ADB

Building Climate Resilience in the Agriculture Sector of Asia and the Pacific

Asian Development Bank

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International Food Policy Research Institute

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Acronyms and Abbreviations

ADB	–	Asian Development Bank
°C	–	degrees Celsius
CGIAR	–	Consultative Group on International Agricultural Research
CH_4	–	methane
cm	–	centimeter
CO_2	–	carbon dioxide
CSIRO	–	Commonwealth Scientific and Industrial Research Organization
DRR	–	disaster preparedness or risk reduction
DSSAT	–	Decision Support System for Agrotechnology Transfer
°F	–	degrees Fahrenheit
FAO	–	Food and Agriculture Organization
FCF	–	Future Carbon Fund
GCM	–	General Circulation Model
GDP	–	gross domestic product
GEF	–	Global Environment Facility
GHG	–	greenhouse gas
GMS	–	Greater Mekong Subregion
Gt	–	gigatons
Ha	–	hectare
HadCM3	–	Hadley Centre Coupled Model, version 3
IFPRI	–	International Food Policy Research Institute
IMPACT	–	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	–	Intergovernmental Panel on Climate Change
IRW	–	Internal Renewable Water
IWSR	–	irrigation water supply reliability
Kcal	–	kilocalorie
Kg	–	kilogram
km^2	–	square kilometer
km^3	–	cubic kilometer
LULUCF	–	land use, land use change, and forestry

MDG	–	Millennium Development Goal
MFS	–	microfinance services
mm	–	millimeter
Mt	–	megatons
MT	–	metric ton
NAPA	–	National Adaptation Programme of Action
NCAR	–	National Center for Atmospheric Research
NGO	–	nongovernment organization
NN	–	neural net
N_2O	–	nitrous oxide
ODA	–	overseas development assistance
OECD	–	Organisation for Economic Co-operation and Development
PEF	–	Poverty and Environment Fund
PES	–	payment for environmental services
ppm	–	parts per million
PPP	–	public–private partnership
PRC	–	People’s Republic of China
PRSP	–	Poverty Reduction Strategy Papers
R&D	–	research and development
SCCF	–	Special Climate Change Fund
SOC	–	soil organic carbon
TERI	–	The Energy and Resources Institute
UNDP	–	United Nations Development Programme
UNEP	–	United Nations Environment Programme
UNFCCC	–	United Nations Framework Convention on Climate Change
UNISDR	–	United Nations International Strategy for Disaster Reduction
WFPF	–	Water Financing Partnership Facility
WMO	–	World Meteorological Organization
WSBI	–	World Savings Bank Institute
WTO	–	World Trade Organization

Foreword

The Asian Development Bank (ADB) under the regional technical assistance (RETA) project, "Addressing Climate Change in the Asia and Pacific Region," financed studies on topics that are among the most important issues for policy makers in the region: climate change and energy, building climate resilience in the agriculture sector, and climate change and migration. Together, the three studies address climate change challenges to the key drivers of the region's development – food, fuel, and people.

This report discusses building climate change resilience into the agriculture sector in Asia. It comes at an opportune time. In 2007–2008, the world economy experienced one of the worst food crises in recent memory, with prices of major grains and food products rising sharply and pushing more people toward poverty and extreme hunger. Many studies project that food prices will remain high; the adverse effects of climate change on future production may further exacerbate high prices. Thus, the impact of climate change on Asia and the Pacific's agriculture sector will pose a significant development challenge for the 21st century.

The nexus between climate change and agriculture and the formidable (but not insurmountable) barriers to achieving sustainable development in the developing countries of Asia and the Pacific are the themes of this study. Among the economic sectors, agriculture is the most vulnerable to climate change. With more than 60% of their population directly or indirectly relying on agriculture as a source of livelihood, the developing member countries of Asian Development Bank (ADB) in Asia and the Pacific will be adversely affected by this external factor. Disruptions in food supply will also have negative impacts on the wider population of net food buyers. More importantly, as Asia and the Pacific account for half of the world's supply and demand for grains, any significant changes in the food systems of this region will have global implications on food availability, access, and utilization.

Preparation of the report was led by the dedicated and expert team of the International Food Policy Research Institute (IFPRI), under the direct supervision of Dr. Mark Rosegrant, Director, Environment and Production Technology Division, IFPRI. The Agriculture, Rural Development, and Food Security Unit of the Regional and Sustainable Development Department (RSDD) of ADB coordinated the study. ADB extends its gratitude to IFPRI for leading this highly relevant and timely work on climate change and agriculture in Asia and the Pacific.

Through this joint ADB–IFPRI undertaking, ADB hopes to contribute to the efforts of addressing effectively climate change challenges in Asia and the Pacific. In particular, this includes adapting to and mitigating its adverse impacts on agriculture. In the process, this ensures food security, benefitting primarily the poor and most vulnerable groups, reduces hunger and poverty in the region, and strengthens the pathway to inclusive sustainable development in the region.

Xianbin Yao
Director General
Regional and Sustainable Development Department

Acknowledgments

This study is one of the three studies organized by the Asian Development Bank (ADB) under the regional technical assistance (TA) project Addressing Climate Change in the Asia and Pacific Region. Aside from agriculture, the other two studies relate to energy and migration.

The Washington-based International Food Policy and Research Institute (IFPRI) conducted this study, Building Climate Resilience in the Agriculture Sector. Mark W. Rosegrant, Director of the Environment and Production Technology Division, led the IFPRI team. The work benefited immensely from the research, writing, and editorial contributions of IFPRI staff comprising Miroslav Batka, Lorena Danessi, Mandy Ewing, Jawoo Koo, Christina Lakatos, David Lee, Marilia Magalhaes, Siwa Msangi, Gerald Nelson, Amanda Palazzo, Claudia Ringler, Ricky Robertson, Timothy Sulser, Rowena A. Valmonte-Santos, and Tingju Zhu.

National experts from a number of ADB member countries including Bangladesh, Cambodia, the Fiji Islands, Indonesia, the Maldives, Pakistan, the Philippines, the People's Republic of China, Tajikistan, Thailand, Uzbekistan, and Viet Nam shared good practices regarding adaptation and mitigation measures.

The overall supervision of the regional TA was provided by Diwesh Sharan (Director, Budget, Personnel, and Management Systems Department) and subsequently by Robert Dobias (Senior Advisor for Climate Change Program, Regional and Sustainable Development Department [RSDD]). Lourdes S. Adriano (Principal Agriculture Sector Specialist) and Katsuji Matsunami (Advisor) of the Agriculture and Rural Development and Food Security Unit of the RSDD worked closely with the IFPRI team. The ADB Working Group for the agriculture study provided invaluable comments, references, and technical advice during the inception, midterm review, and final drafting of the report. The members of the working group are Muhammad Ehsan Khan, Cindy Malvicini, Javed Hussain Mir, Akmal Siddiq, and Ancha Srinivasan.

The study went through an iterative consultation process: the first was during the presentation of the midterm draft held in Bangkok, Thailand in March 2009 and the second was during the presentation of the draft final report held at ADB headquarters in May 2009. The study team benefited from the frank and lively discussions and insightful

comments and suggestions received during these workshops from representatives of government agencies, academic institutions, nongovernment organizations, national and international research institutes, and farmers' groups from the subregions (Central, South, Southeast and East Asia, and the Pacific) of Asia and the Pacific. The team is especially grateful to the four external reviewers: Martin Parry, Robert Mendelsohn, Shardul Agrawala, and S. Niggol Seo as well as grateful to Keijiro Otsuka, Sam Mohanty, Arsenio Balisacan, and Lot Felizo.

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Executive Summary

Overview

Climate change is threatening food production systems and therefore the livelihoods and food security of billions of people who depend on agriculture in the Asia and Pacific region (hereafter, Asia and the Pacific). Agriculture is the sector most vulnerable to climate change due to its high dependence on climate and weather and because people involved in agriculture tend to be poorer compared with urban residents. Consistent warming trends and more frequent and intense extreme weather events have been observed across Asia and the Pacific in recent decades. In line with these trends, climate change scenarios consistently project temperature increases across the region, which will require farmers to adapt to changing conditions. At the same time, agricultural activities release significant amounts of greenhouse gases (GHG) into the atmosphere. Asia and the Pacific accounts for 37% of the world's total emissions from agricultural production, and the People's Republic of China (PRC) alone accounts for more than 18% of the total.

The combination of these characteristics of agriculture—its importance as an economic sector, its vulnerability to climate change, and its contribution to emissions—make building resilience to climate change in Asia and the Pacific an enormous challenge. For the sector to meet the food and income needs of current and future generations, individual farmers, governments, community groups, and the private sector will need to implement comprehensive mitigation and adaptation strategies, which will require targeted investments.

This report presents broad indicators of exposure, sensitivity, and adaptive capacity in the region. A review of the indicators highlights the vulnerability of the agriculture sector as a livelihood source for many, and as a source of food security for all. The review also exposes the large heterogeneity in farming systems across Central, East, Southeast, and South Asia and the Pacific Islands, and highlights the many facets of vulnerability to climate change across the region, including undernourishment, poverty, and slowing productivity growth, all of which will be exacerbated by the effects of climate change.

Climate change is expected to have multifaceted impacts on the countries of Asia and the Pacific. Overall, the region is expected to become warmer, with a large degree of variability, depending on latitude. In general, northern areas will experience greater warming than those at lower latitudes. While the Pacific countries will experience low mean annual changes in rainfall and temperature, rising sea levels are expected to alter significantly not only livelihoods but also livability on some of the smaller islands. Coastal areas in South and Southeast Asia and parts of the PRC will face the triple threat of changing precipitation, temperature, and rising sea levels. Finally, the cooler (northern) subregions of the Asian land mass are expected to get warm, which may lengthen agricultural growing seasons.

The combination of poverty in rural areas and the expected impacts of climate change and its remaining uncertainty will require careful planning for adaptation. Targeted climate change investments and more flexible decision making will be necessary to make the most of scarce budgetary resources, which must also be allocated to crucial social development needs.

Agricultural Profile of Asia and the Pacific

Agriculture is important for all countries of Asia and the Pacific. More than 60% of the economically active population and their dependents—which amounts to 2.2 billion people—rely on agriculture for their livelihoods. While agriculture's contribution to gross domestic product (GDP) is declining throughout the region, large populations are still based in rural areas, depending on agriculture directly or indirectly for employment and income. Poverty remains highest in these rural areas, and the disparity between rural and urban areas is widening. On the other hand, there is a heterogeneous poverty profile and divergent growth paths, with some economies growing at an accelerated rate compared to others. In addition, the importance of agriculture to the overall economy is highly variable among subregions and countries. The degree of political stability and the level of institutional maturity also varies. The profile of the region indicates, at the country level, the importance of ensuring food security in the region, to which is added the challenge of achieving food security in the context of climate change. For many countries in Asia and the Pacific, agriculture is not perceived in terms of its contribution to the growth process through increased GDP share, but mainly in the context of attaining food security.

In the Central Asia subregion, and with the exception of Turkmenistan, the importance of agriculture to GDP has been declining. Similarly, agricultural GDP in East Asia has been declining. Although the sector accounts for only 12% of the PRC's total GDP, nearly 64% of its economically active population is still employed in agriculture. Food security has been improving rapidly in East Asia overall, but 30% of Mongolia's population remains undernourished. Given significant land scarcity, several East Asian countries—including the PRC, Japan, and the Republic of Korea—have begun to purchase or lease land for food production in other parts of Asia (Indonesia and the Philippines) as well as in Africa, Eastern Europe, and Latin America.

The importance of agriculture to GDP has been declining in Southeast Asia; however, it still contributes 30% in Cambodia and over 40% in the Lao People's Democratic Republic (Lao PDR). In addition, undernourishment in Southeast Asia has declined since 1995 but still averages 18% of the population, with 26% of the population of Cambodia classified as malnourished. Reducing the food security risk in Southeast Asia, however, has resulted in the large-scale deterioration of the agricultural resource base, e.g., land and water resources.

Unlike Central, East, and Southeast Asia, the importance of agriculture to GDP remains high in South Asia and declined only slightly between 1995 and 2006. As a result, employment in agriculture is also high, with close to 50% or more of the population dedicated to this sector (with the exception of the Maldives). Finally, the proportion of undernourished within the population averages over 20%, making South Asia the least food-secure subregion both in Asia and the Pacific and the world.

Data for the Pacific Islands on irrigated cropland, undernourishment, and the importance of agriculture to GDP are scarce. Data from Papua New Guinea, however, indicates that the share of agriculture within GDP has been rising, from 32% in 1995 to 42% of GDP in 2005. In addition, the proportion of the population employed in agriculture averages nearly 40%.

While agriculture is crucial for the region's food security and forms the backbone of much of the employment, farming agro-ecosystems vary significantly, ranging from the relatively dry wheat-producing areas of Central Asia to the very wet rice-producing lands of Southeast Asia. Similarly, support for agriculture and agricultural technologies varies significantly across countries. The heterogeneity of farming systems will require targeted interventions to support farmers in adapting to and mitigating the effects of climate change.

Even without climate change, competition for land and water resources is high in many countries of Asia and the Pacific. Climate change will intensify the struggle for these natural resources, exacerbating challenges to their management and increasing the risk of conflict. Central and South Asia are particularly prone to conflicts resulting from land and water scarcity.

Finally, the impacts of climate change in Asia and the Pacific will affect food security, not just regionally, but globally. The region accounted for 43% of global crop production in 2000 and is expected to account for one-third of total cereal demand and two-thirds of total meat demand over the next several decades; it also accounts for significant net cereal exports, particularly in terms of rice.

Climate Change Trends

A warmer and mostly wetter rainy season, and possibly drier dry seasons

Climate change is already evident in a number of ways. Consistent warming trends and more frequent and intense extreme weather events have been observed across Asia and the Pacific in recent decades.

All subregions of Asia and the Pacific are expected to become warmer. While there is less certainty regarding changes in precipitation, Asia and the Pacific are expected generally to get wetter, with the exception of Central Asia. However, rainfall tends to be heavier during wet periods, increasing the risk of floods, while dry seasons will remain dry or get drier. Moreover, the region is expected to experience an increased frequency of extreme weather events.

The PRC and Viet Nam are the two countries most affected by sea-level rise in terms of total crop land area, followed by Bangladesh, India, and Indonesia. This is based on the results of the International Food Policy Research Institute (IFPRI) Spatial Allocation Model that excludes 12 countries in the Pacific due to unavailable data. Moreover, glaciers in the Himalayas and Central Asia are already melting as a result of climate change. This brings about potential short-term benefits from increased water flows, as well as increased risks from flooding. In the long-term, impacts on food production and ecosystem health will be negative, particularly during the dry season. Much less is known regarding future changes in extreme weather events. Our knowledge regarding the impact of pests and diseases is also insufficient. Given our limited understanding of the nature and extent of impact of climate change on the sector, planning appropriate adaptation and mitigation measures will be carried out under a scenario of uncertainty.

Impact on agriculture

Developing countries in Asia and the Pacific are likely to face the highest reductions in agricultural potential in the world due to climate change. As a result, climate change will place an additional burden on efforts to meet long-term development goals in Asia and the Pacific. Slow agricultural productivity growth, declining income growth, and problems of maintaining food security already pose challenges to many countries in the region.

Modeling climate change impacts on agriculture

For Asia and the Pacific, depending on the General Circulation Model (GCM) and scenario used, biophysical crop model results show yield reductions under climate change compared to a no-climate change scenario. By 2050, for irrigated paddy, the expected reduction is in the range of 14%–20%; for irrigated wheat, 32%–44%; irrigated maize, 2%–5%; and irrigated soybean, 9%–18%. Spreads across crops and GCM are somewhat wider for rainfed crops, with positive yield effects under some GCM, especially in more temperate areas. If carbon fertilization is modeled, then changes in crop yields are much smaller or even turn positive. However, recent research experiments indicate that carbon fertilization effects have been overestimated, and models have yet to be adjusted to account for recent insights.

Incorporating spatially distributed area and yield impacts into the International Model for Policy Analysis on Agricultural Commodities and Trade (IMPACT, developed by the IFPRI) accounts for the autonomous adaptation effects from supply and demand response adjustments as a result of changes in food prices. Changes in the volume and direction of international trade in agricultural commodities are another avenue to compensate for the differential impacts of climate change, and are also taken into account in IMPACT.

When biophysical impacts of climate change are integrated into the IMPACT model, food prices increase sharply for key crops with adverse consequences for the poor. Rice prices are projected to be 29%–37% higher in 2050 compared to a no-climate change case, wheat prices to be 81%–102% higher, maize prices to rise 58%–97%, and soybean prices to increase 14%–49%. Higher food prices lead to declines in total demand for cereal and other crops and a reduction in calorie availability across all Asian subregions, by 13%–15%, on average. The subregion hardest hit is Central Asia, with projected declines in calorie availability of 15% to 18%, given their combination of low levels of calories at the outset and the strong impact from climate change. Childhood malnutrition levels, which are directly linked to calorie availability, are projected to increase dramatically under climate change by between 9 and 11 million children, in addition to the 65 million children projected to remain malnourished in 2050 even under current climate conditions. Avoiding such an increase is difficult but not impossible.

The study implemented several alternative investment scenarios to explore which sectoral investments could help lower future increases in childhood malnutrition for Asia and the Pacific. It found that aggressive investments into agricultural productivity enhancements are the key to reversing climate change impacts on both agriculture and food security—potentially reducing two-thirds of the increase in malnutrition levels arising from climate change. Further reductions could be achieved by more aggressive investments in complementary sectors, such as education, and health. While the strongest climate change reduction results can be achieved from local productivity increases, further trade liberalization, accelerated investments in agriculture in the rest of the developing world as well as by industrialized countries can also provide some relief for Asia and the Pacific.

Climate change will also affect crops and fisheries in the Pacific Island countries, with potential negative consequences for food security. However, the study suffered from a lack of data and additional research will be needed to obtain more specific results for these countries.

Net trade in meats and cereals in Asia will see strong adjustments due to climate change. Under the no-climate change case, only Central Asia will increase its net cereal exports to 2050, while the other subregions of Asia and the Pacific will rely on increasing net imports of cereals. Net cereal imports are projected to increase in East Asia and South Asia under all climate change scenarios. In Southeast Asia, the impact of climate change on trade varies according to the GCM applied. The final trade results produced by the study are the outcome of a complex interaction between the size of the biophysical impact, the resulting price increases, and the responsiveness of demand and supply to prices in each subregion.

Moreover, a warmer and drier climate and more frequent and intense extreme weather events will reduce the agricultural GDP of all countries in Asia, particularly in South and Southeast Asia. Economic losses in the Pacific Island countries are also likely to be high. Fundamentally, across all Asia and the Pacific subregions, but particularly in South and Southeast Asia, climate change will lead to the reduction of agricultural GDP and worsening trade conditions, which will likely increase poverty.

As a result of uncertain climate predictions and other factors (e.g., CO_2 fertilization effects, socioeconomic pathways, as well as the individual adaptive capacity of countries), projections of the impacts of climate change on agriculture are not as precise as desired and depend heavily on scenario assumptions. Nonetheless, projections show that agriculture systems in many vulnerable subregions in Asia and the Pacific will suffer with climate change, particularly in South Asia. Further research should be done to better assess detailed impacts in Central Asia and the Pacific Islands.

Resilience as the Conceptual Framework

Resilience is used to describe the magnitude of a disturbance that a system can withstand without crossing a threshold into a new structure or dynamic. In human systems, resilience refers to the ability of communities to withstand and recover from stress, such as environmental change or social, economic, or political upheaval, while for natural systems, it is a measure of how much disturbance (e.g., storms, fire, and pollutants) an ecosystem can handle without shifting into a qualitatively different state. This definition implies that social systems have the additional ability to anticipate and plan according to perceived and real changes. Therefore, the ability of institutions and individuals to avoid potential damage and to take advantage of opportunities will be a critical factor in building resilience to climate change. In addition, building resilience to climate change requires simultaneously building resilience in human systems and in the interlinked ecosystems on which they depend.

The concept of resilience has emerged in response to the need to manage interactions between human systems and ecosystems sustainably. Humans depend on ecosystem services (e.g., water filtration, carbon sequestration, and soil formation) for survival, yet the ability of institutions to manage these natural systems sustainably has not kept pace with the changes occurring within these systems. Socioeconomic institutions have considered ecosystems and the services they provide to be infinite and largely in a steady cycle of regeneration. This attitude has led to the creation of economic instruments and incentives that use ecosystems deterministically, from extraction to consumption. The concept of resilience, however, recognizes that social and environmental systems are interlinked, complex, and adaptive; process dependent—rather than input dependent—and self-organizing rather than predictable. The lens of resilience is useful in analyzing climate change because it is founded on the recognition that human existence within ecological systems is complex, unpredictable, and dynamic, and that institutional measures and responses should be based on this principle.

Agriculture is a form of natural resource management for the production of food, fuel, and fiber. As such, it depends on the resilience of both social and ecological systems. In social systems, resilience varies greatly among households, communities, and regions, depending both on the assets and knowledge farmers can mobilize and the services provided by governments and institutions. On the other hand, the resilience of agriculture-related ecosystems depends largely on slowly changing variables, such as climate, land use, nutrient availability, and the size of the farming system. In addition, agriculture is a source of livelihood for billions of people—particularly poor people—and their income directly contributes to society's resilience. As a result, enacting measures to build agricultural resilience requires an understanding of strategies to reduce vulnerability while at the same time generating income and reducing poverty.

This report introduces a conceptual framework for building resilience in the agriculture sector (Figure 1.1). This framework introduces key concepts related to building resilience and provides entry points for policy and investments. Figure 1.1 outlines factors that influence resilience to climate change—namely, the nature of the biophysical impacts, a society's sensitivity to those impacts, its capacity to cope and adapt, and the adaptation and mitigation strategies implemented by governing institutions. These components will be used to guide the discussion throughout this report.

Vulnerability to climate change in Asia and the Pacific

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as a function of the character, magnitude, and rate of climate variation to which a system is exposed; its sensitivity; and its adaptive capacity. More succinctly, vulnerability is defined as having three components: exposure, sensitivity, and adaptive capacity.

Exposure has been used in the literature to characterize the biophysical impacts of climate change on agroecological systems. Exposure encompasses the spatial and temporal dimensions of climate variability, such as droughts and heavy rains, the magnitude and duration of weather events, and long-term change in mean climate (temperature and precipitation).

Vulnerability to climate change depends not only on exposure to climate events, but also on physical, environmental, socioeconomic, and political factors that influence how sensitive countries will be to a changing climate, as well as their ability to cope and to adapt. For adaptation and mitigation measures to be successful, an assessment of poor communities' current vulnerabilities, needs, and coping abilities is needed, including influential factors such as gender equality.

Sensitivity is defined by the IPCC as "*the degree to which a system is affected, either adversely or beneficially, by climate variability or change*" and refers to the ability of an agroecological system to withstand impacts without overt efforts to adapt. Sensitivity is a complex concept because the responsiveness of a system can be influenced by both intrinsic characteristics and degrees of external manipulation. For example, unprotected low-lying coastal areas may be more sensitive to rising sea levels and storm surges than those that have sea walls. Similarly, water-stressed areas that have no irrigation infrastructure will be more sensitive to drought compared to those that do have such systems in place. In Asia and the Pacific, many countries are sensitive to climate change and extreme weather events because of high water stress, high rates of land degradation, and the high dependency of their economies on agriculture.

Low-income and other vulnerable populations will feel the effects of climate change and increases in the incidence of natural disasters most strongly. For instance, climate change is likely to increase the vulnerability of poor farmers who already struggle with land degradation in Asia and the Pacific. In areas highly dependent on livestock production, such as Mongolia and Inner Mongolia, the PRC, overgrazing increases vulnerability to climate change.

Rural women from developing countries will be among the most affected groups in the world given their dependence on subsistence crops, their limited access to resources, and their lack of decision- making power. Adaptation strategies should acknowledge the greater vulnerability of women to climate change.

Health impacts in developing countries are expected to be mostly negative. The ultimate impacts of climate change will be highly dependent on the capacity of countries to limit disease transmission and treat infections. Climate change might increase the global burden of disease as more frequent and severe floods and droughts, as well as changes in mean temperatures and rainfall are likely to increase the number of people at risk.

