net gain	Project costs	Benefit-cost ratio
	With adaptation	Without adaptation			
Wet2	-61.48	-131.80	70.32	6.32	11.1
Wet1	-17.67	-55.60	37.93	7.50	5.1
Dry1	-32.67	-88.41	55.74	6.98	8.0
Dry2	-124.06	-264.59	140.54	10.30	13.6

Notes: Cumulated losses and costs over the period 2010-2050, no discounting

ratios. Adaptation reduces the losses from the climate change shocks by over half, and the investment costs are much lower than this gain in all cases. In the worst scenario, Dry2, the benefit-cost ratio is highest (13.6), which indicates that these projects are very worthwhile. Discounting does not change these results.

CLOSING THE WELFARE GAP CAUSED BY CLIMATE CHANGE

Sector-wise adaptation enables the achievement of sector-level objectives in a cost-effective manner. But it also entails the opportunity cost of diverting resources toward investment in climate resilience, and therefore it does not necessarily enable Ethiopia to fully eliminate the welfare impacts of climate change. What would it take to "make the economy whole" again? Two options are explored in this section.

The first is to estimate the "residual compensation costs" as the transfers (in $ US) that would be required to completely offset the loss of absorption from CC shock, after implementing adaptation investments. The second is to explore an alternative development strategy not considered in the sector-wise analysis, namely a strategy of labor force upgrading in order to offset the negative impacts of CC on growth and to complement other adaptation investments.

Residual compensation costs. Residual compensation costs are measured as the difference between total absorption in the base run (with historical climate) and various climate change scenarios, including adaptation investments.
The Dry2 scenario has the largest residual compensation costs, while the impact of the increased number of extreme floods in the last decade generates large losses in the Wet2 scenario, which are only partly reduced by adaptation investment projects (Figure 46).

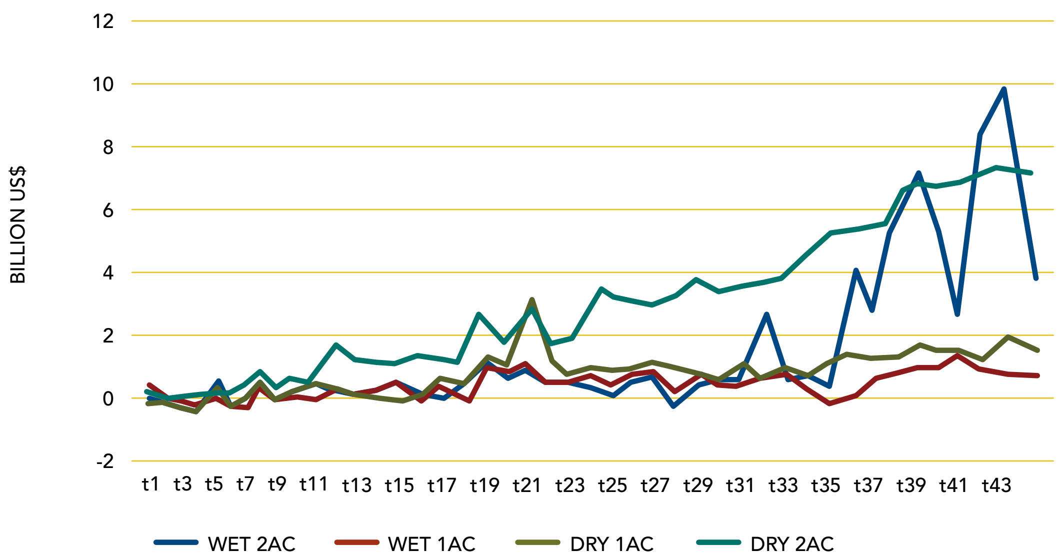
Closing the "welfare gap" through residual compensation would entail mobilizing a volume of resources much larger (Wet2 and Dry2 scenarios) than in the case including only adaptation costs.