A combination of indicator values representing exposure (change in temperature and precipitation), sensitivity (share of labor in agriculture), and adaptive capacity (poverty) identifies Afghanistan, Bangladesh, Cambodia, India, Lao PDR, Myanmar, and Nepal as the countries most vulnerable to climate change in Asia and the Pacific. Countries with significant vulnerability—poor outcomes in two out of the above three components—include Bhutan, the PRC, Indonesia, Pakistan, Papua New Guinea, Sri Lanka, Thailand, Timor-Leste, Uzbekistan, and Viet Nam. As in Africa, those countries least responsible for climate change are likely to suffer most from its adverse impacts as a result of their location and low adaptive capacities. On the positive side, however—as has been shown by improvements in Bangladesh's ability to withstand tropical cyclones—adaptation is possible even for the most destitute and vulnerable countries.

The Role of Adaptation

Important ongoing development initiatives need to be strengthened to reduce vulnerability to climate change, including developing agricultural markets, reducing distortions and subsidies in agricultural policies, continuing trade liberalization policies, enhancing social protection and microfinance, preparing for disasters and, critically, mainstreaming climate change in agricultural policies. However, neither these development policies, nor autonomous or reactive adaptation, will be enough for countries of Asia and the Pacific to adapt to climate change.

Instead, adaptation will require improvements that take existing development policies above and beyond their current capacity. Innovative policies include: (i) changing investment allocation within and across sectors, (ii) increasing the focus on risk-sharing and risk-reducing investments, (iii) improving spatial targeting of investments, (iv) eliminating existing detrimental policies that will exacerbate climate change impacts, and (v) reducing greenhouse gas (GHG) emissions from agriculture and increasing the value of sustainable farming practices through the valuation of carbon and other forms of agricultural ecosystem services such as water purification and biodiversity.

Key components of new and innovative adaptation measures to climate change include (i) changes in agricultural practices to improve soil fertility and enhance carbon sequestration; (ii) changes in agricultural water management for more efficient water use; (iii) agricultural diversification toward enhanced climate resilience; (iv) agricultural science and technology development, agricultural advisory services, and information systems; and (v) risk management and crop insurance.

Changing investment allocation within and across sectors

Developing countries have chronically underinvested in science, technology, and innovation. However, crop breeding—using biotechnology and genetic modification—will be an essential component of adapting to key biotic and abiotic stresses related to climate change, including drought, heat, salinity, pests, and disease. These should be combined with tapping of traditional knowledge on crop varieties and adaptation.

Policies that favor private sector investment in crop improvements targeted to climate change in the developed and developing world are critical. These policies include (i) decreasing the bureaucratic hurdles to business formation, (ii) developing infrastructure that enables the production and distribution of improved seeds and other agricultural inputs, (iii) developing appropriate regulatory and biosafety protocols for the introduction of transgenic cultivars, and (iv) reforming intellectual property rights that could encourage private investment in crop improvement. A growing number of food companies are successfully adopting various sustainable pathways as new marketing strategies. This includes growing crops organically, offsetting GHG, sourcing fair-trade, and promoting biodiversity. These companies' experiences should be documented and lessons should be extracted on how the public sector can facilitate scaling up these initiatives.

In much of Asia, growth of public investments in research slowed after the 1980s. Investments in biotechnology and biosafety regulatory systems have been insufficient to address pressing needs in both areas, especially when focused on resolving national constraints. Many countries in Asia and the Pacific need to develop the infrastructure and scientific capacity to implement risk assessments and biosafety regulations to enable effective development and adoption of biotechnology.

In irrigation and water resources, investments may be needed to expand large-scale storage to deal with the increased variability of rainfall and runoff. On the other hand, in regions where changes in precipitation are highly uncertain, investments might be better distributed in a variety of small catchments. Climate change and variability in water supply, together with potential long-term changes in the cost of energy, could also dramatically change the cost–benefit calculus for big dams for storage, irrigation, and hydropower, making these investments more attractive despite the environmental and human relocation issues that dams raise. The appropriate level and location of future irrigation investments could also change dramatically.

Increasing the focus on risk-sharing and risk-reducing investments

Greater variability in weather and production outcomes will require enhanced attention to risk-sharing and risk-reducing investments. Such investments include financial market innovations, weather-based crop insurance, and broad-based social safety nets, which both protect against the negative impacts of increased risk and induce farmers to make decisions that are not excessively risk-averse. International agricultural trade is an important mechanism for sharing climate change risk, so open trading regimes should be supported. Appropriate agricultural advisory services, hydro-meteorological infrastructure, functioning financial markets, and effective institutions are necessary to minimize the risks to farmers as they make decisions about agricultural production. Institutional innovations—such as various forms of contract farming—will facilitate participation of smallholders in export markets.

Also directly related to managing risk is the need to upgrade the efficiency and sophistication of infrastructure and other investments, including modernizing instead of just rehabilitating irrigation and investing in paved, not dirt, roads. More sophisticated agricultural practices, such as integrated pest management, are also needed, requiring improvement in human capacity in agricultural management. Strengthening the role of women in household and agricultural production, as well as their rights to and control of assets, would improve the effectiveness of risk management.

An existing mechanism to reduce risk and improve disaster preparedness is the Indian Ocean Tsunami Warning and Mitigation System, which is funded by the United Nations Economic and Social Commission for Asia and the Pacific. The fund aims to strengthen tsunami early warning capabilities by building institutional, technical, and system-wide capacity in the countries of the region. The fund will be administered by governments, which will identify their own priorities and design and implement projects. At the end of 2008, the fund had approved 11 projects in the region with a budget of $9.2 million. Although currently operating at a relatively small scale, this initiative shows the potential for regional cooperation.

Improved spatial targeting of investments

Broad-based investment in adaptation is needed, but funds should also be targeted on the margin to those areas most vulnerable to climate change—that is, areas with the largest climate change signal and highest sensitivity to climate change, particularly those depending on rainfed agriculture or in low-lying delta areas. Sea-level rise will increase the concentration of salt in farm areas, which may require retooling of production systems. In some areas, for example, instead of producing crops, farmers may need to pursue alternative livelihoods, such as raising livestock or practicing aquaculture, as is already being done in the southwestern coastal areas of Bangladesh during flooding season. More and better spatial analysis is needed to reduce uncertainty about where climate change will have impacts.

Eliminating existing detrimental policies that will exacerbate climate change impacts

Climate change increases the costs of subsidy policies because climate change will contribute to increased food, energy, and water prices. Perverse subsidies for water, energy, and fertilizer should be reduced, with the savings invested in adaptation activities that boost farm income. These subsidies have not only distorted production decisions, but also encouraged carbon emissions beyond economically appropriate levels. As the real prices of natural resources rise, market-based approaches for managing environmental services in response to climate change (such as through water pricing, payment for environmental services (PES), and carbon trading) will become increasingly important. Improved definition and protection of land and water property rights will be necessary to implement effectively market-based approaches to climate change policy, including PES.

One way to improve upon previous PES approaches is to involve local communities, allowing them to negotiate to determine the terms of the payments. For example, downstream users in a watershed may try to negotiate with upstream users to protect the water from pollution and sedimentation. The downstream users may offer a payment or reward in exchange for implementing agreed-upon management practices. When the initiative comes from local people who are direct stakeholders, it may make sustainability easier to achieve, because the downstream users will have an interest in continuing to monitor compliance. Such negotiation and collective agreements are more likely within relatively small and cohesive communities than between wider communities and where the ability to ensure that all resource users benefit, is greater. The fact that few such examples exist in practice may be less dependent on local leadership and other idiosyncratic factors and more related to absence of local control over resources.

Increasing the value of sustainable farming practices through the valuation of carbon

Carbon needs to be recognized as a global externality, with carbon valued through carbon trade to increase the value of sustainable farming practices. This situation improves the likelihood that farmers will adopt long-term sustainable farming practices such as minimum tillage; integrated soil fertility management; and integrated pest, disease, and weed management.

Property rights

A lack of property rights makes farmers reluctant to invest in measures to conserve land, as they cannot secure future rights. Insecure land tenure reduces incentives to improve practices to cope with environmental degradation, which intensifies the adverse impacts of climate change and variability on crop production. Unsustainable land practices increase land degradation, which can further contribute to climate change. Increasing the profitability of land, such as through the potential for income from carbon markets and biofuels, may actually worsen the position of famers with insecure property rights, as the land may be expropriated by landlords seeking to increase their share of new income streams.

Meeting the challenges of climate change adaptation in agriculture requires long-term investment by farmers. Secure property rights are needed for these investments (such as integrated soil fertility management, tree planting, and water harvesting) to provide people with the incentive and authority to make the investments. Improved definition and protection of land and water property rights is therefore an essential component in effective and equitable adaptation and market-based approaches to climate change policy.

Secure property rights do not necessarily need to be individual or titled land; secure collective or customary tenure can also be options. In cases where pressure on land is growing, however, customary tenure may no longer be secure. These cases call for innovative approaches to guaranteeing land tenure, which may involve alternatives to titling. These alternatives could range from recognizing customary rights to land, to identifying agents to represent customary interests, to formalizing groups and granting them collective rights over resources. Again, special attention needs to be given to the rights of women.

Implementing climate change adaptation investments and policies

Climate change adaptation investments have been extremely slow in developed countries and will be difficult to implement in developing countries, including those in Asia and the Pacific, given competing short-term budgetary needs and a lack of capacity in key ministries to assess adaptation requirements. To mainstream climate change adaptation, countries will need to undertake multifaceted risk assessments that incorporate not only climate risk, but also existing vulnerabilities such as low levels of development, poor governance, political instability and expected future trends such as population growth, rapid urbanization, and increasing land and water scarcity. Qualitative and quantitative scenarios will need to be developed at the country level and potentially at the subnational and regional levels. Combined with detailed economic analysis of adaptation options, these multifaceted risk assessments and scenarios should serve as the basis for developing comprehensive and robust adaptation plans. The National Adaptation Programmes of Action (NAPAs), with the financial support of the United Nations Framework Convention on Climate Change, could be key mechanisms for mainstreaming climate change into development planning, but progress on NAPAs has been slow.

Climate change can also become the stimulus for implementing difficult but necessary changes to the status quo. Rising prices of carbon, food, fuel, and environmental resources due to climate change could stimulate significant policy and investment opportunities. The IMPACT model is used to estimate the required adaptation investments in agricultural research, irrigation, and rural roads in Asia and the Pacific under alternative climate change scenarios. Adaptation investment costs are defined in this paper as the amount needed to reduce the level of child malnutrition projected in 2050 under a climate change scenario to the levels that would prevail in a no-climate change scenario. The study estimates that, to offset the negative impacts of climate change in Asia, additional spending in the agriculture sector of $168–$201 billion is needed over the period 2010–2050. This figure is above the amounts that are projected to be spent on agriculture under baseline assumptions of $350–$388 billion total or $4.9–$5.8 billion per year, and translates into an additional $4.2–$5 billion per year. Agriculture sector expenditures would need to increase by two-thirds to 2050. The bulk of this additional spending (over 60%) should be dedicated to enhancing investments in agricultural research and development, which has been steadily decreasing over time, both in Asia and the rest of the world. Attention must also be paid to maintaining adequate access to roads in rural areas as they expand to sustain the integration of rural agricultural markets with national and world market forces. The role of irrigation, especially in light of the coming environmental stresses posed by climate change, is also important.

Governance of adaptation implementation

Effectively planning and implementing climate change adaptation for agriculture requires the engagement of a core ministry, such as the Ministry of Finance or Planning, alongside the Ministry of Agriculture, to ensure strong government support. The core capacities of these entities will need to be strengthened in the areas of climate forecasting and scenario planning. Adaptive and flexible management will be essential. The broadening nature and increasing severity of potential climate impacts in a given area and the unavoidable uncertainties associated with predicting these impacts require innovative approaches to management and development that go beyond centralized prediction and control practices. Moreover, effective cooperation among governments in Asia and the Pacific is necessary to ensure sound implementation of adaptation and mitigation strategies in their respective countries, as well as to explore financial means to address climate change.

Better risk-sharing policies, likely provided by both the government and markets, such as weather-based crop insurance, need to be tested and implemented. An appropriate balance between public sector efforts and incentives, such as capacity building, the creation of risk insurance, and private investment, needs to be struck so that the burden can shift away from poor producers.

Experience with collective action in other types of natural resource management suggests that systems that are developed in a top-down manner and which do not engage local people in designing them are unlikely to create viable institutions that operate at the local level in the long run. This experience serves as a warning against focusing only on national-level negotiations and systems for climate change mitigation or adaptation, because they are unlikely to create effective institutions to execute the programs, especially among smallholders.

Markets also play a coordination function, ranging from global to local. The question of when market (rather than state or collective action) institutions work best depends not so much on scale but on issues of transaction costs and attitudes toward markets. Market-based approaches for managing environmental services in response to climate change (such as water pricing, PES, and carbon trading) will be increasingly important. Successful experience—such as the case of organic agriculture development, which has been the most rapidly growing sector in agricultural trade and is uniquely pro-poor—should be further investigated to extract lessons.

The importance of financing adaptation

The outcome of negotiations on a new international architecture for climate change policy will have profound implications for development financing for adaptation in Asian agriculture. Therefore, stakeholders need to emphasize the importance of adaptation and the synergies with mitigation in the agriculture sector in their recommendations and negotiations.

Specifically in Asia and the Pacific, the Asian Development Bank (ADB) is supporting the creation of regional funding modalities. The main mechanism in the region available for both adaptation and mitigation is the Climate Change Fund, with an initial contribution of $40 million. Two other smaller funding sources have been created—the Water Financing Partnership Facility (WFPF) and the Poverty and Environment Fund (PEF). The WFPF has secured donor commitments totaling $26 million, while the PEF has a more modest $3.6 million budget.

In addition, the private sector—the insurance and reinsurance industries in particular—has started to engage in adaptation activities in developing countries. The most advanced initiatives have been developed by two global reinsurance companies, Munich Re and Swiss Re. These initiatives focus on developing new risk-transfer products such as microinsurance, weather and crop insurance, and other mechanisms such as risk pooling and disaster-related bonds. A set of pilot programs is currently underway in various developing countries, and implementing partners are assessing their efficacy and the overall business case for engagement.

Important Synergies between Adaptation and Mitigation

Asia and the Pacific is a key emitter of agricultural GHG through fertilizers and soils (nitrous oxide or N_2O), as well as livestock and rice production (methane or CH_4). Emissions in Asian agriculture are expected to increase due to the growth in food production required to feed a larger, wealthier population.

Contributing to emission reductions

The global technical mitigation potential of all strategies in the agriculture sector is 5,500–6,000 megatons of carbon dioxide equivalent per year (Mt CO_2-eq/yr) by 2030. Of this estimate, carbon sequestration accounts for nearly 90% of the potential, and CH_4 mitigation and soil N_2O emission reductions account for 9% and 2%, respectively. Across the subregions of Asia, up to 50% of these emissions (approximately 1,100–3,000 Mt CO_2-eq/yr) can be mitigated by 2030 for all GHGs, much of which can be achieved through the implementation of zero- and low-cost technologies that enhance soil carbon sequestration. Key low- or no-cost GHG mitigation activities in Asia and the Pacific include low- or no-till and other sequestration methods, as well as reducing CH_4 emissions from rice fields. The PRC and India could each reduce CH_4 emissions from rice fields by 26% over the baseline scenario at low cost (that is, less than $15 per ton of CO_2-eq) by 2020. Using high-yielding crop varieties, shifting to rice and/or wheat production systems, and alternating dry/wet irrigation, are strategies that both mitigate emissions and build resilience by conserving water, reducing land requirements, and reducing fossil-fuel use.

Asia could potentially reduce emissions by 276.79 Mt CO_2-eq/yr at a carbon price of $20 per ton of CO_2-eq, which represents approximately 18% of the total global economic potential (including soil carbon sequestration). At this price, the benefit stream from agricultural mitigation in Asia could amount to more than $5.5 billion a year.

The role of biofuels

The use of high-yielding feedstock crops grown on existing cropland or degraded lands for biofuel production has the potential to offer carbon savings compared with the use of conventional fossil fuels. The potential of biofuels to reduce carbon emissions, however, is highly dependent on the nature of the production process. The current generation of crop-based biofuels has had a low or even negative effect on carbon mitigation when land use change for biofuel production is taken into account. Ensuring that biofuel production does not create negative tradeoffs with food and land markets, land use change, biodiversity, and environmental degradation, will require careful policy design, as well as subsequent monitoring.

From the farmer's point of view, biofuels are a cash crop that would generate higher incomes. Yet, while biofuel producers will likely benefit from the creation of new markets for their crops, the competition between food and fuel markets and the subsequent impact on food prices may outweigh the benefits of income generation under current biofuel technologies. Projections show that the prices of all feedstock commodities—cassava, maize, oil seeds, sugar, and wheat—will increase if biofuel expansion continues without significant breakthroughs in technology. For example, in a high biofuel scenario, depending on the rate of expansion, the price of oil seeds increases by 20%–40% by 2050 compared to the baseline scenario. While these projections assume baseline productivity growth, they are an important illustration of the tradeoffs that crop-based biofuels will likely present with food security—even in the absence of climate change.

Countries in Asia and the Pacific are stepping-up investments in biofuel production capacity. Indonesia, Malaysia, and the Philippines have national blending targets for biofuels, while countries like India and Thailand are making significant investments in conversion technologies and expanding the production of key feedstocks. The most widely produced feedstock crop is oil palm for biodiesel in Southeast Asia. Oil palm production on degraded lands would provide net carbon savings, but the crop is currently considered a cause of deforestation in the region, and oil palm cultivation on deforested land is currently up to 10 times more profitable to landowners than preserving the land for carbon credits in the voluntary market. Thus, developing formal carbon markets to pay for environmental services, such as avoided deforestation, may be critical mitigation policies in the region. Rather than subsidizing less efficient biofuels, governments should invest in developing the next generation of cellulosic biofuels or in improving the efficiency of sugarcane-based ethanol, which is currently the most efficient crop-based biofuel. In addition, the broader treatment of biomass energy sources, such as biogas and fuelwood alternatives that provide GHG savings and low-cost energy, should be promoted.

Agricultural mitigation could provide benefit streams to smallholder farmers

There is significant potential for small farmers to sequester soil carbon if appropriate policy reforms are implemented. If the high transaction costs for small-scale projects can be eliminated, carbon markets could be a significant source of financing. Successful implementation of soil carbon trading would generate important co-benefits for soil fertility and long-term agricultural productivity.

As with adaptation, the outcome of international climate change negotiations will have major effects on the role of agriculture in mitigation. Actions toward including agriculture in a post-Kyoto regime should be taken now, with a focus on integrating smallholder farmers in carbon markets. Soil carbon sequestration has the highest technical potential for mitigation in the agriculture sector, but carbon sequestration projects are not included in the Clean Development Mechanism (CDM). However, there are feasibility issues in selling agricultural soil carbon within a market-based credit-trading program related to current carbon markets rules, as well as to transaction costs when working with smallholder farmers. To ensure that emerging carbon markets benefit developing countries, rules for carbon trading—whether for CDM or a more flexible successor mechanism—should encourage the participation of small farmers and protect them against major livelihood risks, while at the same time meeting investor needs and rigorously ensuring carbon goals. New rules can support these goals by promoting measures to reduce transaction costs, establishing international capacity-building and advisory services, and investing in advanced measurement and monitoring.

Synergies between adaptation and mitigation strategies need to be actively pursued

Synergies between adaptation and mitigation strategies exist, but many have yet to be exploited. Many changes in agricultural and water management practices, as well as crop productivity improvements, contribute to adaptation while also fulfilling mitigation objectives. Examples include zero- or low-till land management practices, soil and water conservation techniques, and alternative wetting and drying for rice production. These practices can help build ecosystem resilience and generate income, helping to ensure food security in the region. Given that benefit streams from global carbon markets are not generally available to mitigation in agriculture, synergies between adaptation and mitigation are undervalued. It will therefore be important to incorporate agriculture, forestry, and other land uses into carbon markets through global commitments, and to strengthen and simplify monitoring rules.

Adoption by farmers of any mitigation technology depends on their assessment of its effects on their well-being. It is important to distinguish between two types of mitigation strategies. The first is financially attractive but involves upfront investments or significant technical capacity unavailable to farmers. Policies and programs to improve access to credit and provide technology and management training will accelerate adoption of these desirable mitigation strategies, as farmers see it in their long-term interest to do so.

The second type would result in an economic loss, either because of reduced income or increased risk. Adoption by farmers will require some form of payment for these services. Essentially, society will need to pay farmers to provide the mitigation service, e.g., PES. To be most effective, PES programs identify, and pay for, only those services with the greatest mitigation benefit per unit of payment. Choice of payment mechanism can have a substantial effect on adoption of a mitigation technology and costs.

Conclusions and Priority Actions

- Climate change poses a major challenge for agriculture at the global level and in Asia and the Pacific. Given the role of agriculture in employment, economic development, and global food security, adverse impacts on agriculture are of particular concern. Decreased agricultural production in most of the region owing to climate change will result in higher food prices and decreased food consumption, especially among the poor, leading to an increased number of people at risk of hunger. Areas that are already lagging behind in achieving important human well-being outcomes will likely suffer the most.

- Sound development policies are necessary but not sufficient to adapt agriculture to climate change in Asia and the Pacific as well as elsewhere. A pro-growth, pro-poor development agenda that supports agricultural sustainability and includes better targeting to climate change impacts will improve resilience and climate change adaptation. Because climate change has a negative impact on agricultural production in most developing countries, achieving any given food security target will require greater investments in agricultural productivity. Key areas for increased investment include agricultural research, irrigation, rural roads, information technologies, market support, and extension services. Public–private partnerships will play an important role in achieving advances in these areas. Even so, there is still uncertainty about where climate changes will have impacts. This uncertainty can be reduced through more spatial analysis and improved information.

- Cooperation among governments in Asia and the Pacific is necessary to ensure effective implementation of adaptation and mitigation strategies in their respective countries, as well as to explore financial means for addressing climate change. Regional cooperation, even when not initially designed to deal with climate change, can provide essential building blocks for climate change adaptation. ADB-sponsored regional programs have important roles to play. The Central Asian Countries Initiative for Land Management (CACILM) project supports regional cooperation on sustainable land management, including transboundary issues, which will generate greater knowledge-sharing and impacts than individual country initiatives could accomplish. The Greater Mekong Subregion (GMS) Core Environment Program assesses risks and vulnerabilities of the GMS countries from climate change within the GMS Economic Corridors. This initiative focuses, among other things, on local livelihoods and ecosystem services; agriculture and food security; energy (particularly hydropower); and tourism (specifically ecotourism)—all of which can contribute to climate change adaptation and mitigation.

- Funding modalities related to climate change (and accessibility of these funds by the vulnerable people), such as a reformed CDM that includes agricultural mitigation and streamlined administration, payment for environmental services, or other mechanisms to mitigate GHGs, must be implemented by Asian development planners and policy makers. Climate action plans, including NAPAs, need to be integrated into Poverty Reduction Strategy Papers and other national development plans. Without this integration, climate adaptation plans may simply add another layer of planning rather than aid the mainstreaming process. Actors at all levels are called to action in the effort to adapt to climate change.

- Beyond Asia and the Pacific, agricultural adaptation and mitigation need to be incorporated into the ongoing international climate negotiations. This will help to assure that appropriate incentive mechanisms and innovative institutions, technologies, and management systems can be developed, along with the necessary financing opportunities. Mitigation strategies that support adaptation should be favored. Final negotiation outcomes will have direct consequences for adaptation requirements. Also at the international level, agricultural trade should be liberalized to help spread the risks of climate change and thus increase resilience to its impacts.

Based on our results, the study identifies six key messages for the governments of Asia and the Pacific:

1. **Climate change will have negative impacts on agricultural production and food security throughout Asia and the Pacific.** Adverse impacts of climate change on agriculture are of particular concern for the region given the dominant role of agriculture in employment, economic development, and global food security.

2. **Agricultural adaptation funding is required for all countries in the region. On the margin, assistance should be targeted to those countries with the highest vulnerability to climate change.** These highly vulnerable countries are Afghanistan, Bangladesh, Cambodia, India, Lao PDR, Myanmar, and Nepal, taking into account the suitability of governance structures and absorptive capacity. Required public agricultural research, irrigation, and rural road expenditures are estimated to be $3.0–$3.8 billion annually during 2010–2050, *above and beyond* projected baseline investments. In addition, these agricultural investments require complementary investments in education and health, estimated at $1.2 billion annually up to 2050 for countries in Asia and the Pacific.

3. **Several important adaptation and mitigation measures should be implemented immediately despite remaining uncertainty regarding climate change impacts.** These include increased investments in agricultural research and rural infrastructure (including irrigation and rural roads as noted in point 2 above), and

investments in market and climate information and disaster preparedness information systems. Key policy measures to be implemented include those that improve the efficient use of land, water, and ecosystems; reduce inefficient subsidies; support the development of carbon markets and other ecosystem services; and promote open and transparent trade. Remaining uncertainty as to where climate change will have impacts should be reduced through more spatial analysis, as well as improved information—generated by local agencies, users, and scientists.