Labor force upgrading. The second approach considered to close the welfare gap is to imagine a significant departure from the baseline development trajectory, rather than considering the latter as fixed and seeking ways to offset the impacts that climate change may have on it. In particular, a program of labor-force upgrading is analyzed, whereby it is assumed that unskilled rural labor

TABLE 28 ADAPTATION COSTS AND RESIDUAL DAMAGE (ANNUAL AVERAGE, 2010-2050), US$ BILLIONS

Scenario	*Adaptation costs*	*Residual Damage*	*Total*
Wet 2	2.45	1.52	3.97
Wet 1	0.79	0.43	1.22
Dry 1	0.94	0.81	1.75
Dry 2	2.81	3.03	5.84

FIGURE 53 RESIDUAL DAMAGE COSTS ($ BILLIONS)



migrates to the urban area, lowering the rural share of total labor by 0.1 percent a year. The migrated labor is assumed to lead to skill upgrading, with all categories of urban labor increasing.

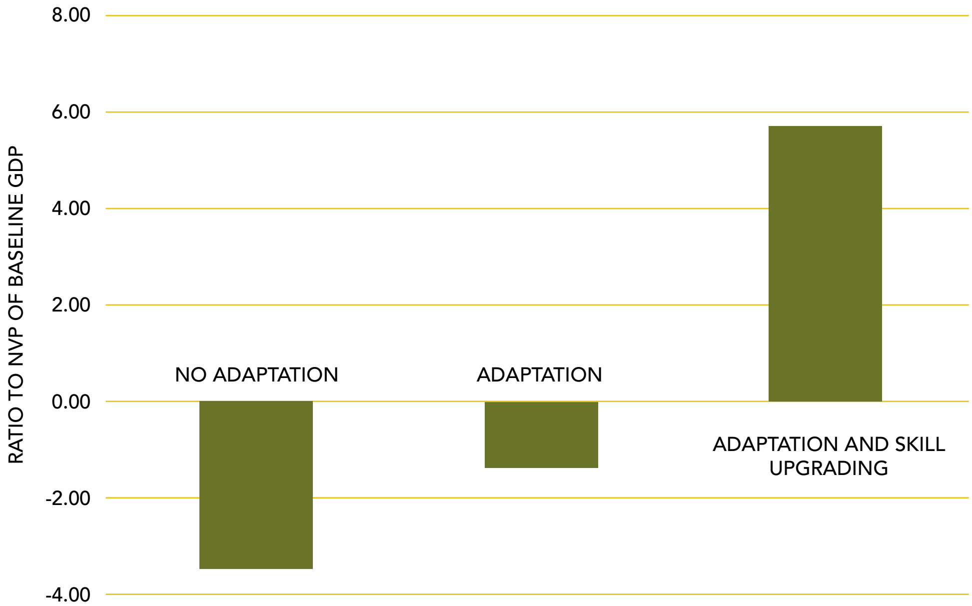
When tested under the Wet2 scenario, an adaptation strategy including such a labor-upgrading program appears to be able to more than offset, over the whole time horizon considered, the negative impacts of climate change on welfare (Figure 54).

While this scenario does not involve costing the skill upgrading program, this finding points to the significant potential benefits of accelerating the diversification of the economy away from highly climate sensitive sectors, such as agriculture.

IMPACTS ON POOR AND NON-POOR HOUSEHOLDS

The Ethiopia data separate poor and non-poor households, so it is possible to analyze the impact of climate change and adaptation scenarios on household welfare. The figures below provide information on these impacts.

FIGURE 54 DISCOUNTED DIFFERENCES IN ABSORPTION FROM BASELINE (2010–2050, WET2 SCENARIO)



Note: NPV of Absorption, Difference from Base (% of NPV of GDP). Absorption is defined as GDP, plus imports minus exports

Figures 55 to 58 present results concerning the impact of the climate change scenarios on household welfare, measured by total household consumption. From Figure 55, the impact of climate change shocks on the welfare of poor and non-poor households is roughly the same. The Dry2 scenario is the most damaging in all periods, but the Wet2 scenario is very damaging in the last period, with serious floods affecting roads.

Figure 56 shows the impact of the Wet2 scenario, with and without adaptation. Adaptation investment is very effective, offsetting about half the impact of climate change in both the extreme dry and wet scenarios. In the earlier periods, adaptation greatly reduces the impact of the Wet2 scenario—only in the final period, with extreme floods, does adaptation only partly offset the impact. The impacts of adaptation on household welfare are similar for both poor and non-poor households. Figure 57 provides the same data for the Dry2 scenario. The effects are larger than in the Wet2 scenario, and spread over the entire period.

Figure 58 shows the impact of the extreme wet and dry scenarios, with and without adaptation, on the coefficient of variation of the year-to-year growth rates of total household consumption. The mean of the year-to-year growth rates for both poor and non-poor households is around 5 percent, and the coefficients of variation (CV) range from a low of 0.3 to a high of 0.65. They represent the year-to-year changes in consumption to which households must adjust. A value of 0.3 in the base run indicates that households must manage annual swings in the change in consumption of 30 percent. 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—doubling in the extreme

FIGURE 55 **HOUSEHOLD CONSUMPTION: DIFFERENCE FROM BASE, CC SHOCKS**

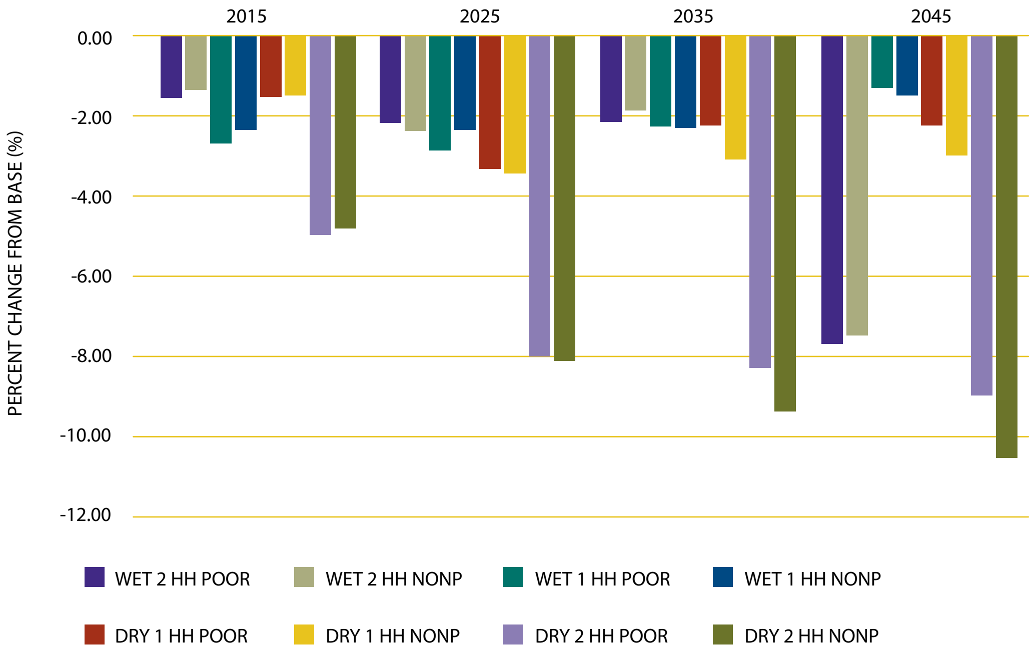


FIGURE 56 **HOUSEHOLD CONSUMPTION, DIFFERENCE FROM BASE, WET2 CC SHOCKS AND ADAPTATION**

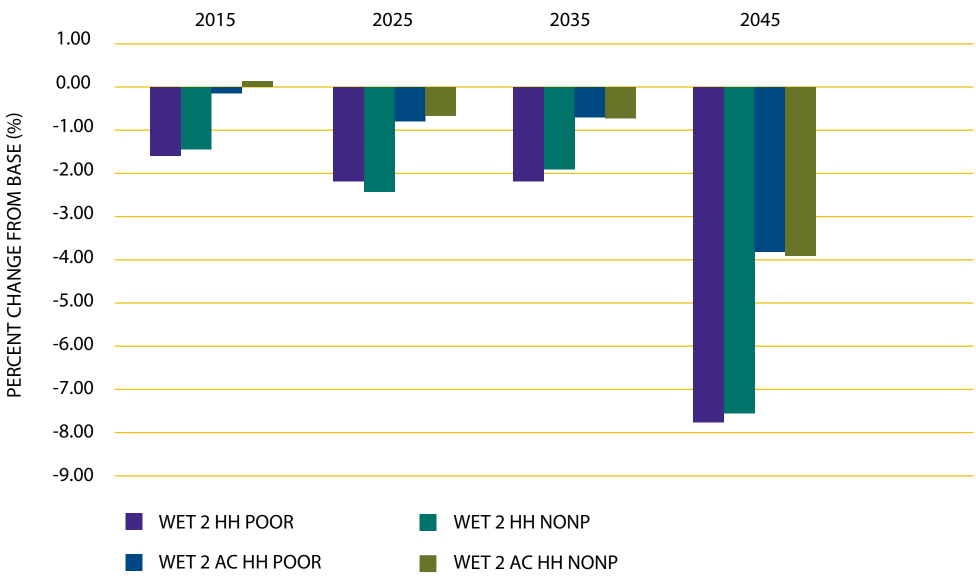


FIGURE 57 HOUSEHOLD CONSUMPTION, DIFFERENCE FROM BASE, DRY2 CC SHOCKS AND ADAPTATION

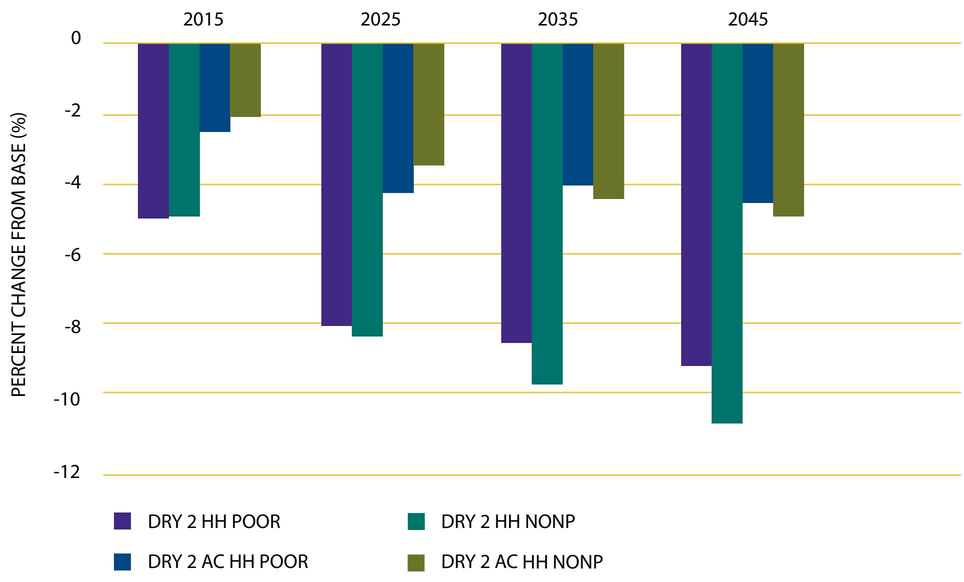
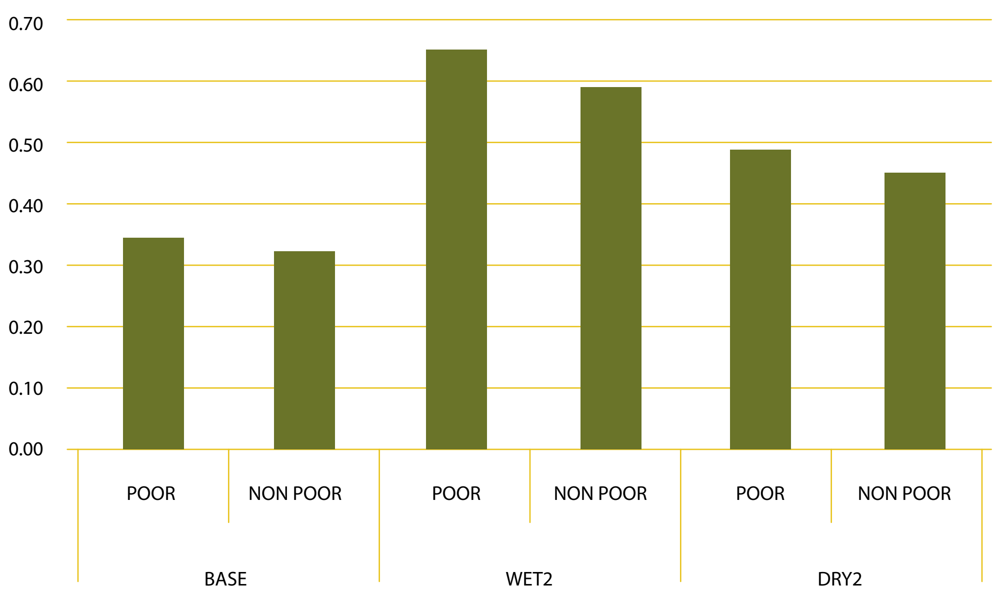