4. **The global agricultural trading regime should be opened so that the risks associated with climate change can be shared and thus resilience increased.** Completion of the Doha Round of Agricultural Trade Negotiations would be an important step forward.

5. **Regional cooperation among governments in Asia and the Pacific needs to be improved to ensure effective implementation of national adaptation and mitigation strategies, and of current and future funding mechanisms to address climate change.** Regional cooperation initiatives in Asia, such as CACILM and GMS, are important building blocks for climate change adaptation. Moreover, formal regional organizations in Asia and the Pacific, including the Association of South East Asian Nations and the South Asian Association for Regional Cooperation, should play more prominent roles in technology and knowledge transfer across the region.

6. **Agricultural adaptation and mitigation strategies must be incorporated into the ongoing international climate change negotiations to ensure the creation of appropriate incentive mechanisms.** These include innovative institutions, technologies, and management systems, as well as the necessary financing mechanisms.

CHAPTER I

Introduction and Overview

Introduction

Climate change is threatening food production systems and therefore the livelihoods and food security of billions of people who depend on agriculture in the Asia and Pacific region (hereafter referred to as Asia and the Pacific). Evidence shows that marginalized populations will suffer disproportionately from the impacts of climate change in comparison with wealthier, industrial countries (IPCC 2007a). Not only will relatively poorer countries experience more severe impacts, but they also often lack the resources to prepare for and cope with environmental risks. Agriculture is the sector most vulnerable to climate change due to its high dependence on climate and weather and because people involved in agriculture tend to be poorer compared with their urban compatriots. Among the developing member countries[1] of the Asian Development Bank (ADB), more than 60% of the economically active population and their dependents—2.2 billion people—rely on agriculture for their livelihoods (FAO 2009a).[2]

Climate change is already evident in a number of ways. Consistent warming trends and more frequent and intense extreme weather events (such as cyclones, floods, hailstorms, and droughts) have been observed across Asia and the Pacific in recent decades. In line with these trends, climate change scenarios consistently project temperature increases across the region. Much less certainty and agreement exists among models on rainfall variability, but extreme weather events are generally expected to increase in frequency and severity across the region, as well as in specific areas.

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[1] A list of ADB developing member countries is presented in Appendix 2

[2] Agriculture, as defined by the Food and Agriculture Organization of the United Nations (FAO), includes farming, fishing, hunting, and forestry.

The observed and projected future effects are diverse and geographically differentiated, creating uncertainty, which makes the task of preparing for climate change impacts difficult. Just as the impacts will be varied, so will each community's ability to respond to changes in environmental conditions. Expected climate effects on agro-ecologies will consist of both rapid and catastrophic shifts that cause crop failure and immediate food shortages, and longer term shifts such as slow changes in mean temperatures and increased interannual and seasonal climate variability. Dealing with the short- and longer term impacts on agricultural systems will require improved understanding of vulnerable production systems and increased capacity to adapt to these changes. At the same time, climate change will place an additional burden on efforts to meet long-term development goals in Asia and the Pacific. The fragility of the global food system became apparent during the 2007–2009 global food and financial crises. High food prices from 2007 through mid-2008 had serious implications for food and nutrition security, macroeconomic stability, and political security. The unfolding global financial crisis and economic slowdown decreased the availability of capital at a time when accelerated investment in agriculture was urgently needed. With some countries resorting to trade restrictions, thus pushing food prices up even further, the crisis also reduced trust in global trade systems which needs to be urgently reestablished. To mitigate long-lasting effects on emerging economies and on poor people, pro-poor agricultural growth needs to be promoted, market volatility reduced, and social protection and child nutrition actions scaled up. These action points are similar to those required under climate change (for more details, see von Braun 2008a).

The overarching goal of this report is to provide a framework for approaching this challenge by establishing baselines of knowledge on climate impacts, and plausible theories about how to build longer term adaptive capacity and resilience. The specific objectives are to provide a critical synthesis of the evidence and future scenarios of climate change in the region by analyzing both the impacts of agriculture on climate change and the impacts climate change is projected to have on agriculture. In addition, the report offers an assessment of the policy and investment options for development practitioners and policy makers, outlining strategies for coping with the threats of climate change, and providing an understanding of the opportunities available to poor farmers dealing with climate change. The remaining sections of this chapter outline a conceptual framework for building climate change resilience in the agriculture sector in Asia and the Pacific.

Conceptual Framework

The concept of resilience is central to an understanding of the vulnerability of the agriculture sector to climate change. Resilience is used to describe the magnitude of a disturbance that a system can withstand without crossing a threshold into a new structure or dynamic. In human systems, resilience refers to the ability of communities to withstand and recover from stresses—such as environmental change or social, economic, or political upheaval—while for natural systems it is a measure of how much disturbance (in terms of storms, fire, pollutants, and so on) an ecosystem can handle without shifting into a qualitatively different state (SRI 2009). This definition implies that social systems have the additional ability to anticipate and plan according to perceived and real changes. Therefore, the ability of institutions and individuals to avoid potential damage and to take advantage of opportunities will be a critical factor in building resilience to climate change. In addition, building resilience to climate change requires simultaneously building resilience in human systems and in the interlinked ecosystems on which they depend. Key concepts describing climate change resilience are presented in Box 1.1.

Box 1.1: Key Concepts in Building Resilience to Climate Change

Adaptation—an adjustment made in response to a perceived change in a human or natural system in order to reduce vulnerability, build resilience, or both. Adaptation can be proactive (anticipatory) or reactive, and planned (involving public intervention) or autonomous (representing spontaneous action by private actors).

Adaptive capacity—the ability of institutions and individuals to avoid potential damage, to take advantage of opportunities, or to cope with consequences of change.

Ecosystem resilience—"*...a measure of how much disturbance (like storms, fire, or pollutants) an ecosystem can handle without shifting into a qualitatively different state. It is the capacity of a system to both withstand shocks and to rebuild itself if damaged*" (SRI 2009).

Exposure—the biophysical impacts of climate change, which can vary in magnitude, frequency, and duration.

Mitigation—the reduction of anthropogenic greenhouse gas emissions or the enhancement of natural sinks (that is, a natural process that absorbs more carbon than it releases) through the implementation of policies (IPCC 2007a).

Resilience—the magnitude of a disturbance a system can withstand without crossing a threshold into a new structure or dynamic.

Social resilience—"*...the ability of human communities to withstand and recover from stresses, such as environmental change or social, economic, or political upheaval*" (SRI 2009). This idea is similar to adaptive capacity.

Sensitivity—"*...the degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (for example, a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (for example, damages caused by an increase in the frequency of coastal flooding due to sea-level rise)*" (IPCC 2007a).

Sustainable development—"*The goal of sustainable development is to create and maintain prosperous social, economic, and ecological systems. Sustainable development has also been described as fostering adaptive capabilities and creating opportunities. This definition comes from combining sustainability—the capacity to create, test, and maintain adaptive capability—and development—the process of creating, testing, and maintaining opportunity*" (Holling 2001 as quoted in RA 2009).

Synergy—"*When the combined effect of several forces operating is greater than the sum of the separate effects of the forces*" (MA 2005).

Vulnerability—"*...the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity*" (IPCC 2007a). "*Vulnerability is often denoted [as] the antonym of resilience*" (SRI 2009).

The concept of resilience has emerged in response to the need to manage interactions between human systems and ecosystems sustainably. Humans depend on ecosystem services (that is, water filtration, carbon sequestration, soil formation, and others) for survival, yet the ability of institutions to manage these natural systems sustainably has not kept pace with the changes occurring within these systems. Socioeconomic institutions have considered ecosystems and the services they provide to be infinite and largely in a steady cycle of regeneration. This attitude has led to the creation of economic instruments and incentives that use ecosystems deterministically, from extraction to consumption. The concept of resilience, however, recognizes that social and environmental systems are interlinked, complex, and adaptive; processes rather than input-dependent; and self-organizing rather than predictable (SRI 2009). The lens of resilience is useful in analyzing climate change because it is founded on the recognition that human existence within ecological systems is complex, unpredictable, and dynamic, and that institutional measures and responses should be based on this principle.

Agriculture is a form of natural resource management for the production of food, fuel, and fiber. As such, it depends on the resilience of both social and ecological systems. In social systems, resilience varies greatly among households, communities, and regions, depending both on the assets and knowledge farmers can mobilize and the services provided by governments and institutions. On the other hand, the resilience of agriculture-related ecosystems depends largely on slowly changing variables, such as climate, land use, nutrient availability, and the size of the farming system. In addition, agriculture is a source of livelihood for billions of people—particularly poor people—the income from which directly contributes to society's resilience. As a result, enacting measures to build agricultural resilience requires an understanding of strategies to reduce vulnerability while at the same time generating income and reducing poverty.

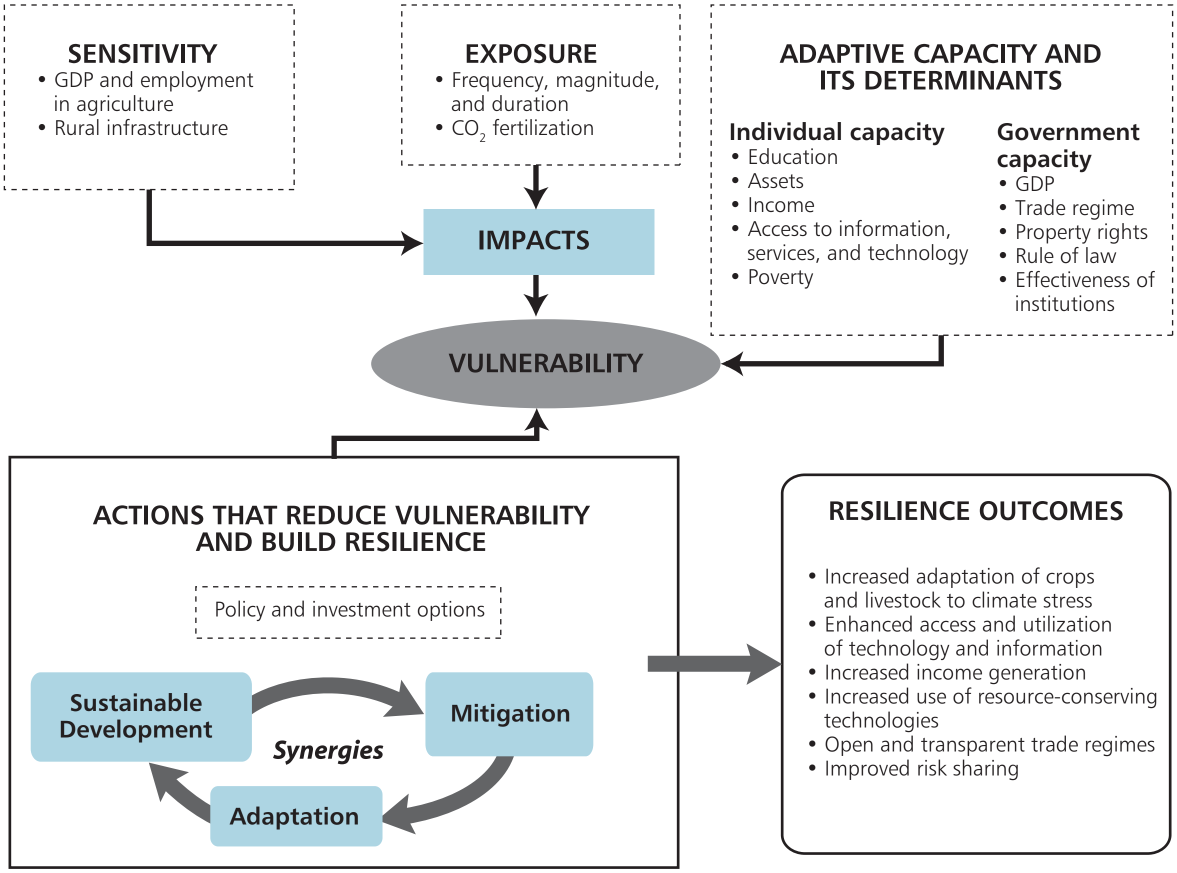
This report introduces a conceptual framework for building resilience in the agriculture sector (Figure 1.1). This framework introduces key concepts related to building resilience, as well as entry points for policy and investments. The figure outlines factors that influence resilience to climate change—that is, the nature of the biophysical impacts, a society's sensitivity to those impacts, its capacity to cope and adapt, and the adaptation and mitigation strategies implemented by governing institutions. Throughout the remainder of this report, each of the framework's components, as outlined below, will be used to guide the discussion.

The Three Dimensions of Vulnerability

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as a function of the character, magnitude, and rate of climate variation to which a system is exposed; its sensitivity; and its adaptive capacity. More succinctly, vulnerability is defined as having three components: exposure, sensitivity, and adaptive capacity. Each of these components is introduced in the following sections, and a more in-depth investigation is provided in Chapter II.

This report is concerned with the measurement of vulnerability and, hence, establishing indicators for its conceptualization. It is important to quantify vulnerability in order to adequately target adaptation and mitigation responses aimed at building resilience to climate change. For the agriculture sector, each dimension of vulnerability can be approximated (Table 1.1). In Chapter II,

Figure 1.1: Conceptual Framework for Building Resilience in the Agriculture Sector



Source: Devised by authors.

indicators are chosen from these categories to construct a simple but consistent vulnerability indicator, combining the elements of exposure, sensitivity, and adaptive capacity. In the next three sections, key indicators of exposure, sensitivity, and adaptive capacity to climate change in the agriculture sector are presented.

Exposure

Exposure has been used in the literature to characterize the biophysical impacts of climate change on agroecological systems (Tubiello and Rosenzweig 2008; Moss, Brenkert, and Malone 2001). Exposure encompasses the spatial and

Table 1.1: Indicators of Vulnerability in the Agriculture Sector

Vulnerability Criterion	Indicator Source	Measurement Class
Exposure (the biophysical impacts of climate change on agroecological systems)	Biophysical indicators	Soil and climate (temperature/precipitation) Crop calendar Water availability and storage Biomass/yield
Sensitivity (the degree to which a system is either adversely or beneficially affected by climate variability or change)	Agricultural system characteristics	Land resources Inputs and technology Irrigation share Production scale
Adaptive capacity (the ability of institutions and individuals to avoid potential damage, to take advantage of opportunities, or to cope with the consequences of change)	Socioeconomic data	Rural welfare Poverty and nutrition Protection and trade Crop insurance

Source: Adapted from Tubiello and Rosenzweig (2008).

temporal dimensions of climate variability, such as droughts and heavy rains, and also the magnitude and duration of weather events. In addition, exposure to higher levels of atmospheric carbon dioxide may have biophysical benefits, such as increasing plant biomass production in certain crops via the carbon fertilization effect.

Temperature and precipitation

Under the IPCC's nonmitigation scenarios, which assume a doubling of atmospheric carbon dioxide (CO_2), the global mean surface air temperature is likely to increase by 2–4.5 degrees Celsius (°C) (Meehl et al. 2007). The analysis of the impact of climate change on agriculture was implemented using the United Kingdom Meteorological Office Hadley Centre's Coupled Model, version 3 (HadCM3) with the A2a scenario from the IPCC's Third Assessment Report (IPCC 2001). Other climate models used were the National Centre for Atmospheric Research, Community Climate System Model version 3.0 (NCAR-CCSM3), and the Australian Commonwealth Scientific and Industrial Research Organization Climate Change Model (CSIRO-Mk3.0 A2), both following A2 scenarios from IPCC's Fourth Assessment Report (IPCC 2007a).[3] The A2 scenario is generally considered a worst-case scenario lacking mitigation; however, recent rates of emissions have already exceeded the A2 emission assumptions. Rates of CO_2 absorption by the natural carbon sink have been decreasing, while observations and projections of sea-level rise have been up to 50% higher than suggested under the Fourth Assessment Report, and rates of observed impact are greater than anticipated

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[3] For a more in-depth explanation of the A2a/A2 scenario, see Appendix 5.

regarding melting Arctic ice and Himalayan glaciers. As a result, A2 may actually underestimate the future under climate change without mitigation (Table 1.2).

Focusing more closely on the HadCM3 A2a climate change scenario, temperature increases are expected to be largest in Central Asia, averaging 3.5°C higher in 2050 relative to their historical mean. East, South, and Southeast Asia are expected to warm by over 2°C by 2050 on average, with the more northern subregions experiencing the greatest increases. The Pacific subregion is predicted to warm the least, averaging 1.3°C by 2050, given lower overall temperatures due to ocean proximity (Figure 1.2). These predictions are similar to Christensen et al. (2007) who found that warming is expected to be similar to the global mean in Southeast Asia (mean warming between 1980–1999 and 2080–2099 of 2.5°C).

IPCC predictions also indicate that very likely, there will be longer and more intense summer heat waves and/or hot spells in East Asia and fewer cold days in East and South Asia (Christensen et al. 2007). Trends in that direction can already be perceived. In Southeast Asia and in the Pacific, analyses of daily temperature for 1961–1998 for 15 countries (91 stations) indicate significant increases in the annual number of hot days and warm nights, and significant decreases in the annual number of cool days and cold nights. These trends were consistent across these subregions (Manton et al. 2001).

While there is some confidence regarding temperature changes in the tropics as a result of climate change (at least regarding direction), there is far greater uncertainty about precipitation changes (Kurukulasuriya and Ajwad 2007; Mendelsohn and Williams 2004). For many subregions, there is even a lack of consistency in predicting overall precipitation trends. Nevertheless, the inclusion of precipitation predictions in climate scenarios is extremely important, so it is necessary to interpret results with an understanding of predictions in relation to precipitation and temperature changes.

In past decades, rainfall trends in Asia and the Pacific have varied by subregion. A review of studies about observed past and present climate trends and variability indicates decreasing trends in annual mean rainfall in northeast and north PRC, the coastal belts and arid plains of Pakistan, parts of northeast India, the east coast of India, Indonesia, and the Philippines (Cruz et al. 2007; Preston et al. 2006). Increasing trends of annual mean rainfall have been observed in western PRC, the Changjiang (River Yangtze) Basin, the southeastern coast of the PRC, the Arabian Peninsula, Bangladesh, and along the western coasts of the Philippines (Bates et al. 2008; Preston et al. 2006).

The IPCC's Fourth Assessment models predict an increase in annual precipitation in most parts of Asia during this century, with larger and more consistent increases in North and East Asia. Projections suggest that boreal (that is, forest areas of the northern North Temperate Zone) winter precipitation is "very likely to increase" in northern Asia and the Tibetan Plateau, and "likely to increase" in eastern Asia and the southern parts of Southeast Asia. An exception is Central Asia, where a decrease in precipitation is predicted for the summer months. In that subregion, the projected decrease in mean precipitation is expected to cause an increase in the frequency of dry spring, summer, and autumn seasons (Christensen et al. 2007). Increases in precipitation levels for most Asian countries and decreases in Central Asian countries are confirmed by a recent study that makes country-level predictions (Cline 2007). However,

Table 1.2: Projected Change in Long-Term Mean Temperature and Precipitation under Climate Change, Various Scenarios

	Precipitation (mm/yr)				Temperature (°C)			
		2050 projections				2050 projections		
Subregion and country	Current Levels[a]	Hadley A2a Scenario	CSIRO A2 Scenario	NCAR A2 Scenario	Current Levels[a]	Hadley A2a Scenario	CSIRO A2 Scenario	NCAR A2 Scenario
Central Asia								
Armenia	392.1	431.2	360.7	401.0	7.1	9.6	8.3	9.8
Azerbaijan	366.3	398.0	361.3	365.2	12.5	15.7	13.9	14.8
Georgia	647.6	862.3	631.6	634.6	6.9	10.8	8.0	9.3
Kazakhstan	207.2	251.6	219.6	221.9	5.9	9.1	7.8	8.5
Kyrgyz Republic	359.5	430.7	343.4	381.1	1.0	4.1	3.3	3.8
Tajikistan	458.4	589.9	451.5	462.9	2.8	5.2	5.0	5.8
Turkmenistan	135.8	169.1	139.3	153.7	15.3	17.8	17.0	17.6
Uzbekistan	163.3	204.2	169.9	173.8	12.5	15.1	14.4	14.9
East Asia								
China, People's Republic of	467.3	610.9	474.1	542.4	6.4	9.0	8.1	8.9
Hong Kong, China	–	–	–	–	–	–	–	–
Taipei,China	2,129.7	2,868.7	2,205.8	2,157.2	19.6	20.3	20.9	21.1
Korea, Republic of	1,104.0	1,642.9	1,171.8	1,231.6	10.8	13.8	12.4	13.0
Mongolia	164.0	204.8	172.7	209.5	–0.1	2.7	1.7	2.9
Pacific Islands								
Cook Islands	–	–	–	–	–	–	–	–
Fiji Islands	2,196.9	2,934.7	2,282.8	2,376.4	23.9	24.9	24.97	25.5
Kiribati	–	–	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–	–	–
Micronesia, Federated States of	–	–	–	–	–	–	–	–
Nauru	–	–	–	–	–	–	–	–
Palau	–	–	–	–	–	–	–	–
Papua New Guinea	2,548.8	3,469.8	2,605.6	2,640.9	23.7	24.9	25.0	25.29

continued on next page

Table 1.2 continued

	Precipitation (mm/yr)				Temperature (°C)			
		2050 projections				2050 projections		
Subregion and country	**Current Levels[a]**	**Hadley A2a Scenario**	**CSIRO A2 Scenario**	**NCAR A2 Scenario**	**Current Levels[a]**	**Hadley A2a Scenario**	**CSIRO A2 Scenario**	**NCAR A2 Scenario**
Solomon Islands	2,729.0	3,623.6	3,032.9	2,964.6	25.5	26.5	26.7	27.16
Timor-Leste	1,402.0	1,595.1	1,246.5	1,464.8	25.3	25.5	26.3	26.9
Tonga	–	–	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–	–	–
Vanuatu	2,325.0	2,678.6	2,363.8	2,318.30	23.8	24.5	25.0	25.4
South Asia								
Afghanistan	259.9	327.3	258.8	316.6	11.8	14.3	13.9	14.6
Bangladesh	1,798.3	2,437.5	1,856.9	1,827.5	25.6	27.6	27.1	27.2
Bhutan	1,139.7	1,632.2	1,140.4	1,197.6	8.6	12.1	10.2	10.6
India	934.4	1,210.0	949.9	1,025.5	23.9	25.9	25.5	25.8
Maldives	–	–	–	–	–	–	–	–
Nepal	1,171.3	1,618.6	1,127.6	1,211.1	14.5	16.1	16.5	16.7
Pakistan	223.7	316.7	237.1	319.8	19.9	22.6	21.8	22.2
Sri Lanka	1,550.9	1,894.0	1,600.9	1,618.6	26.7	27.9	28.1	28.3
Southeast Asia								
Cambodia	1,516.9	1,674.5	1,598.70	1,508.7	26.8	28.9	28.3	28.4
Indonesia	2,279.7	2,770.8	2,331.20	2,352.6	25.0	26.3	26.3	26.7
Lao PDR	1,527.9	1,972.7	1,577.20	1,563.9	23.1	24.7	24.4	24.6
Malaysia	2,465.6	2,837.4	2,563.10	2,527.7	25.5	26.9	26.9	27.2
Myanmar	1,687.4	2,210.1	1,691.40	1,672.6	23.2	24.9	24.6	24.9
Philippines	2,144.9	2,583.6	2,160.20	2,162.4	25.1	26.5	26.4	26.8
Singapore	–	–	–	–	–	–	–	–
Thailand	1,243.6	1,499.4	1,285.40	1,221.0	26.2	27.8	27.7	27.8
Viet Nam	1,515.8	1,808.3	1,559.40	1,562.9	23.2	25.4	24.6	24.6

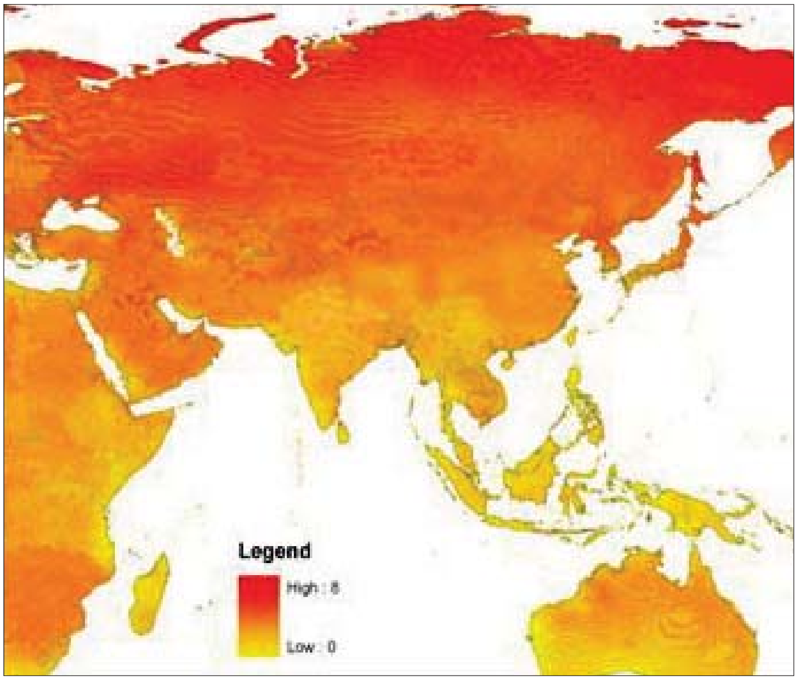
mm/yr = millimeter per year, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research.

Note: "–" indicates no data available. More detailed information on the HadCM3 A2a scenario is provided in Appendix 5. Further details of the CSIRO-Mk3.0 A2 and NCAR-CCSM3 A2 scenarios can be found in IPCC (2007a).

[a] Current levels pertain to the average of 1950–2000 levels.

Source: Calculated by authors based on Hijmans et al. (2005).

Figure 1.2: Projected Annual Mean Change in Temperature in the 2050s Relative to 1950–2000 Historical Mean (°Celsius)



Note: Projections are based on the HadCM3 A2a scenario.

Source: Authors, based on Hijmans et al. 2005.

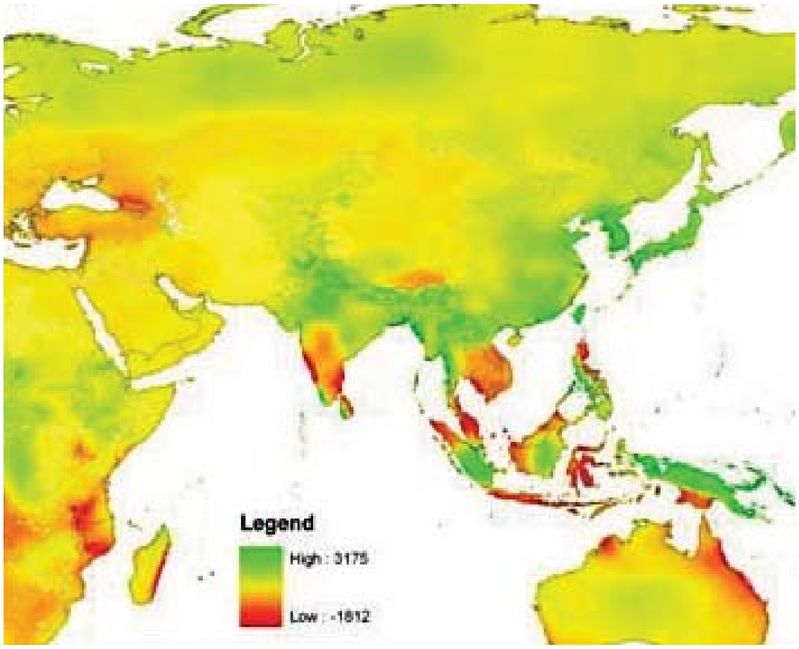
increases in annual rainfall do not necessarily mean that subregions will have fewer drought events, as in many cases, rainfall tends to be heavier during wet periods, increasing the risk of floods, but dry seasons continue and in some cases worsen.

Table 1.2 presents changes in precipitation for the HadCM3 A2a scenario compared with the historical mean, while Figure 1.3 depicts these changes graphically. Rainfall is expected to increase slightly in all subregions with the exception of parts of Central Asia, Cambodia, and Malaysia. East and South Asia and the Pacific are projected to experience increased rainfall of approximately 10% above the historical mean in 2050, whereas rainfall in Southeast Asia is projected to increase only slightly. These projections are consistent with trends predicted by Cline (2007).

Frequency and severity of extreme weather events

Table 1.3 indicates country-level vulnerability to rising sea levels, floods, droughts, and storms based on historical disaster frequencies for the period 1900–2008. All countries of Asia and the Pacific have experienced weather-related disasters in the past hundred years. In addition, extreme weather events such as floods, droughts, and typhoons have increased in both frequency and severity in many regions of the world (Sanker, Nakano, and Shiomi 2007; IPCC 2007a; Cruz et al. 2007). Along with environmental degradation, land use changes, and high population density, climate change is considered one of the main causes of these changes. For instance, a study shows that droughts in Southwest Asia, southern Europe, and the United States in 1998–2002 were linked to cold sea surface temperatures in the eastern tropical Pacific and unprecedented warm sea surface temperatures in the western tropical Pacific and Indian oceans. Climate models indicate that each of these regions contributed to the generation of a synchronized drought. Despite the fact that the El Niño Southern Oscillation (ENSO)[4] is a natural phenomenon that has occurred for a long time, the warming of the Indian Ocean and the western Pacific Ocean was beyond that expected from natural variability and partly due to the ocean's response to increased greenhouse gases (GHG) (Hoerling and Kumar 2003). Therefore, parts of Asia have experienced

Figure 1.3: Projected Annual Mean Change in Total Precipitation in the 2050s Relative to 1950–2000 Historical Mean (mm)



mm = millimeter.

Note: Projections are based on the HadCM3 A2a scenario.

Source: Hijmans et al. (2005).

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[4] ENSO is a disruption of the ocean's atmospheric system in the tropical Pacific that significantly affects global weather patterns, for example, by redistributing rainfall and thereby causing extreme floods and droughts (Neelin et al. 1998).

Table 1.3: Countries Vulnerable to Rising Sea Levels and Extreme Weather Events

Subregion and country	Rise in Sea Level	Floods	Droughts	Storms
Central Asia				
Armenia		X	X	
Azerbaijan		X	X	
Georgia		X	X	X
Kazakhstan		X		X
Kyrgyz Republic		X		X
Tajikistan		X	X	
Turkmenistan		X		
Uzbekistan		X	X	
East Asia				
China, People's Republic of	X	X	X	X
Hong Kong, China	X	X		X
Taipei,China	X	X		X
Korea, Republic of	X	X	X	X
Mongolia		X	X	X
Pacific Islands				
Cook Islands	X			X
Fiji Islands	X	X	X	X
Kiribati	X	X	X	X
Marshall Islands	X		X	X
Micronesia, Federated States of	X		X	X
Nauru	X	NA	NA	NA
Palau	X	NA	NA	NA
Papua New Guinea	X	X	X	X
Samoa	X	X		X
Solomon Islands	X			X
Timor-Leste	X	X		X
Tonga	X			X
Tuvalu	X			X

continued on next page

Table 1.3 continued

Subregion and country	Rise in Sea Level	Floods	Droughts	Storms
Vanuatu	X	X		X
South Asia				
Afghanistan		X	X	X
Bangladesh	X	X	X	X
Bhutan		X		X
India	X	X	X	X
Maldives	X	X		X
Nepal		X	X	
Pakistan	X	X	X	X
Sri Lanka	X	X	X	X
Southeast Asia				
Cambodia		X	X	
Indonesia	X	X	X	X
Lao People's Democratic Republic		X	X	X
Malaysia	X	X		X
Myanmar	X	X		X
Philippines	X	X	X	X
Singapore	X			X
Thailand	X	X	X	X
Viet Nam	X	X	X	X

NA = indicates no data available for Palau and Nauru; however, they are assumed to be vulnerable to sea-level rise given that they are small island-nations.

Note: Disasters were taken from EM-DAT lists and represent the top ten natural disasters by numbers of people affected, killed, and the costs of economic damage for the period 1900–2008. The "X" indicates that the country is vulnerable to the indicated climate event.

Source: EM-DAT 2009.

longer heat waves and more frequent and intense droughts. In Southeast Asia, extreme weather events associated with El Niño have also increased in frequency and intensity in recent decades (Cruz et al. 2007). Damage caused by cyclones has also significantly risen in countries such as India, the PRC, the Philippines, Japan, Viet Nam, Cambodia, Iran, and the Tibetan Plateau (Cruz et al. 2007).

Several models predict an increase in the intensity of heavy rainfall and winds in South Asia (over the Arabian Sea and the tropical Indian Ocean; northern Pakistan; the northwest, northeast, west coast, and west central areas of India; Bangladesh; and Myanmar), East Asia (the PRC, Japan, and Republic of Korea), and Southeast Asia (Christensen et al. 2007). For the Pacific Islands, by 2030 and 2070, models consistently predict more intense cyclones (increased wind speed) and increases in rainfall of greater than 10% in the Islands east of Papua New Guinea (Kiribati, the Solomon Islands, and Tuvalu) (Preston et al. 2006; World Bank 2000). In particular, Pacific atoll countries are likely to see more intense rainfall events and droughts. In 2080, flood risk is expected to be 200 times greater than at present for these countries (Barnett and Adger 2003).

Sensitivity

Sensitivity is defined in the IPCC's Fourth Assessment Report (IPCC 2007a) as "*the degree to which a system is affected, either adversely or beneficially, by climate variability or change*" and refers to the ability of an agroecological system to withstand impacts without overt efforts to adapt. Sensitivity is a complex concept because the responsiveness of a system can be influenced by both intrinsic characteristics and degrees of external manipulation. For example, unprotected low-lying coastal areas may be more sensitive to rising sea levels and storm surges than those that have sea walls. Similarly, water-stressed areas that have no irrigation infrastructure will be most sensitive to drought. In Asia and the Pacific, many countries are sensitive to climate change and extreme weather events because of high water stress, high rates of land degradation, and the high dependency of their economies on agriculture. Other indicators of agricultural sensitivity to climate change include rural population density, irrigated land, and agricultural employment. Key indicators of sensitivity to climate change in Asia and the Pacific are reviewed in the next section.

Key indicators of sensitivity to climate change in Asia and the Pacific

Approximately 55% of the world's population resides in the ADB's developing member countries.[5] As previously stated, agriculture—which is the principal source of livelihood for more than 60% of the population of Asia and the Pacific—is extremely vulnerable to climate change, so billions of people in the region will be sensitive to the impacts climate change will have on agricultural production systems. Moreover, disturbances in food supply will have implications for the wider population who are net food purchasers. Moreover, global food security will be sensitive to the impacts of climate change in Asia and the Pacific given that the region was responsible for 43% of global crop production in 2000, is expected to account for one-third

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[5] For the remainder of this section, statistics for this region follow the ADB's member-country classification as defined in Appendix 2 and are from FAO (2009a).

of total cereal demand and two-thirds of total meat demand over the next several decades, and accounts for significant net cereal exports.

Tables 1.4 and 1.5 present important indicators for use in assessing the vulnerability of the agriculture sector to climate change in the countries of Asia and the Pacific. Table 1.4 presents historic annual mean climate data, as well as indicators of agricultural dependence and poverty in the region. Table 1.5 presents the main crop and livestock products produced in each of the countries of Asia and the Pacific by tonnage in 2007. These production statistics are useful for understanding the differences in main crop and livestock products among subregions, and provide an indication of the type of production technologies that may be most sensitive to climate change. For example, in 2007 the PRC accounted for almost one-fifth of global maize and wheat production and 29% of global rice production, indicating that global food security will be sensitive to changes in production in the PRC. An overview by subregion is also presented.

Table 1.4: Indicators of Climate Change Sensitivity in the Agriculture Sector in Asia and the Pacific

Subregion and country	Climate Variables (1961–1990 average)		Rural Population Density (people per km^2 of arable land), 2002	Irrigated Land (% of cropland) 2003–2005	Agriculture (% of GDP)		Agricultural Employment (% of total employment) 2004	Dietary Energy Consumption (kcal/person/day)		Proportion of Undernourished in Total Population	
	Precipitation (mm)	Temperature (°C)			1995	2006		1995–1997	2003–2005	1995–1997	2003–2005
Central Asia											
Armenia	505	6.4	202	51.2	42	20	10.9	2,080	2,310	34	21
Azerbaijan	437	12.2	220	69.1	27	7	25.1	2,180	2,530	27	12
Georgia	960	7.4	280	44.1	52	13	17.8	2,250	2,480	24	13
Kazakhstan	252	6.0	30	15.7	13	6	16.1	3,250	3,110	–	–
Kyrgyz Republic	391	1.1	244	73.1	44	33	23.4	2,520	3,120	13	–
Tajikistan	494	3.0	488	68.2	38	25	31.2	1,940	2,070	42	34
Turkmenistan	158	15.2	142	89.2	17	20	31.9	2,560	2,780	9	6
Uzbekistan	193	12.5	357	87.4	32	26	25.0	2,710	2,440	5	14
East Asia											
China, People's Republic of	572	6.3	559	35.5	20	12	64.4	2,840	2,990	12	9
Hong Kong, China	–	–	–	–	0	0	–	–	–	–	–
Taipei,China	2,005	19.0	–	–	–	–	–	–	–	–	–
Korea, Republic of	1,345	10.7	481	47.1	6	3	7.7	3,020	3,030	–	–
Mongolia	228	–0.5	88	7.0	41	22	21.5	1,960	2,190	40	29
Pacific Islands											
Cook Islands	2,182	24.0	–	–	–	–	28.6	–	–	–	–
Fiji Islands	2,827	24.1	–	–	–	–	38.1	2,770	3,010	–	–
Kiribati	1,046	27.5	–	–	–	–	23.9	2,810	2,830	–	–
Marshall Islands	–	–	–	–	–	–	25.0	–	–	–	–
Micronesia, Federated States of	–	–	–	–	–	–	24.4	–	–	–	–

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Table 1.4 continued

Subregion and country	Climate Variables (1961–1990 average)		Rural Population Density (people per km² of arable land), 2002	Irrigated Land (% of cropland) 2003–2005	Agriculture (% of GDP)		Agricultural Employment (% of total employment) 2004	Dietary Energy Consumption (kcal/person/day)		Proportion of Undernourished in Total Population	
	Precipitation (mm)	Temperature (°C)			1995	2006		1995–1997	2003–2005	1995–1997	2003–2005
Nauru	–	–	–	–	–	–	33.3	–	–	–	–
Palau	–	–	–	–	–	–	22.2	–	–	–	–
Papua New Guinea	3,102	25.1	2,007	–	32	42	72.0	–	–	–	–
Samoa	–	–	–	–	–	–	31.8	2,520	2,820	–	–
Solomon Islands	3,157	25.7	–	–	–	–	71.7	2,320	2,450	–	–
Timor-Leste	1,248	25.0	–	–	–	–	81.1	2,400	2,160	–	–
Tonga	–	–	–	–	–	–	31.6	–	–	–	–
Tuvalu	–	–	–	–	–	–	25.0	–	–	–	–
Vanuatu	2,700	23.7	–	–	–	–	34.4	2,560	2,730	–	–
South Asia											
Afghanistan	312	12.9	273	33.8	–	36	65.7	–	–	–	–
Bangladesh	2,286	25.5	1,249	54.3	26	20	51.8	1,960	2,230	40	27
Bhutan	1,833	9.4	–	–	–	–	93.6	–	–	–	–
India	1,082	24.0	466	32.7	26	18	57.8	2,380	2,360	21	21
Maldives	–	–	–	–	–	–	19.3	2,430	2,630	–	–
Nepal	1,432	12.7	659	47.0	42	34	93.0	2,180	2,430	24	15
Pakistan	305	20.0	447	84.2	26	19	45.0	2,390	2,340	18	23
Sri Lanka	1,710	26.7	1,588	34.4	23	16	44.3	2,260	2,360	24	21
Southeast Asia											
Cambodia	1,926	26.9	292	7.0	48	30	68.6	1,860	2,160	41	26
Indonesia	2,795	25.7	588	12.7	17	13	45.7	2,500	2,440	13	17
Lao PDR	1,764	23.2	480	17.2	56	42	75.8	2,090	2,300	26	19
Malaysia	2,990	25.1	557	4.8	13	9	15.9	2,950	2,860	–	–
Myanmar	2,033	23.0	353	17.9	60	–	68.9	2,050	2,380	34	19

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Table 1.4 continued

Subregion and country	Climate Variables (1961–1990 average)		Rural Population Density (people per km² of arable land), 2002	Irrigated Land (% of cropland) 2003–2005	Agriculture (% of GDP)		Agricultural Employment (% of total employment) 2004	Dietary Energy Consumption (kcal/person/day)		Proportion of Undernourished in Total Population	
	Precipitation (mm)	Temperature (°C)			1995	2006		1995–1997	2003–2005	1995–1997	2003–2005
Philippines	2,322	25.3	559	14.5	22	14	37.1	2,380	2,470	18	16
Singapore	–	–	–	–	–	–	0.1	–	–	–	–
Thailand	1,543	26.3	310	26.6	10	11	53.3	2,370	2,490	21	17
Viet Nam	1,845	24.1	901	33.9	27	20	65.7	2,360	2,650	21	14

°C = degrees Celsius, GDP = gross domestic product, kcal = kilocalories, km² = square kilometer, mm = millimeter.

Note: "–" indicates no data available.

Source: Climate variable data are from Mitchell et al. (2004), Mitchell and Jones (2005); rural population density data are from World Bank (2005); agricultural GDP data are from World Bank (2008a); agricultural employment and dietary data are from FAO (2009a).

Table 1.5: Production of Crop and Livestock Products in the Asia and Pacific Countries, 2007

	Main Products			
Subregion and country	**Crops**	**('000 mt)**	**Livestock**	**('000 mt)**
Central Asia				
Armenia	Potatoes	540	Milk	613
	Tomatoes	250	Cattle meat	43
Azerbaijan	Wheat	1,334	Milk	1,301
	Potatoes	1,178	Cattle meat	76
Georgia	Potatoes	175	Milk	734
	Grapes	93	Cattle meat	49
Kazakhstan	Wheat	16,500	Milk	5,007
	Barley	2,600	Cattle meat	384
Kyrgyz Republic	Potatoes	1,374	Milk	1,192
	Wheat	709	Cattle meat	92
Tajikistan	Potatoes	660	Milk	529
	Wheat	612	Goat's milk, whole, fresh	55
Turkmenistan	Wheat	2,700	Milk	1,333
	Seed cotton	946	Cattle meat	102
Uzbekistan	Wheat	5,900	Milk	5,121
	Seed cotton	3,300	Cattle meat	586
East Asia				
China, People's Republic of	Rice, paddy	187,040	Pig meat	61,150
	Maize	151,970	Milk	32,820
Hong Kong, China	–	–	–	–
Taipei,China	–	–	–	–
Korea, Republic of	Rice, paddy	5,960	Milk	2,140
	Vegetables, fresh	3,550	Pig meat	915
Mongolia	Potatoes	114	Milk	335
	Wheat	110	Sheep meat	72
Pacific Islands				
Cook Islands	Roots and tubers	3	Pig meat	1
	Coconuts	2	Hen's eggs (in shell)	0
Fiji Islands	Sugarcane	3,200	Milk	58
	Coconuts	140	Chicken meat	12
Kiribati	Coconuts	110	Pig meat	1
	Roots and tubers	8	Chicken meat	0
Marshall Islands	Coconuts	20	–	–
Micronesia, Federated States of	Coconuts	41	Pig meat	1
	Cassava	12	Cattle meat	0
Nauru	Coconuts	2	Pig meat	0
	Vegetables, fresh	1	Hen's eggs (in shell)	0
Palau	–		–	–
Papua New Guinea	Oil palm fruit	1,400	Game meat	330
	Bananas	870	Pig meat	68
Samoa	Coconuts	146	Pig meat	4
	Bananas	23	Milk	2
Solomon Islands	Coconuts	276	Pig meat	2
	Oil palm fruit	155	Milk	1
Timor-Leste	Maize	63	Pig meat	10
	Cassava	50	Chicken meat	2

continued on next page

Table 1.5 continued

	Main Products			
Subregion and country	**Crops**	**('000 mt)**	**Livestock**	**('000 mt)**
Tonga	Coconuts	59	Pig meat	2
	Pumpkins, squash, and gourds	21	Milk	0
Tuvalu	Coconuts	2	Pig meat	0
	Vegetables, fresh	1	Chicken meat	0
Vanuatu	Coconuts	322	Milk	3
	Roots and tubers	43	Pig meat	3
South Asia				
Afganistan	Wheat	3,800	Milk	2,035
	Vegetables, fresh	540	Cattle meat	175
Bangladesh	Rice, paddy	43,504	Goat's milk, whole, fresh	2,016
	Sugarcane	6,000	Milk	818
Bhutan	Maize	95	Milk	41
	Rice, paddy	69	Cattle meat	5
India	Sugarcane	355,520	Buffalo milk, whole, fresh	56,960
	Rice, paddy	141,134	Milk	42,140
Maldives	Vegetables, fresh	28	–	…
	Bananas	11		
Nepal	Rice, paddy	3,681	Buffalo milk, whole, fresh	930
	Sugarcane	2,600	Milk	386
Pakistan	Sugarcane	54,752	Buffalo milk, whole, fresh	21,500
	Wheat	23,520	Milk	11,000
Sri Lanka	Rice, paddy	3,131	Milk	143
	Coconuts	954	Chicken meat	65
Southeast Asia				
Cambodia	Rice, paddy	5,995	Pig meat	140
	Cassava	2,000	Cattle meat	63
Indonesia	Oil palm fruit	78,000	Poultry meat	1,356
	Rice, paddy	57,049	Chicken meat	1,331
Lao PDR	Rice, paddy	2,870	Pig meat	47
	Vegetables, fresh	660	Buffalo meat	19
Malaysia	Oil palm fruit	77,700	Chicken meat	931
	Rice, paddy	2,231	Hen's eggs (in shell)	465
Myanmar	Rice, paddy	32,610	Milk	900
	Sugarcane	7,450	Chicken meat	653
Philippines	Sugarcane	25,300	Pig meat	1,501
	Rice, paddy	16,000	Chicken meat	638
Singapore	Vegetables, fresh	18	Chicken meat	76
	Spinach	2	Hen's eggs (in shell)	21
Thailand	Sugarcane	64,366	Chicken meat	1,050
	Rice, paddy	27,879	Pig meat	700
Viet Nam	Rice, paddy	35,567	Pig meat	2,500
	Sugarcane	16,000	Chicken meat	344

mt = metric tons.

Note: "–" indicates no data available.

Source: FAO (2009a).

Central Asia

With 75 million inhabitants, Central Asia is the second least populated subregion in Asia and the Pacific. Among the countries in Central Asia, Uzbekistan has the largest population (36% of the total). More than half of the subregion's population lives in rural areas (42 million), but less than a quarter (17 million) derive their livelihoods from agriculture. Population density on arable land is moderate, with an average of 245 people per square kilometer (km^2). Despite being relatively land abundant, the importance of agriculture to GDP has been declining, with the exception of Turkmenistan. The Republic of Georgia has made the most significant strides in this category, reducing the importance of agriculture to GDP from 52% in 1995 to 13% in 2006. In Tajikistan and Turkmenistan, where agriculture still contributes a significant share of GDP, employment in agriculture remains high—around 30% of the economically active population. Finally, the proportion of undernourished in the total population has been falling since 1995, with the exception of Uzbekistan, which has nearly tripled the percentage from 5% to 14% in 2003–2005.

Rainfall in this subregion is lowest compared with the others, averaging less than 500 millimeters (mm) annually. As a result, more than half of the countries in this subregion irrigate at least 50% of their cropland, which is crucial for food production and employment. Key crops are wheat, which is chiefly produced in Kazakhstan, and potatoes and seed cotton; the main livestock products are milk and beef.

East Asia

East Asia is the second-largest subregion in terms of population, with 1.4 billion inhabitants who mostly reside in the PRC. Nearly 60% of the people live in rural areas (792 million) and about the same proportion rely on some form of agriculture (847 million). Rural population density on arable land is high (559 people per km^2 in the PRC) but below that of some of the more land-scarce countries in South and Southeast Asia. The importance of agriculture to GDP has been declining across this subregion. While the sector accounts for only 12% of GDP in the PRC, nearly 64% of the economically active population is employed in agriculture. Finally, whereas food security has been improving in this subregion overall, nearly 30% of the population of Mongolia is undernourished. Given significant land scarcity in East Asia, several of the countries in this subregion, including the PRC, Japan, and the Republic of Korea, have started to purchase or lease land for food production in other parts of Asia (Indonesia and the Philippines) and in Africa, Eastern Europe, and Latin America.