FIGURE 58 COEFFICIENT OF VARIATION OF YEAR-TO-YEAR GROWTH RATES, HOUSEHOLD CONSUMPTION



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

wet scenario (Wet2) and increasing by half in the extreme dry (Dry2) scenario. While not shown in Figure 58, adaptation is effective in reducing the impact of the climate change shocks on the coefficients of variation, moving them about half way to the base run values.

Adaptation: Priorities at the Community Level

ADAPTATION PRACTICES AND COPING STRATEGIES

Adaptation practices by households vary according to hazard type, location and asset base holdings. The most common forms of adaptation practices currently used by households as identified by the survey were (a) crop selection of drought-tolerant crops (78 percent of households); (b) terrace rehabilitation (72 percent); (c) soil erosion prevention programs (69 percent); and (d) homestead or forest restoration (62 percent) and change of planting dates (51 percent). Income diversification strategies (including migration, non-timber forest product sales, handicrafts, and timber sales) were not common. The households in these areas (drought-prone highland, midland, and lowland areas) already face significant deprivation currently, with 84 percent of surveyed households reporting food shortages during part of the year. This makes the selection of transformative adaptation strategies more difficult for individual households. Private collective action was also not common. The outreach of agricultural extension agencies in the field-site villages was high, though NGOs and cooperative activity much less prevalent. This suggests the importance of considering the use of existing public service providers in adaptation planning and capacity-building.

Focus group discussions identified additional elements of coping strategies. They included some temporary migration, sale of assets, and participation in cash for work programs. Specifically, household coping strategies in Kalu district included migration to neighboring towns (with migration distances becoming longer as the effects of extreme events become more pronounced), and the sale of goats. In Fentalle district, coping strategies included the sale of livestock; camel migration during the dry season from October to January; reducing household expenditures to staple items only; firewood and charcoal sales in nearby towns; and participation in cash-for-work projects from January to June. None of the coping strategies identified in the study could significantly reduce the effect of climate impacts on communities. Some also further contribute to environmental degradation, as in the case of illegal firewood and charcoal sales.

As one farmer said in Choresa *kebele*, "I am aware of the use of the forest for environment, for the soil and rainfall situation in the area, but I can't let my family die when there are some trees around to cut and make money out of."

Long-term adaptation planning (beyond short and medium-term measures such as changing crop types and planting dates) include the need for economywide diversification to industry and services, as well as significant improvements in human capital levels (education and training) to allow households to take advantage of risk-prevention strategies at household and community levels.

Finally, complex social responses to past extreme events hold important lessons on the need to consider the indirect impacts of, for example, distress migration to cities. In Ethiopia, the influx of rural in-migrants during drought events led to slum overcrowding, decreases in urban wage rates, and increases in food prices. The timing and scale of migrant flows to second- and first-tier cities also changed as the crisis deepened, with the capital Addis Ababa ending up as the refuge of last resort for the entire country. Earlier public and private actors (e.g., church institutions and family networks) played complementary social protection roles in Ethiopia, providing formal state cash transfers and private housing respectively. State support now predominates.

ADAPTATION PREFERENCES ARISING FROM PSD WORKSHOPS

The PSD workshop process included participants identifying their preferred long-term development vision for the area, as well as expected impacts of climate change on that vision, and adaptation investments needed in order reach toward that vision.