Rice is the major crop, with the PRC producing 187 million metric tons in 2007. Other key crops include maize, pig meat, and milk in the PRC, and rice, fresh vegetables, and milk in the Republic of Korea. Irrigated land has a moderate presence in the PRC and the Republic of Korea, as cereals other than rice are often only rainfed. Rainfall is lowest in Mongolia and moderate in the PRC—with large variations across the country—whereas the Republic of Korea receives the most rainfall, with an average of over 1,300 mm per year.

South Asia

South Asia comprises eight countries, the largest of which is India. More than one-quarter of the population of the developing world is found in South Asia. Of this population of more than 1.6 billion people, more than two-thirds (70%) live in rural areas. Approximately 787 million people can be classified as agriculture-dependent. Given the high population density in this subregion, there is only about 0.16 hectares (ha) of agricultural land per capita. Rural population density per km^2 of arable land is highest in Bangladesh and Sri Lanka, each with over 1,000 inhabitants, whereas India, Nepal, and Pakistan have comparatively moderate density. The importance of agriculture to GDP remains high in South Asia and only declined slightly between 1995 and 2006. As a result, employment in agriculture is also high, with close to 50% or more of the population dedicated to this sector (with the exception of the Maldives). Finally, the proportion of undernourished in the population averages over 20%, making South Asia the least food-secure subregion of either Asia and the Pacific or the world.

Average rainfall varies across South Asia, with Bangladesh receiving the most and Pakistan the least. The regional average is about 1,300 mm per year, which is on par with averages for India and Nepal. As a result, irrigation coverage is high, varying from over 80% of cropland in Pakistan to at least 30% of cropland in Afghanistan, Sri Lanka, and India. Irrigation supports the production of major crops such as sugarcane, rice, and wheat in India and Pakistan, and rice in Nepal.

Southeast Asia

Southeast Asia comprises nine countries and 564 million people, with more than 40% of the population living in Indonesia (229 million). More than half this subregion's population resides in rural areas. Approximately 46% of people rely on agriculture for their livelihoods (257 million). Rural population density per km^2 of arable land is moderate, ranging from 901 inhabitants in Viet Nam to less than 300 in Cambodia. The importance of agriculture to GDP has been declining; however, it still contributes 30% in Cambodia and over 40% in Lao PDR. Finally, undernourishment in Southeast Asia has been declining since 1995 but still averages 18% of the population, with 26% of the population of Cambodia classified as malnourished.

Southeast Asia receives over 2,000 mm of rainfall, on average, each year, which is second only to the Pacific subregion. As a result, agricultural areas remain largely rainfed, whereas irrigated cropland averages approximately 17% of the total. These conditions favor crops such as rice, sugarcane, and oil palm fruit, which are the dominant crops in terms of tonnage of production. In terms of livestock production, poultry and chicken are of greatest importance to Indonesia, whereas the Philippines produces a significant amount of pig meat.

The Pacific Islands

The smallest subregion in terms of population is the Pacific, with 9.4 million inhabitants. Eleven of the 14 countries in this subregion have less than 500,000 inhabitants. The most populous country is Papua New Guinea, with 5.9 million people. More than 80% of the population of these islands can be classified as rural, and about 67% are dependent on agriculture for their livelihoods (6.1 million). Data on irrigated cropland, undernourishment, and the importance of agriculture in GDP are scarce for this subregion. Data from Papua New Guinea, however, indicates that agriculture's share of GDP has been rising, from 32% in 1995 to 42% in 2005. In addition, the proportion of the population employed in agriculture averages close to 40%. Finally, caloric availability has improved slightly since 1995, rising from 2,560 to 2,660 kilocalories (kcals) per person per day in 2005.

Adaptive Capacity

The third dimension of vulnerability is adaptive capacity, which is defined in this report as the ability of institutions and individuals to avoid potential damage, to take advantage of opportunities, or to cope with the consequences of change. This aspect of vulnerability is most difficult to conceptualize because many socioeconomic variables determine adaptive capacity. Indicators such as poverty rates, access to credit, literacy rates, and farm income can be used to measure adaptive capacity. At the farm level, the adaptive capacity of farmers is influenced in part by their knowledge of and access to alternative technologies. Furthermore, many factors determine the extent to which farmers and other stakeholders can mobilize and gain access to pooled resources and knowledge. For example, government-provided extension services will influence a farmer's knowledge of alternative technologies, and property rights provide an incentive for continued investment. Economic aspects will shape the level of investment and planning, as well as how much access a farmer may have to inputs such as fertilizer and irrigation.

Achieving enhanced resilience in the face of climate change will require enhancing the adaptive capacity of countries in Asia and the Pacific, as well as implementing appropriate adaptation investments, policies, and institutions. Adaptation measures should be targeted to the countries, sectors and people most vulnerable to the adverse impacts of climate change—that is, those most exposed and sensitive to its effects as well as those having the least adaptive capacity to counter these impacts. (Chapter IV develops a framework for prioritizing adaptive measures and building adaptive capacity.)

Implementation of the Conceptual Framework

The conceptual framework is implemented both qualitatively and quantitatively. An overview of the current status of knowledge is provided regarding the various dimensions of climate change and agriculture in Asia and the Pacific. In addition, qualitative descriptions of various parameters that are difficult to model in the global modeling framework are also given, such as the roles of gender and governance. The modeling results are compared to those of the literature, which continues to evolve.

The modeling effort undertaken by the International Food Policy Research Institute (IFPRI) has three main parts: (i) detailed modeling of crop growth for five key crops (rice, wheat, maize, soybeans, and groundnuts) and extension of modeled crop growth results to climate-relevant, phenologically similar crops, (ii) estimation of a nonlinear reduced form function for each crop variety that incorporates a wide range of biophysical and climate drivers, and (iii) projections of world agricultural production, consumption, and trade derived from IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT).

Actions to Reduce Vulnerability and Build Resilience

Actions to reduce vulnerability and build resilience in the agriculture sector can be defined as either strategies for adaptation or strategies for mitigation. Policies and institutions that take advantage of synergies between adaptation and mitigation strategies provide a more holistic and streamlined investment climate for building resilient communities.

A key adaptation and mitigation strategy is to build the resilience of agroecological systems because these systems determine our capacity to produce food and clean water. Whereas climate change will disturb the functioning of these systems in ways that could lead to severe losses of ecosystem functioning, such as desertification and soil degradation, building ecosystem resilience will enhance the capacity of these systems to withstand shocks and rebuild after damage. The adoption of resource-conserving technologies—such as rainwater harvesting; conservation tillage; and integrated crop, water, and pest management—will form the backbone of actions to sustain and enhance agroecological systems. In addition, the most effective policy measures will be those that promote research and the adoption of new drought- and heat-resistant crop varieties, strengthen water-use productivity and performance, and promote synergies between adaptation and mitigation. (More detail and a variety of synergistic adaptation and mitigation measures are discussed in Chapters IV and V.)

Adaptive and flexible management will be essential, including the capacity to monitor the results of managers' decisions and to subsequently modify actions as needed. The broadening nature and increasing severity of potential climate impacts in a given area and the unavoidable uncertainties associated with predicting these impacts require innovative approaches to management and development that go beyond centralized prediction and control practices (Nelson et al. 2008; Pahl-Wostl 2007a). One approach—adaptive management, or adaptive governance—has received attention because it enables decision makers and resource managers to work with the inherent uncertainty associated with climate change (Pahl-Wostl 2007b; Brunner et al. 2005; Tompkins and Adger 2004; Folke et al. 2002). Supporting knowledge, coordination, collaboration, information exchange, and institutional responsiveness will be the backbone for building the broad set of technical skills needed to prepare, plan, and respond to a wide range of unpredictable contingencies. To that end, it will be important to investigate the types of policies that enhance social learning and build institutions' adaptive capacity to deal with uncertainties in their local settings. This approach will require, in part, a detailed institutional assessment that highlights key areas of need and opportunity for building resilience in institutions that support agricultural decision makers and, more generally, vulnerable populations. (Strategies for building capacity in adaptive management are presented in Chapter IV).

Adaptation

Adaptation policies will be critical in reducing agricultural vulnerability to climate change and extreme weather events. Formally defined, adaptation is an adjustment made in response to a perceived change in a human or natural system in order to reduce vulnerability, build resilience, or both. Types of adaptation measures include proactive (anticipatory) or reactive changes, as well as planned versus autonomous changes. Planned adaptations are proactive measures taken by public agencies, whereas autonomous or spontaneous adaptation is a reactive response taken by private actors triggered by market or welfare changes induced by climate change. Our integrated modeling framework considers some forms of autonomous adaptations through supply responses as a result of higher food prices, as well as through changes in trading patterns, whereby food imports increase in those areas where food production declines. Both types of adaptation responses will be important; however, proactive adaptation measures have the most implications for policy. These types of adaptation will be further investigated in Chapter IV.

Governments and institutions also have critical roles to play in building adaptive capacity. In general, governments need to ensure a policy environment in which individual farmers have adequate rights, resources, and information in order to make proactive choices that build resilience. For example, to protect against devastating outcomes from agricultural failures due to weather and climate, programs and policies should be implemented to improve risk management and promote crop insurance, including weather-index insurance. These programs can also reduce risk aversion by farmers in their production decisions and thus enhance the potential for the adoption of adaptive farming systems. A stable and supportive policy environment that makes those programs available and profitable is also a critical factor. Such a policy environment requires strengthening important development initiatives in support of climate change adaptation that have been implemented in varying degrees throughout the developing world.

Some innovative responses to climate change needed for agricultural adaptation are already being developed but have not been implemented on a wide scale. Enhancing farmers' ability to respond to climate variability and climate change will require significant improvements in developing and disseminating agricultural technologies targeted at the major evolving biotic and abiotic stresses generated by climate change. Improved crop varieties have the potential to be more drought-tolerant and enable both an increase in nutrient- and water-use efficiency as well as a decrease in pesticide use. But new technologies, by themselves, are not sufficient to successfully address the challenges climate change poses for agriculture; appropriate dissemination channels need to be created to maximize adoption.

Adaptation measures are necessary to improve performance under climate change. The first goal of adaptation measures is to reduce risk, in terms of both agricultural systems and human systems. The second goal is to ensure that adaptation measures offer opportunities for alternative economic activities in vulnerable sectors. The third and final goal of adaptation, as presented in this report, is to ensure that proactive adaptation measures support sustainable development and poverty reduction, particularly in rural agricultural areas. These goals are consistent with the idea that adaptation policy should go beyond good development policy to achieve current development targets, such as the Millennium Development Goals (MDG). Adaptation policy needs to be more comprehensive and requires additional investments to deal with the pressures of climate change in Asia and the Pacific. Chapter IV will provide an in-depth analysis of the types of adaptation policy that will be critical to agriculture in the region.

Mitigation

Mitigation, or the removal and avoidance of GHG in the atmosphere, is another key entry point for policy and investments toward building resilience. Strategies for GHG mitigation in agriculture will be important in the region for various reasons. First, reducing the amount of emissions will reduce the extent of climate change and therefore the extent of adaptation required. Second (as shown in Chapter V), mitigation in the agriculture sector in Asia and the Pacific could generate billions of dollars in financial flows for rural communities. In addition, mitigation measures have significant synergies with adaptation by improving ecosystem functioning, increasing water availability, and improving resilience to drought, pests, and other climatic threats. Finally, mitigation measures can be integrated into sustainable development pathways by enhancing soil quality and boosting longer term, land-saving productivity growth.

In Chapter V, the opportunities for mitigation and synergies with adaptation and sustainable development are explored. Asia is a key emitter of GHG through fertilizers and soils (in the form of nitrous oxide or N_2O), as well as through livestock and rice production (in the form of methane or CH_4). Much of the expected increase in agricultural emissions will be in Asia as a result of food production growth required to feed larger, wealthier populations. Key low- or no-cost GHG mitigation activities in the region include low- or no-till and other sequestration methods (meaning methods that enhance the absorption of GHGs), as well as reducing CH_4 emissions from ricefields. Using high-yielding varieties, shifting to rice and/or wheat production systems, and alternating dry-wet irrigation are technologies that both mitigate emissions and build resilience by conserving water, reducing land requirements, and reducing fossil-fuel use. Suggested strategies for increasing carbon sequestration and reducing the transaction costs of other mitigation strategies are provided in detail in Chapter V.

As with adaptation, the outcome of international climate change negotiations will have major effects on the role of agriculture in mitigation. Actions toward including agriculture in a post-Kyoto Protocol[6] must be taken now with a focus on integrating smallholder farmers in carbon markets. Institutional innovations that link communities with those global markets, such as regional centers for carbon trading, specialized business services and local intermediaries, are outlined in Chapter V, along with opportunities to simplify methods of monitoring, reporting, and verifying small-scale projects. Finally, effective implementation of this aggressive climate change adaptation agenda will require mainstreaming climate change and adaptation into development planning, reforming climate-related governance and institutions, and undertaking massive new investments. These issues will also be described in detail in Chapter V.

Outcomes of Improved Resilience

Examples of improved resilience outcomes in the agriculture sector may include:

- increased adaptation of crops and livestock to climate stress,
- enhanced access and utilization of technology and information,
- increased income generation,
- increased use of resource-conserving technologies,
- open and transparent trade regimes, and
- improved risk sharing.

Some of these outcomes—such as the investments needed for agricultural research and development (R&D), irrigation investments, and the relative role of trade liberalization versus trade distortions—will be modeled, while other outcomes—such as the potential benefits from smallholder participation in agricultural mitigation—will be qualitatively described based on the current state of literature and on our policy assessment.

Limitations of the Modeling Undertaken

While the study covers key dimensions of climate change, that is, rising temperatures, changing mean precipitation, and associated biophysical adaptations—including the hydrologic, agronomic, and economic impacts on agricultural production, as well as autonomous and proactive adaptations—there are other dimensions of climate change that are not adequately covered in this (or any other) integrated modeling framework. These dimensions include the impacts of degraded grazing and/or

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[6] The Kyoto Protocol establishes binding commitments among 183 countries under the United Nations Framework Convention on Climate Change for the reduction of GHGs from 1990 levels, which entered into force on 16 February 2005.

pasture land on livestock production, of pests and diseases under changing climates, of rising sea levels and retreating glaciers, and—most importantly—of increases in extreme weather events.

Livestock impacts are generally expected to be mostly from grazing and pasture land, factors not yet included under the IMPACT framework. While much of Asia is on the path of intensive agriculture with feedlot systems, grazing is the key livestock feed source in some countries, including Mongolia, parts of the PRC (Inner Mongolia, Qinghai, Xinjiang Uygur, and Tibet), and parts of Central Asia. The full impact of climate change on cereal crops used for animal feed are currently captured, but not the impact of potentially declining availability of grazing and pasture land, the smaller estimated impact of heat stress on animal production, nor the impacts of a change in animals' drinking water supply.

The study also does not incorporate the impact of pests and diseases under changing climate. Among the various unfavorable climatic and soil conditions that severely affect crop production are salinity, extreme temperatures, droughts, and floods. Effects from these stresses compound each other, further aggravating the situation—for example, when drought is associated with high temperatures; salinity is linked with water stress; or oxidative damage is caused by excessive light, water scarcity or excess, and extreme temperatures. Drought, high temperatures, flooding, and wind velocity during critical stages of crop growth can severely disturb the development and production cycles of key staple crops. Once plants are weakened from abiotic stresses, biotic stresses can set in, more easily increasing the incidence of pest and diseases (Rosegrant et al. 2007a).

While rising sea levels are not modeled explicitly, we have developed an estimate of the staple crop area affected under two scenarios of rising sea levels outside of our modeling framework. The analysis neither considers impacts on food prices under these estimates, nor the tidal effects and concomitant changes in flows from rivers to the coast, which can compound or ameliorate the impacts of rising sea levels.

In general, there are few model-based hydrology studies on retreating glaciers. The study does not explicitly model such retreats, but we do include seasonal accumulation and melting snow. The main effects of retreating glaciers under climate change are increased water flows in glacier-fed rivers in the near future and reduced flows in the distant future as glaciers shrink or permanently disappear. As a result, the timing of flows might change, possibly increasing water storage requirements in order to meet water demands.

General circulation models (GCM) are both spatially aggregated and unable to sufficiently capture climate variability, so global impact assessment models ignore extreme weather events and thus do not provide the information needed to model floods, hailstorms, storms, or hurricanes—events of key importance for agricultural production into the future. Nevertheless, the impacts of more frequent natural disasters on agricultural systems could well be even more severe than the impacts of increased temperatures and precipitation (Easterling et al. 2007). Moreover, the variability of climate is typically much greater at the local level than when averaged across large areas, with the effect that short-term fluctuations cancel each other out. Despite the importance of local weather in climate change adaptation, macroeconomic models have limited resolution, and therefore cannot capture location-specific changes in the variability of precipitation and temperature levels. In this analysis, we have sought to reconcile the limitations of macroeconomic models by incorporating results from crop growth models, as well as location-specific changes in suitability for existing crops, thus arriving at a level of detail that is superior to other integrated model results currently available (see analysis in Chapter III).

Summary

Building resilience in the agriculture sector in Asia and the Pacific poses enormous challenges in the face of climate change. In order for the agriculture sector to meet the food and income needs of current and future generations in the face of climate change, actions need to be taken and strategies implemented, both autonomously by individual farmers, and collectively by governments, community groups, and institutions. Building resilience requires reducing vulnerability by minimizing the impacts of climate change and raising adaptive capacity. This in turn requires targeted investments to effect adaptation and mitigation strategies and ultimately improve knowledge.

This chapter has also presented broad indicators of exposure, sensitivity and adaptive capacity in the region. A review of the indicators highlights the vulnerability of the agriculture sector as a livelihood source for many of the region's inhabitants and as a source of food security for all inhabitants. The review also exposed the large heterogeneity in farming systems across Central Asia, East and Southeast Asia, South Asia and the Pacific Islands. Existing undernourishment, poverty, and slowing productivity growth put many at a disadvantage, which will only be exacerbated by climatic change. The review of the indicators also highlights wide-ranging levels of exposure and vulnerability to climate change across the region.

Climate change is expected to have multifaceted impacts in the Asia and the Pacific. Overall, the region is expected to become warmer, with a large degree of variability depending on latitude. In general, northern regions will experience greater warming and than those at lower latitudes. While the Pacific countries will experience low mean annual changes in rainfall and temperature, rising sea levels are expected to alter significantly not only livelihoods but also livability on some of the smaller islands. Coastal areas in South and Southeast Asia will face the triple threat of changing precipitation, changing temperatures, and rising sea levels. Finally, cooler northern subregions are expected to get warm, which may bring welcome news to farmers in terms of longer growing seasons.

The combination of poverty in rural areas combined with the expected, but uncertain, impacts of climate change will require careful planning for adaptation. Scarce budgetary resources face competing claims from crucial social development initiatives, such as those related to education, health, and emergency assistance, further supporting careful targeting to build resilience to climate change. This, in turn, calls for greater flexibility in decision making, especially in terms of investments.

CHAPTER II

Vulnerability of Countries in Asia and the Pacific to Climate Change

Factors Affecting Vulnerability to Climate Change

This chapter reviews the literature on the vulnerability of countries in Asia and the Pacific based on composite indicators reflecting exposure, sensitivity, and adaptive capacity to climate change. It follows the Intergovernmental Panel on Climate Change (IPCC) definitions (McCarthy et al. 2001) and notes that the IPCC's definition of vulnerability combines information on potential climate impacts with current socioeconomic capacity to cope and adapt (O'Brien et al. 2004; Fussel 2007; O'Brien et al. 2007).

The economies of developing and smaller countries are less able to cope with disasters of similar magnitude than are the economies of developed or larger countries. Vulnerability assessments show that the poorest countries and populations are the first and most affected by extreme weather events. Whereas mortality risks are clearly lower in countries with developed economies, high mortality rates and vulnerability to natural disasters have been associated with low-income countries, densely populated areas, inefficient governments, lack of accountability, high levels of inequality, and low literacy rates (Stromberg 2007; Kahn 2005) (Table 2.1). On the other hand, countries with higher literacy rates, better institutions, higher per capita incomes, higher degrees of openness to trade, and higher levels of government spending are better able to cope with the initial shock of the disaster and avoid spillovers into the macroeconomy (Noy 2009). Marginalized social groups in developing countries— including poor women, children, the elderly, and disabled people—suffer the most from natural disasters. Consequently, increases in such events as a result of climate change will affect these groups disproportionately because the impact of such disasters depends not only on exposure, but also on people's levels of vulnerability (Ehrhart et al. 2008).

Furthermore, climate change will hit communities in Asia and the Pacific that already experience high levels of food insecurity. According to the FAO, the region accounts for 68% of the developing world's population and 64% of its undernourished population (FAO 2006).

Asia and the Pacific is already highly prone to natural disasters. Statistics for 1975–2006 show Asia as the most disaster-afflicted region in the world. Asia accounted for about 89% of people affected by disasters worldwide, 57% of total fatalities, and 44% of total economic damage. In that period, 75% of all natural disasters in Asia were hydrometeorological disasters (Sanker, Nakano, and Shiomi 2007; Table 2.1). In 2006, 21 of the world's top 25 natural disasters, in terms of number of people affected, occurred in Asia. Of those 21 disasters, 11 occurred in the PRC. In 2007, nine of the 10 countries with the highest death rates caused by extreme weather events were in Asia. The most affected countries, in order, were Bangladesh, India, the PRC, Pakistan, the Republic of Korea, the United States, Indonesia, Viet Nam, Afghanistan, and Nepal (Harmeling 2008).

Countries with more experience in managing natural disasters perform better over time, so intergovernmental mechanisms should enable countries to learn from one another's experiences. Comparing experiences following extreme weather events in Bangladesh (the 1998 floods), Ethiopia (the 2002 drought), and Malawi (the 2001 drought), it was found that community-based targeting strategies were much more successful in Bangladesh, as it had the most experience with targeting emergency assistance on a unified, national scale (Yamauchi et al. 2009). Furthermore, in Bangladesh, the decline in the number of people killed in the tropical cyclone of 1997 (fewer than 200 people) compared with a similar storm in 1991 resulting in a death toll of 138,000, shows that successful adaptation (in this case disaster management involving governmental and nongovernmental organizations) can significantly reduce a country's vulnerability to climate events (Brooks, Adger, and Kelly 2005).

On the other hand, when no such experience exists, like storm Linda hitting the Mekong Delta

Table 2.1: Global Impacts of Hydrometeorological Disasters by Income Level, 1975–2006

Income Class	% of People Killed	% of People Affected	Share of Damage (%)
High-income countries	4.4	0.8	55.4
Lower-income countries	79.2	52.0	7.9
Lower middle-income countries	11.7	45.5	30.4
Upper middle-income countries	4.7	1.7	6.3
Total	100.0	100.0	100.0

Source: Sanker, Nakano, and Shiomi (2007).

in 1997, outcomes can be disastrous. That storm claimed 1,792 lives (dead and missing) and sank thousands of fishing vessels. It also destroyed more than 200,000 homes and ruined 500,000 hectares (ha) of farm and aquacultural land. Minimal disaster response systems were in place in the Mekong River Delta, reflecting how unprepared the subregion was for extreme weather events. Most of the impacts were in coastal areas in vulnerable, poor, and isolated communities (Truong and Ketelsen 2009).

According to Preston et al. (2006), Asia and the Pacific is exposed to a range of climate conditions and extreme weather events, and, as mentioned in Chapter I, the El Niño Southern Oscillation strongly influences rainfall patterns in the region, bringing periodic drought and rising sea levels in the southwest Pacific. Furthermore, tropical cyclones and associated high winds, storm surges, and extreme rainfall events are common in the coastal areas of Asia and the Pacific (Preston et al. 2006). Climate change might significantly alter the dynamics of these events, possibly increasing their frequency and intensity in many countries. Low-lying countries, including small islands, will face the highest exposure to rising sea levels, which will increase the risk of floods that might affect millions of people in the region.

Vulnerability to climate change will also be higher in countries where agriculture accounts for a large share of gross domestic product (GDP) and employment, where levels of poverty are high, and where population density is high—all factors expressing sensitivity to climate change. These characteristics apply to many countries in South Asia. Finally, land and water degradation— important causes of crop yield decreases—will also make countries more sensitive to a changing climate.