Notably, workshop participants' future visions for the area were not limited to climate outcomes, but sought reduction of social tension, improved safety net programs, benefit-sharing with external investors in the area and Awash National Park, resettlement programs, improved participation/ use of consultation in development planning processes, and improved livestock services. Similarly, the Kalu district workshop included a vision of improvements in education, employment, and infrastructure. In terms of impacts, Karrayu pastoralists in the Fentalle district PSD workshop identified how their vulnerability and worsening livelihood position was related not only to rain shortages but also due to additional factors of forced land alienation, population growth, and land conflict, which interacted with the naturally degrading pasturelands to cause animal (and eventually human) disease and death, as well as migration and withdrawal from school.

The PSD workshops conducted in case countries revealed broad support for NAPA and related climate strategy priorities in-country, in such areas as agriculture and water resources management, land management, roads, and early warning systems. However, they also revealed stakeholder preferences for investments in governance, social protection, training and education, and land tenure. Training and education were identified as a need not only for livelihood diversification, but also in the area of increased capacity building in community-based approaches to climate change adaptation and natural resource management.

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

FIVE

Recommendations

The findings of this analysis suggest that impacts of climate change will be quite significant, particularly as Ethiopia approaches the middle of the century. While the magnitude of the impacts remains considerable—irrespective of whether the climate of the future will be wetter or drier—several important adaptation decisions are sensitive to what climate is expected.

Given the large uncertainties regarding future climate outcomes, the approach to enhance Ethiopia's climate resilience should be couched in terms of a gradual, adaptive, and learning paradigm. Such an approach could be articulated for both the shorter term—including the implementation of the Growth and Transformation Plan (GTP) recently issued by the government)—and for the longer term.

Shorter Term (up to 2015)

By and large, the Growth and Transformation Plan supports a number of actions which, by boosting growth, will contribute to the enhancement of Ethiopia's resilience to climatic shocks. Robust growth based on infrastructure investment is likely to be the first line of defense against climate change impacts. Relatively small deviations from the ambitious investment targets set forth by the government for roads, dams, hydropower, water management, and irrigation would significantly increase longer-term vulnerability to climate change and thus make adaptation costlier. However, there are a number of additional issues that the government could consider to further enhance the contribution of GTP to Ethiopia's climate resilience (and thus, ultimately, to the ability of the country to support sustained, longer term growth). In particular, two of the GTP pillars deserve attention:

- The agricultural sector as the engine of growth.
- Expand the coverage and enhance the quality of infrastructure.

AGRICULTURE

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

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

ROAD INFRASTRUCTURE

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

Modeling results show that existing infrastructure design standards—the level of prevention against extreme events, such as local and regional flooding—are inadequate to address current climate variability and will impact economic growth rates in the near and middle terms. Results from climate change analyses show that this issue is likely to become worse in the middle to long term. The government should consider enhancing infrastructure design standards as soon as possible. This would make sense—in benefit/ cost terms—already under today's climate, but even more so under the harsher climate of the future.

The GTP includes ambitious targets for upgrading the road network, including 70,000 km of all-weather, woreda-level roads. Unpaved roads only have a 5-year design span until resurfacing and are very susceptible to flooding damage, which has very large indirect, economywide costs on supply chains and health and education services. The government may want to consider a more detailed economic analysis of the road expansion targets to determine if building fewer, but more climate resilient roads, is preferable to building a larger number of roads, but which are likely to be more vulnerable to climate shocks. The case for the former option seems compelling under current climate, and will become even sounder under the climate of the future. In addition, should international climate finance resources become available in the future for Ethiopia—from the Copenhagen Green Fund or other mechanisms—the government might consider utilizing these resources for enhancing the climate resilience of the road network expansion plans.

ENERGY

Current water resources and Ethiopian topography indicate an overall potential of more than 30,000 megawatts in economically viable hydropower generation capacity. The GTP approach is to focus on "the development of water and wind energy options to fulfill the energy demand of the country," with targets for hydropower of 6,000 to 8,000 MW in additional generation capacity. The hydropower analyses of this report (conducted at the monthly scale, which is adequate for sector-wide planning purposes, although not for plant-level design and operation), provides support, from a climate change perspective, for the GTP targets. The projects likely to go online in the next 5 years have very low risk of being impacted by climate change.