Results of Vulnerability Assessments for Asia and the Pacific

Globally, during 1980–2004, droughts were the most deadly geophysical and hydrometeorological event, followed by windstorms and tsunamis, while floods affected the largest number of people (Stromberg 2007). Flood-risk hotspots[7] were identified in South and Southeast Asia; drought-risk hotspots in South Asia (Afghanistan, Pakistan, and parts of India) and Southeast Asia (Indonesia, Myanmar, and Viet Nam); and cyclone-risk hotspots in Bangladesh, parts of India, Viet Nam, and other Southeast Asian countries (Ehrhart et al. 2008). Thus, many countries in the region, particularly those in South and Southeast Asia, have areas at risk from more than one climate-related hazard (Figure 2.1).

Studies using different methodologies have proposed various vulnerability indexes to assess countries' vulnerability to climate change (see summary in Table A1.1). As described here, some countries are considered vulnerable according to several different criteria. Detailed scenario analysis of vulnerability in Central Asia and the Pacific Islands is excluded from the analysis in this report because of the lack of reliable data and comprehensive studies investigating vulnerability in these subregions. An overview of the most vulnerable countries in Asia and the Pacific is presented below.

Bangladesh

A low-lying coastline, high population density, and a highly agriculture-dependent economy combine to make Bangladesh one of the most vulnerable countries to rising sea levels and other effects of climate change (Poverty-Environment

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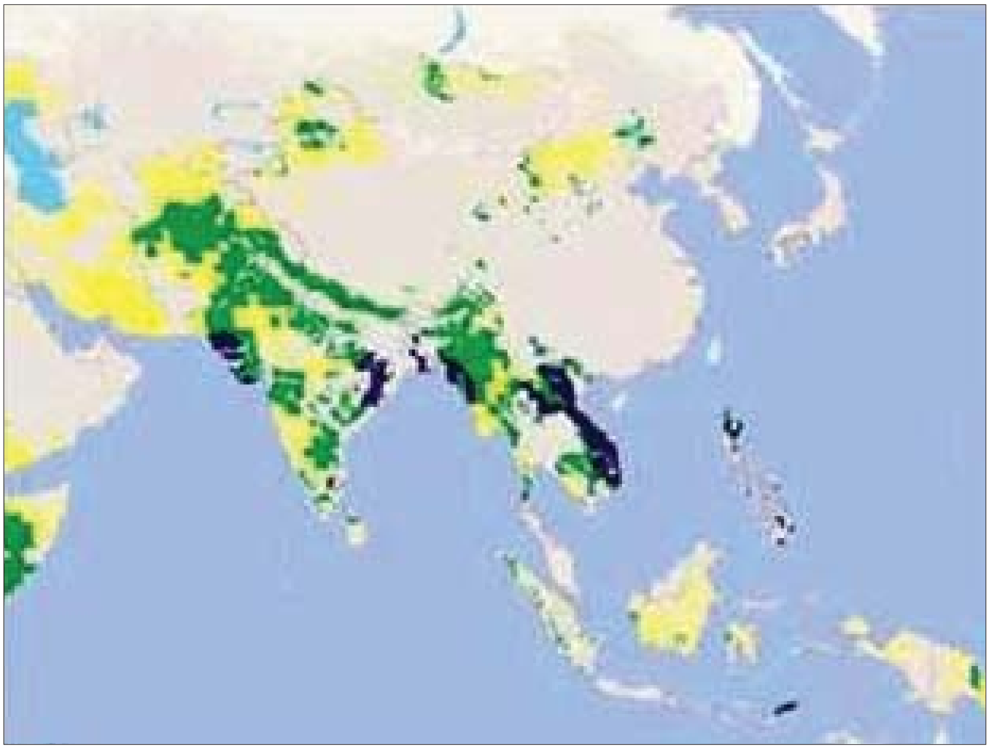
[7] Risk hotspots combine areas of significant hazard risk with those of significant human vulnerability.

Figure 2.1: Cumulative Hotspots of Humanitarian Risk for Floods, Cyclones, and Droughts



Legend: Yellow = 1 hazard
Green = 2 hazards
Blue = 3 hazards

Note: Risk hotspots combine areas of significant ecological hazards with those of human vulnerability. This map shows cumulative hotspots of humanitarian risk for three climate-related hazards: floods, cyclones, and droughts. Areas at risk for more than one type of hazard are considered to be of most concern for humanitarian actors.

Source: Ehrhart et al. (2008).

Partnership 2003). Bangladesh is a cyclone- and flood-risk hotspot (Ehrhart et al. 2008). Most of the country's elevation does not exceed 10 meters, and a 1-meter rise in sea level might well result in the flooding of 16% of the country's land area (Karim, Hussain, and Ahmed 1996). Even a rise in sea level of 0.30 or 0.75 meters is expected to wreak havoc on the eastern coast of Bangladesh, flooding areas of 5.80 and 11.20 km^2, respectively; 95% of which is agricultural land (Ali 1999). Further details on rising sea level predictions for Asia and the Pacific are presented in Box 2.1. Finally, Bangladesh will

Box 2.1: Predictions of Rising Sea Levels for Countries of Asia and the Pacific

Countries in South Asia, Southeast Asia, and the Pacific Islands are highly vulnerable to rising sea levels, which increase the risk of floods. The global sea level gradually rose during the 20th century and continues to rise at increasing rates (Cruz et al. 2007). In Asia and the Pacific, the sea level is expected to rise approximately 3–16 centimeters (cm) by 2030 and 7–50 cm by 2070 in conjunction with regional sea level variability (Preston et al. 2006).

Under a conservative scenario of a 40 cm rise in sea level between today and the end of 21st century, the number of people facing floods in coastal areas will increase from 13 million to 94 million annually, with 60% of this increase occurring in South Asia (the coasts of Bangladesh, India, Pakistan, Myanmar, and Sri Lanka) and 20% in Southeast Asia (the coasts of Indonesia, the Philippines, Thailand, and Viet Nam) (Cruz et al. 2007).

Studies on the vulnerability of coastal zones to rising sea levels and storm surges are severely hampered by lack of data on coastal protection, including both natural and artificial protection systems. It is likely, however, that the low-lying river deltas of Bangladesh, the PRC, India, Viet Nam, and the small island states in the Pacific face the largest risk of coastal inundation, soil erosion, displacement of communities, loss of agricultural land, intrusion of saline waters into surface and groundwater, and other consequences of a rise in sea level (Arnell et al. 2002; Parry, Rosenzweig, and Livermore 2005; Preston et al. 2006). In the Zhujiang Estuary in the PRC, for instance, rising sea levels of 0.4 to 1.0 meters can induce further saltwater intrusion of 1–3 km (Bates et al. 2008). Although this particular distance is quite small, such distances can be significant if they interrupt domestic or irrigation water supplies.

also be affected by melting glaciers, which in the long run could further exacerbate the impacts of a rise in sea level because lower dry-season river flows would further draw in saltwater (see Box 2.2 for more information on the impacts of melting glaciers under global warming).

About 20% of Bangladesh' GDP is derived from the agriculture sector, which employs more than half the country's total workforce (World Bank 2008a). Furthermore, rural density is extremely high, with 1,249 people per square kilometer (km^2) of arable land (World Bank 2005). According to Moss, Brenkert, and Malone (2001), even the country's current sensitivity to climate change is beyond its adaptive capacity, and by 2095, sensitivity is expected to increase even more under two of three vulnerability scenarios (see Table A1.1). Similarly, according to Yohe et al. (2006), Bangladesh will be *significantly* to *extremely* vulnerable to climate change under all scenarios, including under a scenario combining mitigation and enhanced national adaptive capacity (Yohe et al. 2006).

Nonetheless, as mentioned above, successful adaptation can significantly reduce a country's vulnerability to climate events, and Ehrhart et al. (2008) consider the delta expanse of Bangladesh to be only moderately vulnerable based on investments in preparedness and risk reduction, including a strengthened response capacity and the establishment of early warning systems.

Pakistan

Pakistan is another country expected to be extremely vulnerable to climate change by 2100

Box 2.2: Glaciers in the Himalayas and Central Asia—Melting as a Result of Global Warming

Himalayan glaciers form a reservoir that supports perennial rivers on which millions of people in Bangladesh, Bhutan, India, Nepal, and Pakistan depend for survival (Cruz et al. 2007). Around 10% of the volume of Himalayan rivers comes from melting water from the glaciers, which are essential to sustain river flows during dry seasons (Mirza 2007). As a result of global warming, the Himalayan glaciers are receding faster than any other glaciers in the world. If the present rate of melting continues, there is a high chance that they will disappear by 2035 (Cruz et al. 2007). The Dokriani glacier, for instance, which feeds the Ganges River, receded 20 meters in 1998 compared with an annual average of 16.5 meters from 1993 to 1998, and the Gangotri glacier, which receded at an annual average of 7.3 meters from 1842 to 1935, receded 23 meters a year from 1985 to 2001 (Mirza 2007; Cruz et al. 2007). Mirza (2007) reports on some of the implications of the melting of the Himalayan glaciers, which include more water in the perennial rivers in the Himalayas in the short run—a factor that could be positive in the dry seasons but might also increase the chance of floods (from glacial lake outbursts, for example). The short-term increase in dry-season flows might also increase sediment supply in the rivers, which may pose a threat to dams and reservoirs in the region. In the long run, however, declines in dry-season flows to below current levels are likely, thus posing threats to food security and the environment (Mirza 2007; Preston et al. 2006).

In Central Asia, a subregion highly dependent on irrigation, glacier melt has increased substantially since the 1970s. In Tajikistan, for instance, glaciers lost a third of their area in the second half of the 20th century. As in the Himalayas, the melting of glaciers is expected to increase flows in Central Asia in the short run but exacerbate water shortages in the long run (Schubert et al. 2008). Moreover, rapidly melting glaciers, glacial runoff, and glacial lake outburst are already causing mudflows and avalanches in Asia (Schubert et al. 2008).

under all vulnerability scenarios (Yohe et al. 2006; see Table A1.1). Agriculture contributes about 20% of total GDP and employs more than 40% of the total workforce (World Bank 2008a), making the country sensitive to global warming. Around 23% of the population lives below a poverty line of $1.25 a day (Bauer et al. 2008), which directly affects communities' ability to cope with climate change. Furthermore, only one-quarter of the country's land is arable, and 80% of this land depends on irrigation and faces serious land and water degradation (O'Brien 2000).

Ehrhart et al. (2008) consider that most of Pakistan faces high human vulnerability with both flood and drought hotspots; an exception is the Indus basin with fertile land and ample water supply. Brooks, Adger and Kelly (2005) go even further, reporting on high climate-related mortality in the country associated with poor outcomes for several health, governance, and education indicators.

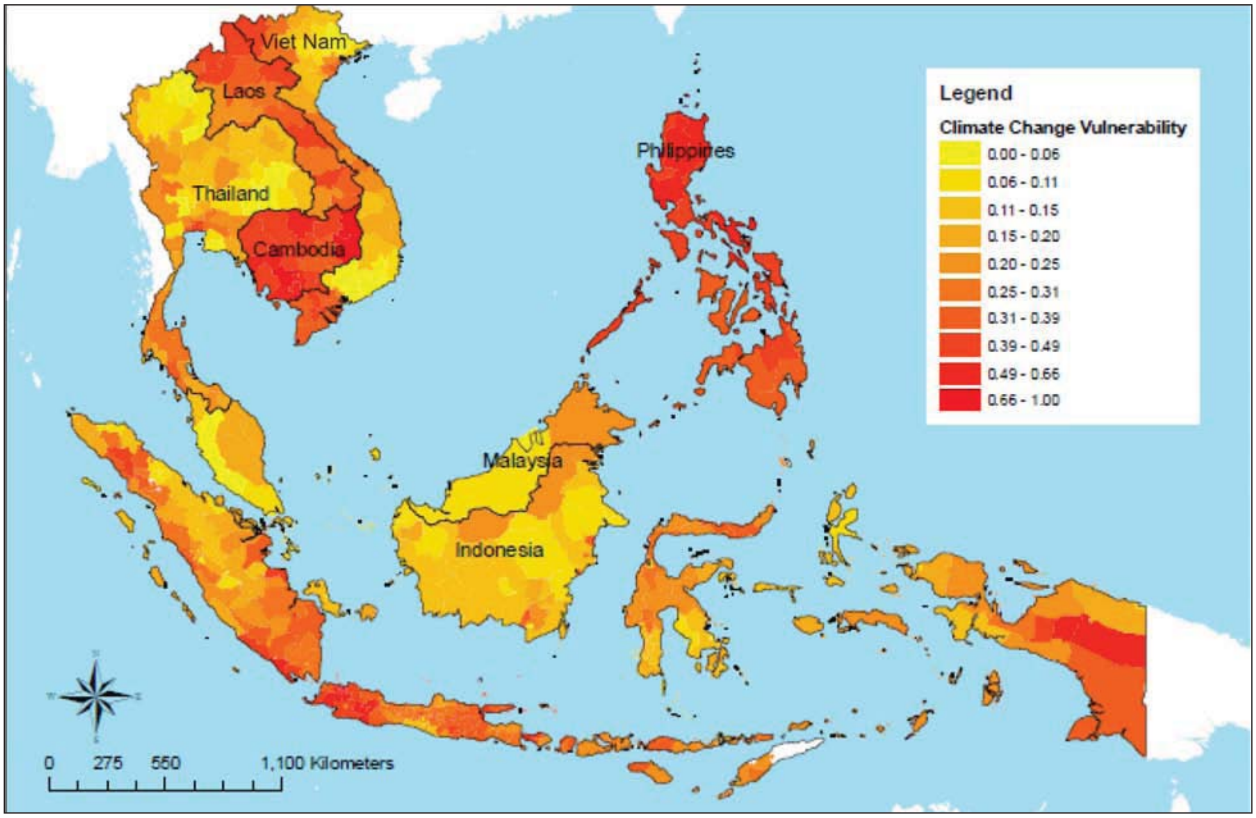
Cambodia

Cambodia is considered one of the most vulnerable countries in Southeast Asia. Although the country is not highly exposed to climate hazards, adaptive capacity is very low. Part of the country lies within the Mekong Delta (Yusuf and Francisco 2009, see Figure 2.2) and highland areas are threatened by landslides. About 40% of the population lives on less than $1.25 a day, and 30% of GDP is derived from agriculture (Bauer et al. 2008; World Bank 2008a). By 2100, Cambodia is expected to be extremely vulnerable to climate change under three of four scenarios (Yohe et al. 2006); only the combined mitigation and enhanced adaptive capacity scenario shows better outcomes for the country. In that study, however, the authors did not project extreme weather events.

Viet Nam and Mekong Delta

Although Viet Nam generally has a high adaptive capacity, much of the country is subject to flood and drought risks, as well as cyclones (Ehrhart et al. 2008; Yusuf and Francisco 2009). The Mekong Delta is also a hotspot for rising sea levels (Yusuf and Francisco 2009; Figure 2.2). Dasgupta et al. (2007), in a study that assessed the impacts of a continuing rise in sea levels on 84 coastal developing countries, included Viet Nam among the top five most-affected countries. A 1-meter rise in sea level would affect 11% of Viet Nam's (current) population, 16% of its land area, and 7% of its agricultural area. Similarly, Cruz et al. (2007) project that a 1-meter rise in sea level would flood 5,000 km^2 of the Red River Delta and 15,000–20,000 km^2

Figure 2.2: Climate Change Vulnerability Map of Southeast Asia



Note: The scale used in the legend is 0–1, indicating the lowest vulnerability level (0) to the highest vulnerability level (1).

Source: Yusuf and Francisco (2009).

of the Mekong River Delta, affecting 4 million and 3.5–5.0 million people, respectively.

Global warming is also expected to affect other Mekong riparians, in particular Lao People's Democratic Republic (Lao PDR) and Thailand. A study of the Mekong River's tributaries in Lao PDR and Thailand shows that climate change is likely to increase water levels in most tributaries given higher precipitation, which will increase the risk of flooding (Snidvongs 2006) (see also Box 2.3 on changes in water supply under climate change).

The People's Republic of China and India

In countries such as the PRC and India, structural change and growth might reduce future sensitivity to climate change and increase the ability to leverage resources to reduce risk (Preston et al. 2006). Parts of these countries, however, are still seen as highly vulnerable to climate change. According to Yohe et al. (2006), both countries are expected to be *significantly* or *extremely* vulnerable to climate change by 2100, even considering mitigation and enhanced adaptive strategies.

Box 2.3: Projections of Changing Water Supply Under Climate Change in Asia and the Pacific

The dominant climatic drivers for water availability are precipitation, temperature, and evaporative demand (Kundzewicz et al. 2007). Although climate change affects the volume and timing of river flows and groundwater recharge, greater water demand in the future as a result of population and economic growth outweighs climate change in defining the state of future global water systems (Vorosmarty et al. 2000; Arnell 2004). The impacts of climate change, however, will continue to increase in importance over time. Scenarios show that in parts of South and East Asia, climate change will increase runoff, which is likely to increase the risk of floods during the wet season, while Central Asia will face a decrease in mean runoff (Arnell 2004; Warren et al. 2006; Shrestha and Yatsuka 2008). In the Mekong, the maximum monthly flow is projected to increase by 35%–41% in the basin and by 16%–19% in the delta (by 2070–2099 compared with 1961–1990 levels), and the minimum monthly flow is projected to decline by 17%–24% in the basin and 26%–29% in the delta. The expected results are increased flooding risk during the wet season and water shortages in the dry season (Bates et al. 2008). In arid and semi-arid Central Asia, climate change is expected to increase the challenges countries face in meeting growing demand for water (Bates et al. 2008).

Climate change is also likely to affect groundwater resources by altering recharge capacities in some areas, increasing demand for groundwater as a result of less surface water availability, and causing water contamination due to rising sea levels (Shrestha and Yatsuka 2008). In Asia, around 2 billion people depend on groundwater resources for drinking water, but agriculture is the largest user of groundwater resources. Agricultural systems are highly dependent on groundwater resources in India (60% of total agricultural water use); in Pakistan's Punjab (40% of total agricultural water use); and in the Shangdong, Henan, Beijing, and Hubei provinces of the PRC (50%, 50%, 65%, and 70%, respectively, of total water use) (Shrestha and Yatsuka 2008).

Ehrhart et al. (2008) consider areas in India to be flood, cyclone, and drought hotspots, and parts of northern and western PRC to be flood-and drought-risk hotspots, and thus, subject to high human vulnerability. Furthermore, an analysis that combines indicators measuring sensitivity to climate change and adaptive capacity (but not exposure) presents India and the PRC as vulnerable countries now and in 2095 (under two of three scenarios) (Moss, Brenkert, and Malone 2001). In the PRC, pasture degradation is another factor that increases the vulnerability of the agriculture sector to climate change (Box 2.4).

Central Asia

Central Asia is a subregion clearly in need of more climate change–related research. Socioeconomic indicators vary substantially among the countries. People living on less than $1.25 a day account for almost 40% of the population of Uzbekistan but only 0.03% of the population of Azerbaijan (Bauer

Box 2.4: Pasture Degradation in the People’s Republic of China and Mongolia

Grazing areas occupy about 26% of the ice-free terrestrial surface of the planet. The total area occupied by feed-crop production is equivalent to 33% of total arable land. Livestock production accounts for 70% of total agricultural land and 30% of the land surface of the planet (Steinfeld et al. 2006). Pasture degradation, caused by a mismatch between livestock density and the capacity of the pasture to be grazed and trampled, is common in the semi-arid and arid areas of both Africa and Asia. Degradation can cause soil erosion, loss of vegetation, carbon release from organic matter decomposition, loss of biodiversity, and impaired water cycles (Steinfeld et al. 2006). Grassland degradation caused by overgrazing can exacerbate the vulnerability of livestock systems to climate change. Studies have shown that grassland productivity is highly sensitive to precipitation changes (Chullun, Tieszen, and Ojima 1999; Christensen et al. 2004). In Mongolia, for instance, 90% of rangeland area, which constitutes more than 80% of total area, is under threat of desertification, and degraded land has increased by 8%–10% over the past decade (Ji 2008).

In Inner Mongolia, the People’s Republic of China, rangelands (representing about 67% of total area) have been steadily deteriorating at an annual rate of approximately 2% a year as a result of a combination of factors such as overgrazing (high livestock density) and climatic stress, and 55%–60% of total area experiences desertification processes. Rangeland productivity has declined in the past 5 decades in meadow steppe (54%–70%), typical steppe (30%–40%), and desert steppe grassland areas (50%) (Angerer et al. 2008). Simulations in the region show that a combination of increased precipitation, temperature, and CO_2 fertilization would have synergistic effects on the typical steppe grassland production of the region (Christensen et al. 2004). Herbaceous above-ground net primary production ($ANPP_h$), however, was found to be most sensitive to changes in precipitation levels. Large decreases in precipitation caused a decline in $ANPP_h$ through a decline in soil water, which in turn decreased plant growth rates. Experiments simulating a decline in livestock density showed that declines in $ANPP_h$ can be reduced or even reversed (Christensen et al. 2004).

et al. 2008). The population of the subregion is highly dependent on agriculture for survival, with the sector employing more than 30% of the total labor force in all countries. Georgia's agriculture sector employs 54% of the total workforce (World Bank 2008a).

Land and water degradation already contribute to crop yield declines in the subregion, which might be further exacerbated under climate change (Box 2.5). Moreover, Central Asian countries are heavy consumers of water for irrigation. In Uzbekistan, for instance, agriculture consumes

Box 2.5: Climate Change and Land Degradation in Asia

Around 54 million square kilometers or 40% of global land area is occupied by dry lands, of which the largest share (34%) is in Asia. Of the land in Asia, 25% is vulnerable to land degradation (WMO 2005). Agroecological zone assessments indicate that 28% of the soils in Asia suffer from severe fertility constraints, and 11% are affected by limitations resulting from salinity, sodicity (excess sodium in the soil), or gypsum constraints. Around 90% of very suitable and suitable rainfed land is currently cultivated, which leaves little room for expansion of agricultural area. The projected population increase in Asia—an additional 1.7 billion people by 2050—will reduce per capita availability of cultivated land to less than 0.1 hectare (ha) per person (Fischer et al. 2001), increasing pressures on land that might contribute to land degradation.

Climate change is likely to increase the vulnerability of poor farmers who already struggle with land degradation. Poor farmers do not have the same access to alternative sources of income—such as borrowing and repaying in better years—as do rich farmers. They also lack the resources for sustainable land management to maintain yields. As a result, unsustainable practices lead to further degradation (FAO 1994).

A doubling of carbon dioxide (CO_2) in the atmosphere might lead to a 17% increase in the world's area of desert land (WMO 2005). Soil erosion can result not only from lack of rainfall, but also from too much rainfall because surface runoff caused by extreme rainfall events carries soil particles away and transports agricultural chemicals, contaminating groundwater. Soil erosion will likely increase the number of landslides in the hilly areas of East and Southeast Asia. Wind erosion is another cause of land degradation. In the People's Republic of China (PRC), wind erosion buries 210,000 ha of productive land annually, a situation that is likely to worsen given that the frequency of strong sandstorms in the PRC has increased from 5–8 annually (in the 1950s and 1960s) to 14–20 (in the 1980s and 1990s) (WMO 2005).

In many countries, land-cover changes come at the cost of increased degradation of ecosystems. In most delta areas of Bangladesh, the PRC, India, and Pakistan, increased aridity has already resulted in the drying of wetlands and ecosystem degradation (Bates et al. 2008). In countries such as Indonesia, which has the world's third-largest area of tropical forest (15% of the world's forest area), land expansion would come at a substantial environmental cost. In fact, 50% of forest area in Indonesia is already degraded, and some parts are in critical condition (Sari et al. 2007). In Asia as a whole, there are 25 million ha of land in forest ecosystems with rainfed cultivation potential for wheat, rice, or maize (6.5% of total forest land area with cultivation potential). The consequences of forest clearing would be serious, however, from loss of biodiversity to the disruption of carbon sinks, hydrological cycles, and fragile ecosystems (Fischer et al. 2001).

Note: This box does not include the Pacific Island countries due to lack of available data.

more than 90% of the water used in the country (FAO 2007). Countries of the subregion have been consuming water at an unsustainable rate for decades, and since independence in 1991, water use has intensified even more (Allouche 2004). Furthermore, more than half of all irrigated areas in the subregion are salinized, waterlogged, or both. About two-thirds of land area in Kazakhstan is affected by desertification. The area is even higher in Turkmenistan and Uzbekistan, at 80%. In the Kyrgyz Republic and Tajikistan, 88% and 97% of agricultural land, respectively, is affected by erosion (Ji 2008). Thus, land degradation, desertification, and droughts in Central Asia are common in all countries, directly affecting the subregion's people, who mostly live in rural areas.

Pacific Island Countries

Indicators for exposure, sensitivity, and adaptive capacity to climate change for the Pacific Islands have not been studied in detail; for instance, there is a lack of reliable poverty data. Work by the Asian Development Bank and the United Nations Environment Programme (UNEP), however, shows that poverty is increasing in those countries (Yari 2003). Small islands in the Pacific are particularly vulnerable to rising sea levels because of their proximity to the El Niño Southern Oscillation. Fifty-years or longer time-series data for sea-level rise from four stations in the Pacific reveal that the average rate of sea-level rise in this subregion is 0.16 centimeters (cm) a year. Twenty-two stations with more than 25 years worth of data indicate an average rate of relative sea-level rise of 0.07 cm a year (Bindoff et al. 2007).[8] A study by the World Bank suggests that under a best-guess scenario, 18% of Buariki, an island in Kiribati, could be inundated by 2050, and 30% by 2100. If storm surges are included in the scenarios, up to 80% of Buariki could be inundated by 2050 (World Bank 2000).

Several current vulnerabilities of the island states are likely to make the impacts of climate change—particularly extreme weather events and rising sea levels—more intense, threatening food security in these countries. In Vanuatu, for instance, small farms are scattered across the islands, which make it extremely difficult to provide services to farmers. During natural disasters, access to farms becomes even more difficult, which affects agricultural production and trade, and consequently the country's food security (FAO 2008a). In the Marshall Islands, a high population growth rate puts considerable pressure on water and land resources, which increases food insecurity caused by climate change (FAO 2008a). In Timor-Leste, increases in extreme weather events will affect a population that is highly food-insecure and dependent on subsistence agriculture (Reske-Nielsen 2008).

In many Pacific Island countries, farmers are increasingly growing nontraditional crops that can grow in poor soils and require low labor inputs (World Bank 2000). These crops, however, are less resilient to the tropical cyclones that occur regularly in this subregion. The combination of more intense cyclones and the trend toward cultivation of nontraditional crops will result in greater food crop losses than would occur if traditional root crops were maintained (World Bank 2000). A recent assessment carried out in four Pacific countries (Fiji Islands, Papua New Guinea, Tonga, and Vanuatu) showed that food security systems in rural areas are mainly based on natural resources,

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[8] The authors of the study mention that data sets contain a large range of rates of relative sea-level changes, presumably as a result of poorly quantified vertical land motions.

whereas urban areas are more dependent on imported food (FAO 2008a). In these countries, the poorest and most vulnerable segments of the population, such as those dependent on subsistence fisheries and crops, are likely to be the most affected by climate change (World Bank 2000).

Vulnerability Indicator for Asia and the Pacific

A simple but consistent vulnerability indicator can be constructed by combining elements of exposure to climate change, sensitivity to climate change, and adaptive capacity. Results are presented in Table 2.2 and Figure 2.3. Exposure was reflected as the delta change in temperature and annual precipitation in 2050, as compared with current levels (average of 1950–2000, Table 1.2). Countries were classified as highly exposed if the temperature is expected to increase by at least 2°C or if annual precipitation levels are projected to change by at least 20%, using results from the HadCM3 A2a scenario (Table 1.2). Data were not available for several Pacific Island countries. As mentioned in Chapter III, how those changes will affect agriculture and livestock production in the countries of Asia and the Pacific will depend on several factors, such as crop type, CO_2 fertilization, and multiple stressors.

The second element of vulnerability—sensitivity—may be assessed through several variables. For instance, in the region, many countries are sensitive to climate change and extreme weather events because of high water stress, high land degradation rates, and the high dependency of their economies on agriculture. Other countries have low-lying coastal areas that are more sensitive to the impacts of rising sea levels and storm surges (Preston et al. 2006). Therefore, many indicators can be used to assess the sensitivity of countries' agriculture to climate change, such as rural population density, irrigated land, and agricultural employment. In this case, sensitivity was represented by the share of labor employed in agriculture (FAO 2004). Countries with agricultural employment above 40% were considered highly sensitive. Bhutan, Nepal, and Timor-Leste have the highest rates of agricultural employment in Asia and the Pacific as a share of total employment (all above 80%). On the other hand, the Republic of Korea and Singapore have less than 10% of the labor force working in agriculture. Several indicators can be used to measure adaptive capacity, such as poverty rates, access to credit, literacy rates, farm income, and agricultural GDP. In this case, the level of poverty was used to represent adaptive capacity in Asia and the Pacific (poverty data from Bauer et al. 2008). A poverty level of more than 30% was considered to indicate low adaptive capacity. Tables A1.2 and A1.3 present the indicator component data for sensitivity and adaptive capacity, respectively.

The indicator in Table 2.2 presents three classes: high vulnerability with poor outcomes in all three indicator components as defined above, significant vulnerability with poor outcomes in two of the components, and vulnerability with at least one of the indicator components in the critical range. While the indicator includes a combination of current and future values, this is appropriate because current climate change impacts are insufficient to describe exposure to climate change, whereas future adaptive capacity and sensitivity cannot be projected and are less important than current levels of these indicators to describe vulnerability to climate change.

A combination of these three indicator components identifies Afghanistan, Bangladesh, Cambodia, India, Lao PDR, Myanmar, and Nepal as most vulnerable to climate change—with poor

Table 2.2. Countries Identified as Vulnerable to Climate Change in Asia and the Pacific

High Exposure[a]	Low Adaptive Capacity[b]	High Sensitivity[c]
Afghanistan	Afghanistan	Afghanistan
Armenia	Bangladesh	Bangladesh
Azerbaijan	Cambodia	Bhutan
Bangladesh	India	Cambodia
Bhutan	Lao PDR	China, People's Republic of
Cambodia	Myanmar	India
China, People's Republic of	Nepal	Indonesia
Georgia	Timor-Leste	Lao PDR
India	Uzbekistan	Myanmar
Indonesia		Nepal
Kazakhstan		Pakistan
Korea, Republic of		Papua New Guinea
Kyrgyz Republic		Sri Lanka
Lao PDR		Thailand
Mongolia		Timor-Leste
Myanmar		Viet Nam
Nepal		
Pakistan		
Papua New Guinea		
Philippines		
Sri Lanka		
Tajikistan		
Thailand		
Turkmenistan		
Uzbekistan		
Viet Nam		

Lao PDR = Lao People's Democratic Republic.

Note: Poor outcomes in all three areas (shaded in dark grey) indicate high vulnerability, and poor outcomes in two areas (shaded in light gray) indicate significant vulnerability. Only countries with data for all three indicator components were included. Data was not available for many of the Pacific Island countries.

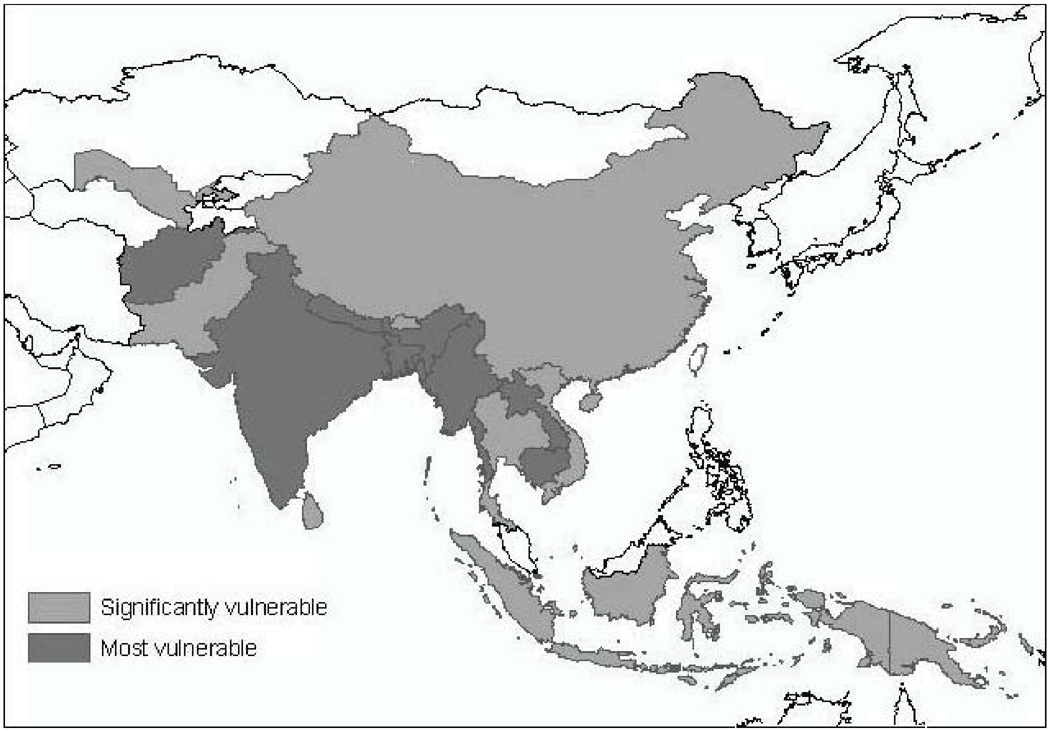
[a] Please refer to Table 1.2 (Exposure was reflected as the delta change in both temperature and annual precipitation in 2050 compared with current climate [1950–2000]. Countries were classified as being highly exposed if the temperature increases by at least 2°C or if annual precipitation levels increase or decrease by at least 20%.)

[b] Details shown in Table A1.3. (Adaptive capacity was represented by poverty level. A poverty level of more than 30% is considered to be low adaptive capacity.)

[c] Details shown in Table A1.2. (Sensitivity was represented by share of labor employed in agriculture [FAO 2004]; countries with agricultural employment above 40% are considered to be highly sensitive.)

Source: Authors. The climate scenarios are derived from Hijmans et al. (2005) for the HadCM3 A2a scenario.

Figure 2.3: Countries Vulnerable to Climate Change



Source: Based on Table 2.2.

outcomes in all three vulnerability components—revealing South and Southeast Asia as the subregions most vulnerable to climate change. Although some of the adaptation (and mitigation) responses will be similar for all four South Asian countries, significant differences in responses will likely be needed in Afghanistan compared, for example, with Bangladesh. Details on adaptation options are presented in Chapter IV. Countries with significant vulnerability—poor outcomes in two of three components—include Bhutan, Indonesia, Pakistan, Papua New Guinea, the PRC, Sri Lanka, Thailand, Timor-Leste, Uzbekistan, and Viet Nam, which are scattered throughout Asia and the Pacific. The vulnerability indicator does not include the role of climate extremes, and also neglects rising sea levels and glacier melt—two climate change–related events of particular relevance to the region. Countries highly vulnerable to natural disasters—Bangladesh, India, and Viet Nam, as well as some of the island states—made the climate change vulnerability list without specific inclusion of rising sea levels or melting glaciers. However, the general lack of data on the Pacific Islands may lead policy makers to overlook their relative vulnerability levels.

Summary

Vulnerability to climate change depends not only on exposure to climate events, but also on physical, environmental, socioeconomic, and political factors that influence how sensitive countries will be to a changing climate and how they will be able to cope.

Studies show that several countries in Asia and the Pacific have high levels of exposure and sensitivity to climate change exacerbated by low adaptive capacity. South and Southeast Asia are among the most vulnerable to the impacts of extreme weather events. Countries in South Asia, Southeast Asia and the Pacific Islands, as well as the coastal areas, and areas along the river deltas of the PRC, are highly vulnerable to rising sea levels, which will increase the risk of floods. Climate change will likely increase runoff in parts of South and East Asia, whereas runoff in Central Asia is expected to decline. In the Mekong Delta, in particular, increased variation in flows is likely to increase the risks of floods and droughts.

Glaciers in the Himalayas and Central Asia are already melting as a result of global warming. This development has potential short-term benefits as well as risks, but will likely have long-term adverse impacts on food production and ecosystem health in the dry season. Climate change is also likely to increase the vulnerability of poor farmers who are already struggling with land degradation. In areas highly dependent on livestock production, such as Mongolia and Inner Mongolia, the PRC, overgrazing increases vulnerability to climate change.

The countries most vulnerable to climate change are Afghanistan, Bangladesh, Cambodia, India, Lao PDR, Myanmar, and Nepal. Countries with significant vulnerability include Bhutan, Indonesia, Pakistan, Papua New Guinea, the PRC, Sri Lanka, Thailand, Timor-Leste, Uzbekistan, and Viet Nam. Data for most Pacific Islands are insufficient to construct the same vulnerability indicator. As in Africa, those countries least to blame for climate change are likely to suffer most from its adverse impacts as a result of their location and low adaptive capacities. As shown by the improved resiliency of Bangladesh to withstand tropical cyclones in 1997 as compared with 1991, however, adaptation is possible even for the most destitute and vulnerable countries.

Each of the three components defining vulnerability to climate change—exposure, sensitivity, and adaptive capacity—requires several strategies to reduce the vulnerability of agriculture and rural communities in Asia and the Pacific. Mitigation and adaptation measures are essential in reducing the extent of global warming, reducing countries' sensitivity, and improving the capacity of countries to adapt to a changing climate.

Vulnerability assessments are important to ensure that scarce public and private resources are allocated to those most in need of adapting to climate change. Although various vulnerability assessments generally come to similar conclusions, differences in results do exist because of the use of different data, different factors representing vulnerability, and differing methodologies. Care must therefore be taken when drawing further conclusions or basing investment decisions on such assessments.

CHAPTER III

Impacts of Climate Change on Agriculture and Food Security

Introduction

This chapter provides estimates of the impacts of climate change on agricultural production, prices, and trade and the costs of adaptation to climate change in Asian agriculture. We focus on three types of investment—agricultural research, rural roads, and irrigation infrastructure—as well as efficiency improvement. We also consider supplemental investments in education and health. We use the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) partial equilibrium model of world agriculture with 32 commodities and 281 regions around the world, linked to biophysical crop models. Two indicators provide the basis for the assessment of the impact of climate change on food security—per capita calorie consumption as a purely agriculture-based measure and child malnutrition count, which incorporates calorie consumption and adds clean water and maternal education. We estimate the cost of investments in agricultural research, rural roads, and irrigation—three primary sources of increased agricultural productivity, that are needed to return the values of our two indicators from their 2050 values *with* climate change to their 2050 values *without* climate change. To provide some idea of the uncertainties inherent in the climate change simulation process, we provide selected results from three general circulation models (GCM) using the A2 Special Report on Emissions Scenarios (SRES)—the Hadley GCM reporting the A2a results for the Intergovernmental Panel on Climate Change (IPCC) third assessment report, and the A2 scenario from the fourth assessment report for the National Center for Atmospheric Research (NCAR) (NCAR-CCSM3) and Commonwealth Scientific and Industrial Research Organization (CSIRO) (CSIRO-Mk3.0) models.

The challenge of modeling climate change impacts arises from the wide-ranging nature of processes that underlie the working of markets, ecosystems, and human behavior. Our analytical framework integrates modeling components that range from the macro to the micro and from processes that are driven by economics to those that are essentially biological in nature.

Figure 3.1 presents an illustrative schematic of the framework of the IMPACT 2009 partial agriculture equilibrium model, and the contribution of biophysical and agronomic factors to global agricultural production, trade, and prices.

The modeling methodology used here reconciles the limited spatial resolution of macro-level economic models that operate through equilibrium-driven relationships at a national or even more aggregate regional level with detailed models of dynamic biophysical processes. The climate change modeling system combines a biophysical model (the Decision Support System for Agrotechnology Transfer [DSSAT] crop modeling suite, see following discussion) of responses of selected crops to climate, soil, and nutrients with the IFPRI Spatial Allocation Method or ISPAM data set of crop location and management techniques (You and Wood 2006). These results are then aggregated and input into the International Food Policy Research Institute's (IFPRI) global agricultural supply and demand projections model, IMPACT. A brief description and summary of results from other models used in climate change analysis are presented in Appendix 4. In the following paragraph, an overview of our modeling methodology is presented. Additional details on IFPRI's climate change modeling framework can be found in Appendix 5.

Components of the Modeling Framework

Crop Modeling

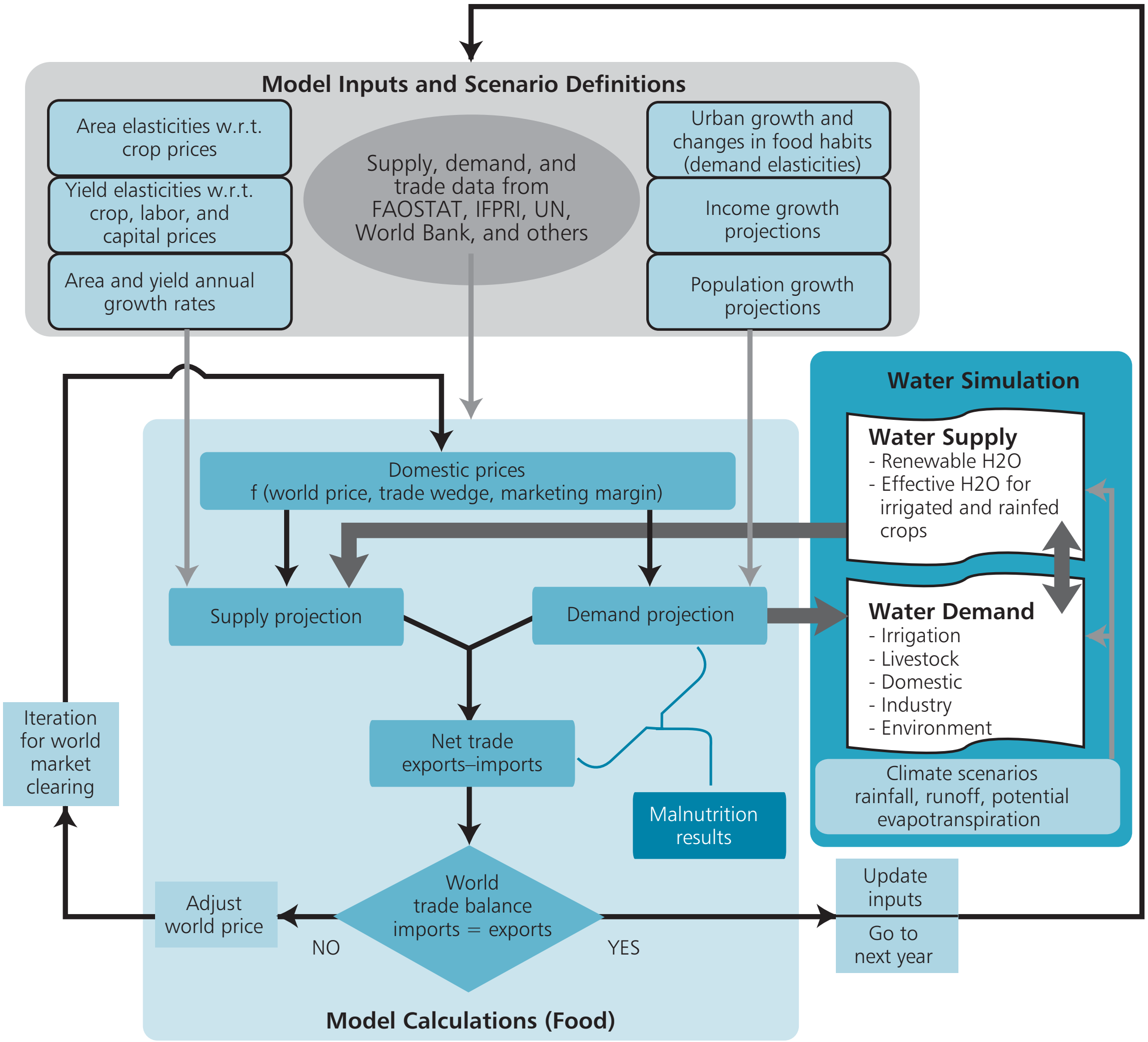
The DSSAT crop simulation model, an extremely detailed process model of the daily development of a crop from planting to harvest-ready, is used as the underlying crop model for the analysis. The model requires daily weather data, including maximum and minimum temperature, solar radiation, and precipitation; a description of the soil physical and chemical characteristics of the field; and crop management, including crop, variety, planting date, plant spacing, and inputs such as fertilizer and irrigation. Crops directly modeled with DSSAT are mapped to all other IMPACT crops based on similarity in photosynthetic metabolic pathways.

Climate Data

DSSAT requires detailed daily climate data, not all of which are readily available, so various approximation techniques were developed. To simulate today's climate, we use the Worldclim current conditions data set (www.worldclim.org), which is representative of 1950–2000 and reports monthly average minimum and maximum temperatures and monthly average precipitation. Site-specific daily weather data are generated stochastically using the SIMMETEO software.

For future climate, we use three GCMs—the AR3 Hadley GCM run with the A2a forcing scenario available from http://www.worldclim.org/futdown.htm, and fourth assessment report A2 runs using

Figure 3.1: The IMPACT 2009 Modeling Framework



FAOSTAT = Food and Agriculture Organization of the United Nations Statistical Databases, IFPRI = International Food Policy Research Institute, IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade, UN = United Nations, w.r.t. = with respect to.

the CSIRO and NCAR models.[9] At one time, the A2 scenario was considered an extreme scenario although recent findings suggest it may not be. We assume that all climate variables change linearly between their values in 2000 and 2050. This assumption eliminates any random extreme events such as droughts or high rainfall periods and also assumes that the forcing effects of greenhouse gas (GHG) emissions proceed linearly; that is, we do not see a gradual speed up in climate change. The effect of this assumption is to underestimate negative effects from extreme weather conditions.

Other Agronomic Inputs

Treatment of six other important agronomic inputs—soil characteristics, crop variety, cropping calendar, CO_2 fertilization effects, irrigation, and nutrient levels—is presented in Appendix 5.

Linking Crop Model Results to IMPACT

The DSSAT crop model is computationally intense. To allow multiple simulations of climate effects for the entire surface of the globe, we developed a reduced form implementation. We ran the crop model for each crop and variety with a wide range of climate and agronomic inputs and then estimated a feed-forward neural net for each of the 27 soil categories. We thus obtained a continuous and differentiable approximation of the crop model results that allows us to find the maximum possible yield and corresponding nitrogen input needed based on location-specific geophysical characteristics and climate. The results of this estimation process were fed into the IMPACT model (Details on IMPACT can be found in Appendix 5).

Modeling Results

The results of our analysis are reported in three sections—the biological effects of climate change on crop yields; the resulting impacts on prices, production, consumption, trade, calorie availability and child malnutrition; and finally the costs of adaptation to climate change to reduce child malnutrition numbers in 2050 *with* climate change to the levels *without* climate change.

Effects of Climate Change on Yields

Climate change alters temperature and precipitation patterns. These have both a direct effect on crop production and indirect effects through changes in irrigation water availability and evapotranspiration potential. In this section, we report on the direct effects on rainfed yields of changing temperature and precipitation, irrigation yields through temperature effects alone, and the indirect effects of water availability through irrigation-related changes in water availability.

Direct climate change effects on yields

Figure 3.2 presents figures of the direct biological effects of the three climate change scenarios on yields (see discussions under Climate Data), with and without CO_2 fertilization on the five crops, which we model with DSSAT. The rainfed system is modeled with both water and temperature stress

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[9] NCAR and CSIRO AR4 data, downscaled by Kenneth Strzepek and colleagues at the Massachusetts Institute of Technology's (MIT) Center for Global Change Science. We acknowledge the international modeling groups for providing their data for analysis—the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for collecting and archiving the model data, the JSC/CLIVAR Working Group on Coupled Modeling (WGCM) and their Coupled Model Intercomparison Project (CMIP) and Climate Simulation Panel for organizing the model data analysis activity, and the IPCC WG1 TSU for technical support. The IPCC Data Archive at Lawrence Livermore National Laboratory is supported by the Office of Science, United States Department of Energy.