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

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

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

Medium to Long Term

As Ethiopia looks into the next stages of development (starting with preparation of the next growth plan, which will follow the GTP 2011-2015), it might want to evaluate more closely the implications of climate change for its overall policies and infrastructure development programs. Early planning for the more severe climate impacts of mid-century is desirable, so as to avoid locking the country into a climate-vulnerable development trajectory, particularly when it comes to economic processes with a high degree of inertia, or investment decisions concerning infrastructures with a long life span.

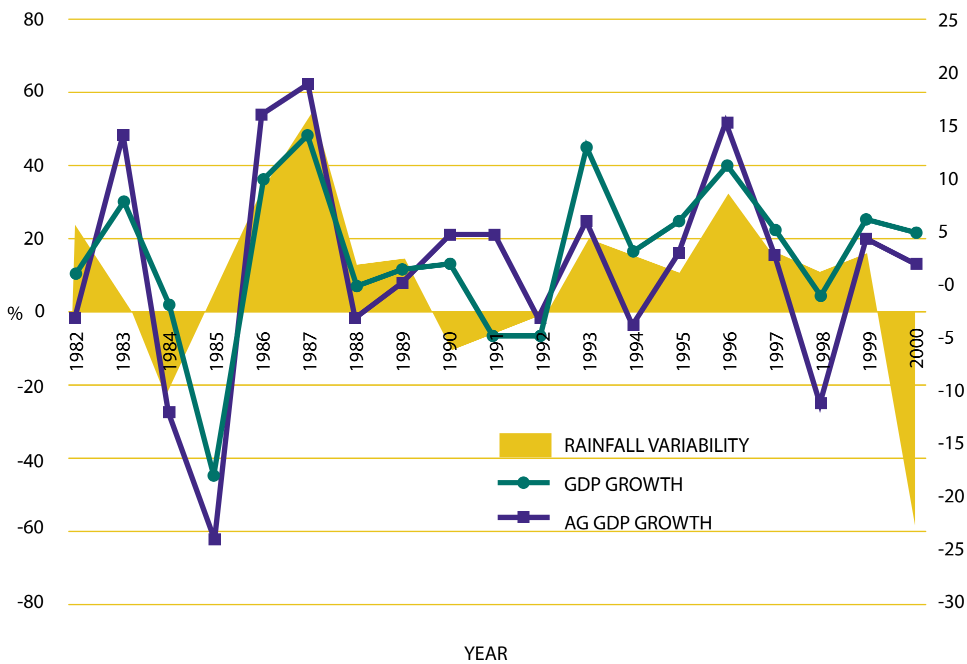
Due to the uncertainty of future climate, a risk-based investment planning approach should be adopted. Robust decision-making principles are needed to minimize the "regrets" of climate-sensitive decisions. As climate shocks become more frequent and severe, the "opportunity costs of capital" invested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

MACROECONOMIC MANAGEMENT

Historically the Ethiopian economy has been vulnerable to climate fluctuations (Figure 59). The analysis of this report shows that climate variability will increase under all scenarios. Since agriculture (the economy's most climate sensitive sector) is likely to remain for some time one of Ethiopia's main engines of growth, climate-induced shocks will continue to be a threat to macroeconomic stability because of the impacts on income, employment, fiscal revenues, capital formation, and the drain on government expenditure and aid flows to support disaster relief.

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

FIGURE 59 ECONOMIC GROWTH AND CLIMATE



Source: De Jong, The World Bank (2005)

PROMOTE DIVERSIFICATION ACROSS SECTORS OF INCOME AND EMPLOYMENT

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

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

EVALUATE THE CLIMATE RESILIENCE OF LARGE INFRASTRUCTURE PROJECTS

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

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

PROACTIVELY ADDRESS CONFLICTS IN WATER USES

Under “dry” future climate scenarios, competition among users of water (e.g. municipal and industrial consumption, hydropower generation and irrigation) might become more acute, particularly in certain river basins. The availability of water to downstream riparian countries might also be affected.

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

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