Figure 3.2: Yield Changes between 2000 and 2050 by Crop and Management System for Three GCMs With and Without CO_2 Fertilization Effects (% change)

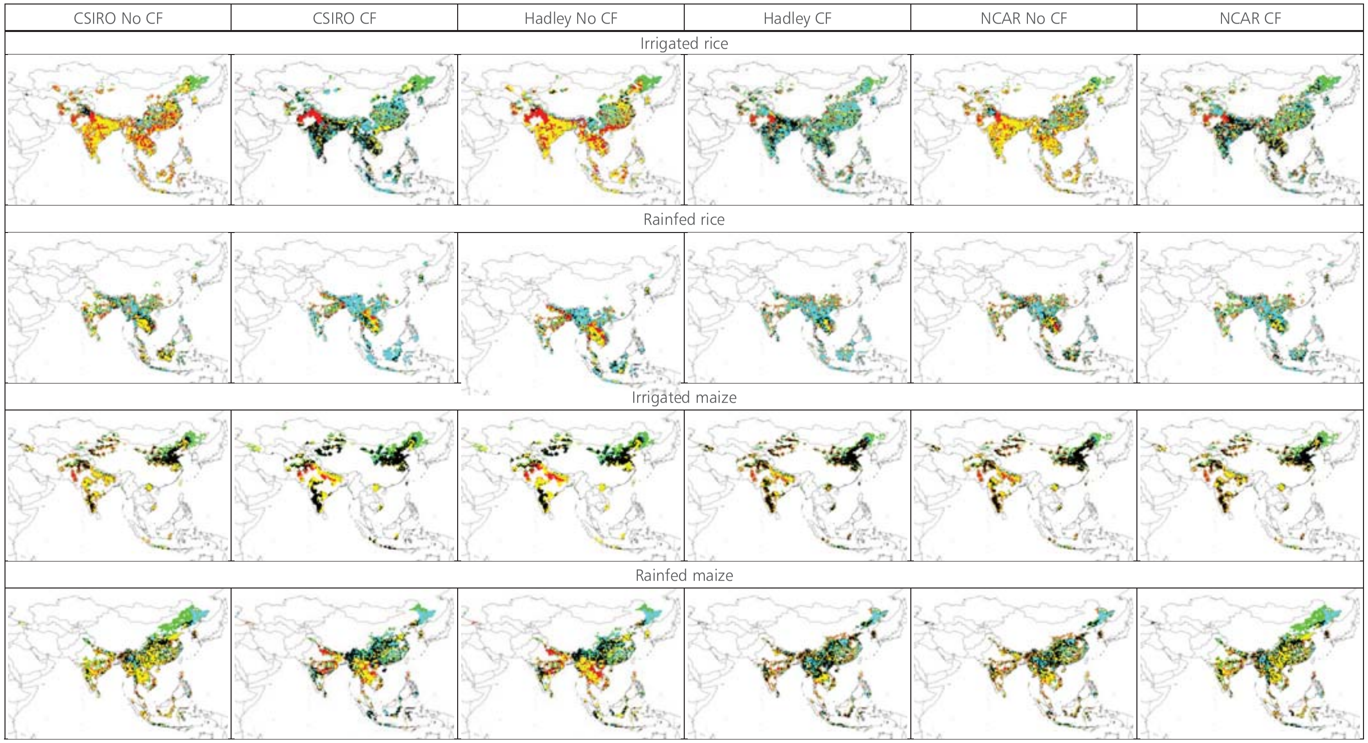

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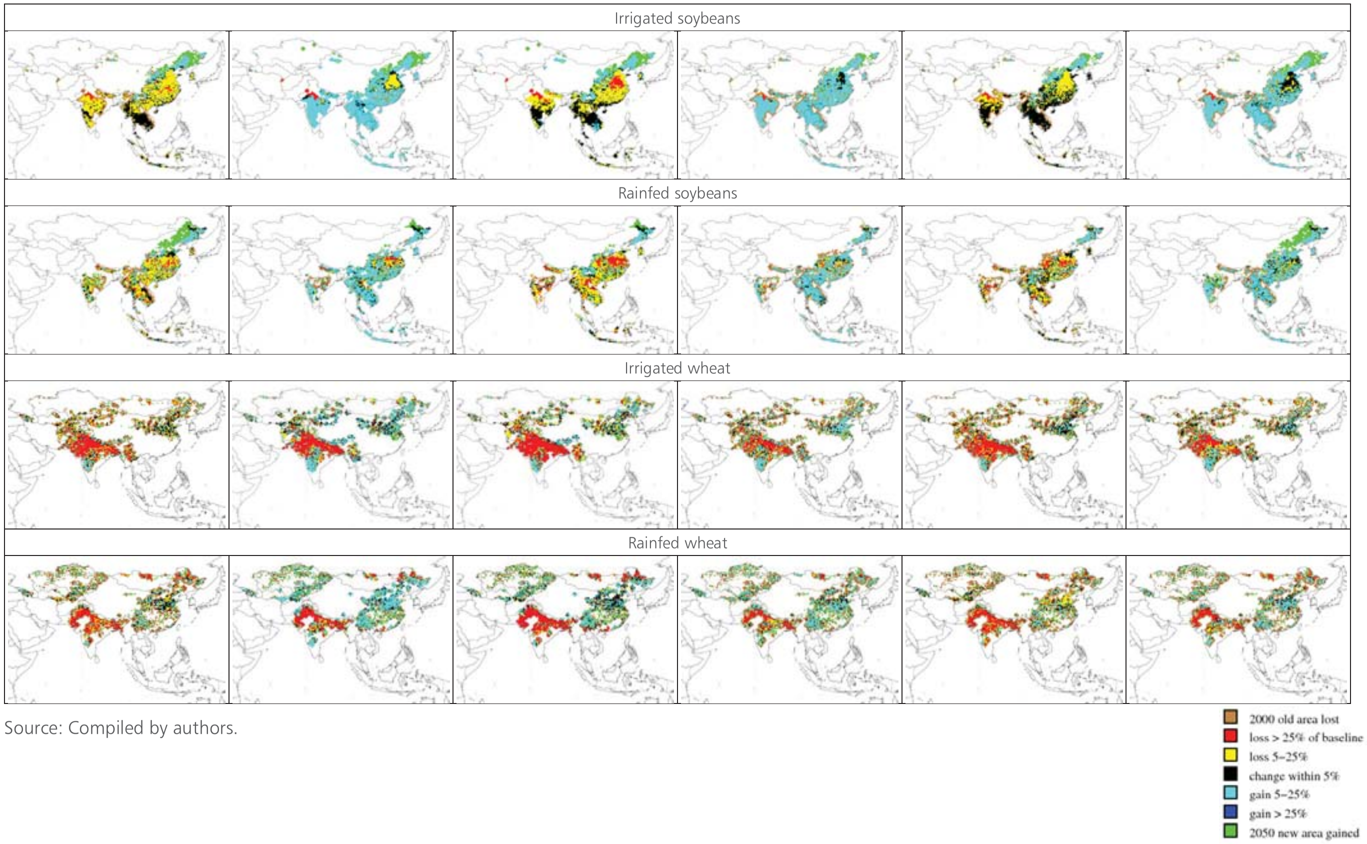
Figure 3.2 continued



Source: Compiled by authors.

effects. For irrigated crops, temperature stress is incorporated from crop models and water stress from the IMPACT global hydrologic model that accounts for rainfall, evapotranspiration and runoff in river basins and takes into account the supply and demand for water for irrigation, livestock, industry, and domestic use. Yellow and red areas are where yields decline. Light and dark blue areas are where yields will increase. For most crops, yield declines predominate when no CO_2 fertilization is allowed. Both irrigated and rainfed wheat are especially hard hit but irrigated rice, irrigated and rainfed maize, and irrigated and rainfed soybeans also see significant yield declines. By 2050, for irrigated paddy, the expected reduction is in the range of 14%–20%; for irrigated wheat, 32%–44%; irrigated maize, 2%–5%; and irrigated soybean, 9%–18%. Spreads across crops and GCM are somewhat wider for rainfed crops, with positive yield effects under some GCM, especially in more temperate areas. The interior reaches of the PRC fare reasonably well for all crops, because higher future temperatures are favorable in locations where current temperatures are relatively low. India and other parts of South Asia are particularly hard hit by climate change. With the CO_2 fertilization effect allowed, the yield declines are lower and in many locations some yield increases occur relative to 2000. However, recent research experiments indicate that carbon fertilization effects have been overestimated, and models have yet to be adjusted to account for recent insights. Nevertheless, rainfed maize and irrigated and rainfed wheat still see substantial areas of reduced yields.

Indirect effects from climate change: Water stress for irrigated crops

Climate change will have a direct impact on regional hydrology and, therefore, affect agricultural production through its impact on water availability for crops. In addition, higher temperatures under climatic change will, for the most part, increase evapotranspiration, requirements of crops. The impacts of climate change on effective rainfall, potential and actual evapotranspiration, and runoff (or internal renewable water) were analyzed for the three climate change scenarios using the global hydrological module linked with IMPACT.

Internal renewable water (IRW) is the water resource (surface runoff plus net groundwater recharge) generated from precipitation falling on a study area such as a river basin or a country. Table 3.1 and Figure 3.3 show average annual IRW under current climate, and the percentage changes in annual IRW with the three GCMs using the Special Report on Emissions Scenarios (SRES) A2a and A2 scenarios. In general, Central Asia is the only subregion in Asia and the Pacific that is projected to have reduced IRW in 2050 under all the three scenarios, which is congruent with the consensus on declining precipitation levels in this subregion. The remaining subregions are projected to have increased IRW in 2050. Overall, the NCAR GCM model has the wettest climatic future while CSIRO has the driest, among the three climate change scenarios.

Table 3.2 summarizes estimated irrigation water requirements in 2000 and 2050 under current climate, and the percentage changes of irrigation water requirements in 2050 under the three climate change scenarios in comparison with the 2050 requirements under current climate. Changes in irrigation water requirements over 2000–2050 reflect the increased demand for food, changes in irrigated areas,[10] and changes in irrigation water use efficiency. Changes of 2050 irrigation water

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[10] Irrigated areas in this study tend to be slightly underestimated so the calculated irrigation water requirements and consumption values could be slightly lower than they should be.

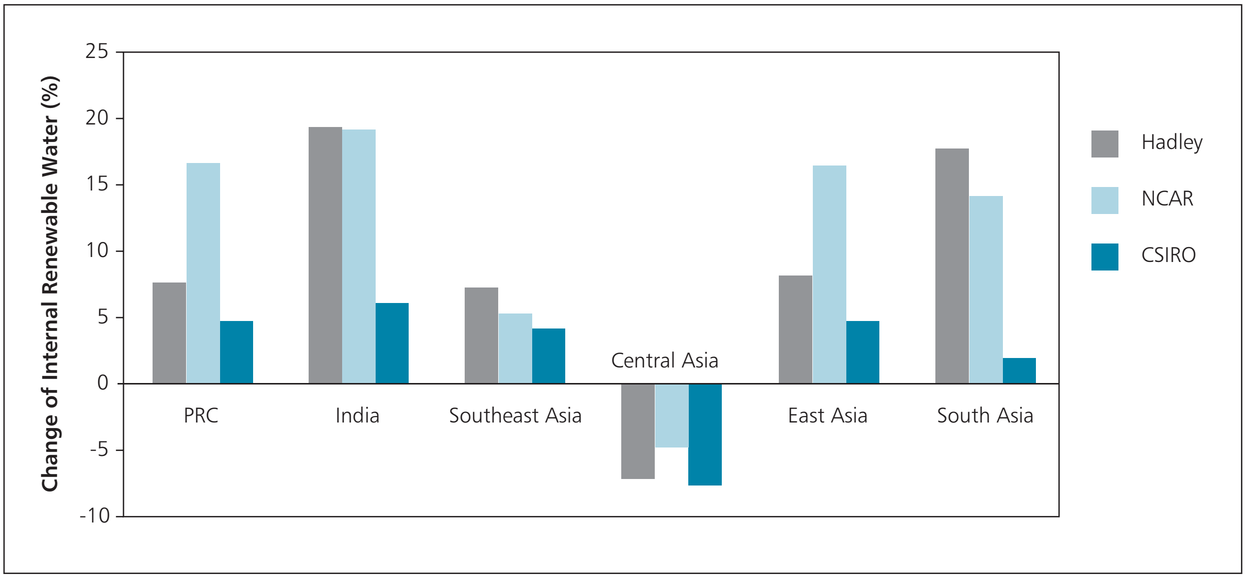
Table 3.1: Internal Renewable Water in 2000 and 2050

Subregion and Country	2000 No Climate Change (km³/yr)	2050: Difference between No and With Climate Change Hadley (%)	NCAR (%)	CSIRO (%)
East Asia	2,907	8.1	16.3	4.7
PRC	2,812	7.6	16.4	4.6
South Asia	1,788	17.6	14.0	2.0
India	1,261	19.2	18.9	6.0
Southeast Asia	5,537	7.3	5.3	4.3
Central Asia	255	(7.1)	(4.8)	(7.6)

( ) = negative number, km^3/yr = cubic kilometer per year, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Source: Compiled by authors.

Figure 3.3: Changes of Internal Renewable Water from 2000 to 2050



CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China

Source: Compiled by authors.

Table 3.2: Irrigation Water Requirements in 2000 and 2050

	No Climate Change			2050: Difference between No and With Climate Change		
Subregion and Country	**2000 (km^3/yr)**	**2050 (km^3/yr)**	**Change from 2000 to 2050 (%)**	**Hadley (%)**	**NCAR (%)**	**CSIRO (%)**
East Asia	294.6	232.3	(21.1)	2.1	(16.0)	10.9
PRC	293.7	231.8	(21.1)	2.1	(16.0)	10.9
South Asia	489.1	515.3	5.4	(0.1)	(13.2)	0.3
India	296.1	336.6	13.7	0.8	(13.8)	2.2
Southeast Asia	50.6	44.9	(11.2)	9.7	0.8	(0.8)
Central Asia	39.0	35.1	(10.1)	13.2	2.0	(0.7)

( ) = negative number, km^3/yr = cubic kilometer per year, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Note: Irrigated areas tend to be slightly underestimated so the calculated irrigation water requirements and consumption values could be slightly lower than they should be.

Source: Compiled by authors.

requirements under climate change scenarios are caused by two different factors—changes in effective rainfall and changes in crop evapotranspiration potential caused by higher temperatures.

As Table 3.2 shows, 2050 irrigation water requirements under NCAR are generally below those of a no climate change scenario, due mainly to larger precipitation volumes under the NCAR scenario. Higher precipitation reduces the portion of crop water requirement that must be met by irrigation. In many subregions, this outweighs increased crop evapotranspiration potential under higher temperatures in irrigated areas. Under the drier CSIRO scenario, on the other hand, irrigation water requirements increase as a result of lower precipitation and higher potential crop evapotranspiration.

Table 3.3 reports irrigation water consumption under current climate and the three climate change scenarios. Projected changes of irrigation consumption are determined by changes of both irrigation water requirements and water availability. Central Asia is projected to have significant declines in irrigation consumption under NCAR and CSIRO scenarios, owing to the decline of IRW, although its irrigation requirements are projected to change little under these two scenarios in 2050. Thus, water stress is expected to increase considerably in Central Asia under two out of three climate change scenarios.

Changes in irrigated area under climate change are shown in Figure 3.4. Compared to the scenario without climate change, irrigated harvested area is projected to increase by 2.2% under the Hadley scenario, but drop by 5% under the NCAR and CSIRO scenarios.

In addition to irrigation water, the water simulation module of the IMPACT model tracks residential, industrial, and livestock water use. Table 3.4 provides total water consumption in 2000 and 2050 under current climate, and percentage changes of total consumption under the three scenarios in comparison to a no climate change

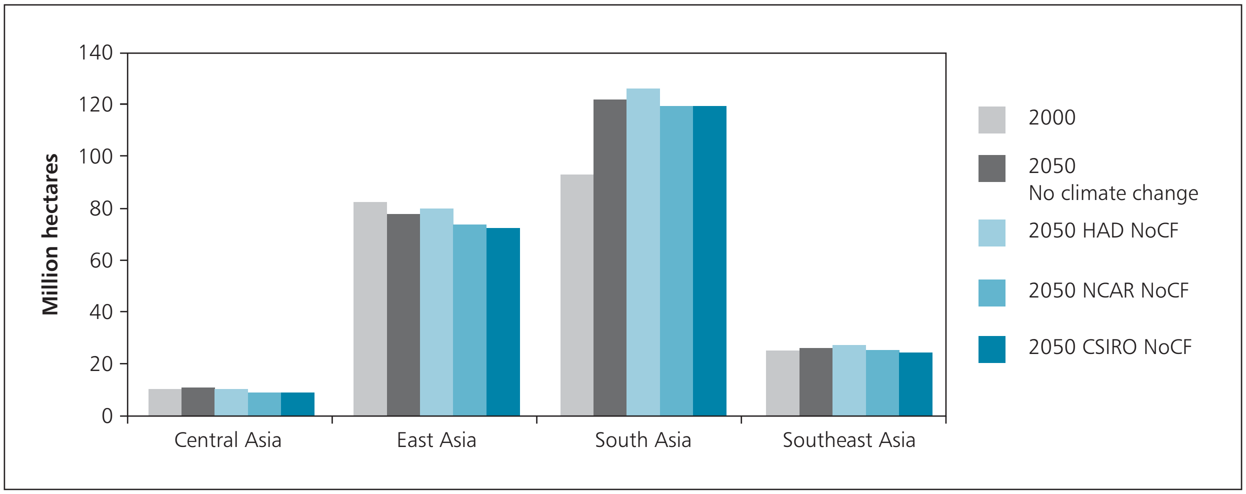
Table 3.3: Irrigation Water Consumption in 2000 and 2050

	No Climate Change			2050: Difference between No and With Climate Change		
Subregion and Country	**2000 (km^3/yr)**	**2050 (km^3/yr)**	**Change from 2000 to 2050 (%)**	**Hadley (%)**	**NCAR (%)**	**CSIRO (%)**
East Asia	188.8	176.5	(6.5)	5.7	(0.4)	(5.4)
PRC	187.9	176.0	(6.4)	5.7	(0.4)	(5.5)
South Asia	367.1	386.5	5.3	(0.6)	(10.8)	(0.9)
India	283.3	312.6	10.3	(2.4)	(10.5)	2.1
Southeast Asia	49.7	42.3	(14.9)	8.5	0.7	(2.4)
Central Asia	34.4	31.5	(8.6)	10.3	(7.5)	(11.9)

( ) = negative number, km^3/yr = cubic kilometer per year, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Source: Compiled by authors.

Figure 3.4: Irrigated Area in 2000 and 2050



Source: Authors.

Table 3.4: Total (Irrigation, Domestic, Industrial and Livestock) Water Consumption in 2000 and 2050

Subregion and Country	No Climate Change			2050: Difference between No and With Climate Change		
	2000 (km³/yr)	2050 (km³/yr)	Change from 2000 to 2050 (%)	Hadley (%)	NCAR (%)	CSIRO (%)
East Asia	285.2	255.7	(10.3)	3.6	(0.3)	(3.4)
PRC	281.9	252.4	(10.5)	3.6	(0.2)	(3.5)
South Asia	404.8	407.9	0.8	(0.3)	(8.3)	(0.6)
India	296.7	314.9	6.1	(1.8)	(8.1)	1.7
Southeast Asia	65.5	65.7	0.3	4.5	0.3	(1.3)
Central Asia	39.9	40.4	1.1	7.3	(5.3)	(8.5)

( ) = negative number, km³/yr = cubic kilometer per year, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Source: Compiled by authors.

Table 3.5: Irrigation Water Supply Reliability in 2000 and 2050 (%)

Subregion and Country	No Climate Change		2050: With Climate Change		
	2000	2050	Hadley	NCAR	CSIRO
East Asia	0.64	0.76	0.79	0.90	0.65
PRC	0.64	0.76	0.79	0.90	0.65
South Asia	0.75	0.75	0.75	0.77	0.74
India	0.96	0.93	0.90	0.96	0.93
Southeast Asia	0.98	0.94	0.93	0.94	0.93
Central Asia	0.88	0.90	0.87	0.81	0.79

( ) = negative number, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Source: Compiled by authors.

scenario in 2050. Irrigation water consumption accounts for the largest portion of total water consumption in Asia and the Pacific. However non-irrigation water use is projected to increase rapidly in the coming decades.

In general, total non-irrigation water consumption in the region is projected to double from 2000 to 2050. Growth is expected to be even more rapid in South Asia, outpacing non-irrigation water demand of East Asia.

Irrigation water supply reliability (IWSR) is defined as the ratio of irrigation water consumption to irrigation water requirement, reflecting the degree that irrigation water requirement is satisfied. Table 3.5 provides IWSR under current climate and the climate change scenarios. A lower IWSR indicates that there may be significant reduction in irrigated crop yields due to insufficient water supply. Note that the PRC improves its IWSR from 2000 to 2050 under current climate, owing to improved irrigation water use efficiency and a slight reduction in irrigated area. However, the IWSR of India is projected to decline slightly due to irrigation expansion, though the level of IWSR in India is higher than that of the PRC. In general, the NCAR GCM brings improved IWSR while the CSIRO GCM leads to IWSR decline, although regional differentiation of climate change effects are important.

Yield reductions of irrigated crops due to water stress are directly estimated in IMPACT using empirical relationships developed by the Food and Agriculture Organization of the United Nations (FAO) (Doorenbos and Kassam 1979) because irrigation water supply changes require the modeling of water availability within hydrologic units. Results are shown in Table 3.6. In Asia and

Table 3.6: IMPACT Model Results: Yield Reductions for Irrigated Crops Due to Water Stress in 2000 and 2050 (%)

	No Climate Change		2050: With Climate Change		
Crop, Subregion, and Country	2000	2050	Hadley	NCAR	CSIRO
Rice					
East Asia	(13.4)	(8.5)	(6.9)	(2.1)	(12.0)
PRC	(13.8)	(8.8)	(7.1)	(2.1)	(12.5)
South Asia	(9.1)	(8.9)	(9.5)	(6.3)	(8.1)
India	(3.2)	(4.0)	(6.0)	(2.2)	(4.0)
Southeast Asia	0.0	0.0	0.0	0.0	0.0
Central Asia	(5.1)	(3.5)	(4.7)	(6.8)	(7.2)
Wheat					
East Asia	(28.2)	(22.1)	(23.3)	(8.7)	(32.8)
PRC	(28.3)	(22.2)	(23.4)	(8.8)	(32.9)
South Asia	(17.9)	(14.4)	(12.3)	(13.9)	(14.8)
India	(0.9)	(1.7)	(1.9)	(1.5)	(1.5)
Southeast Asia	0.0	0.0	0.0	0.0	0.0
Central Asia	(1.0)	(1.0)	(1.0)	(0.6)	(0.9)
Maize					
East Asia	(18.1)	(11.0)	(8.2)	(3.7)	(23.7)

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Table 3.6 continued

Crop, Subregion, and Country	No Climate Change 2000	No Climate Change 2050	2050: With Climate Change Hadley	2050: With Climate Change NCAR	2050: With Climate Change CSIRO
PRC	(18.1)	(11.0)	(8.2)	(3.7)	(23.7)
South Asia	(30.1)	(20.0)	(17.2)	(17.4)	(21.1)
India	(0.4)	(0.6)	(0.4)	(0.1)	(0.2)
Southeast Asia	0.0	0.0	0.0	0.0	0.0
Central Asia	(1.2)	(0.7)	(0.9)	(1.6)	(1.8)

( ) = negative number, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Note: Southeast Asian countries are located primarily in humid or sub-humid climatic zones, implying better water supply if infrastructure is in place. The model has a limit of spatial resolution and cannot capture very localized drought effects, but reflects the effects of important water stress. The results show that irrigation systems in Southeast Asia can effectively mitigate drought events and overall, irrigated crops do not suffer much compared to other subregions.

Source: Compiled by authors.

the Pacific, the PRC is especially vulnerable to crop yield losses (in wheat, maize, and rice) due to water scarcity. In general, crop yield losses due to water stress are higher under the relatively drier CSIRO scenario as compared to the relatively wetter NCAR scenario. Losses are largest for wheat in East Asia under the CSIRO scenario.

Climate Change Impacts on Agriculture and Human Well-being

The direct and indirect effects of climate change on agriculture play out through the economic system, altering prices, production, productivity investments, food demand, food consumption, and ultimately human well-being.

Prices and production

World prices are the most useful single indicator of the effects of climate change on agriculture. Table 3.7 shows the price effects of various permutations of climate change, with and without the CO_2 fertilization effect. Figure 3.5 and Figure 3.6 show the world price effects for livestock production and major grains respectively, assuming no CO_2 fertilization effect.

Even with no climate change, world prices for the most important agricultural crops—rice, wheat, maize, and soybeans—will increase between 2000 and 2050. Climate change adds a significant price increase on top of higher prices under a no climate change scenario. Climate change adds 29% to 37% to the price of rice compared to the no climate change price in 2050. If CO_2 fertilization is effective in the field, these price increases are cut roughly in half. Soybean, wheat, and maize price increases under no climate change are relatively small (26%, 17%, and 5%, respectively) but climate change causes larger price increases (additional 14%–49% for soybeans, 81%–102% for wheat, and 58%–97% for maize). The greatest price increases across crops do not occur in the same scenario. For example, the highest 2050 rice price is with the NCAR scenario while the highest 2050 wheat price is with the CSIRO scenario.

Table 3.7: World Prices of Selected Crops and Livestock Products in 2000 and 2050

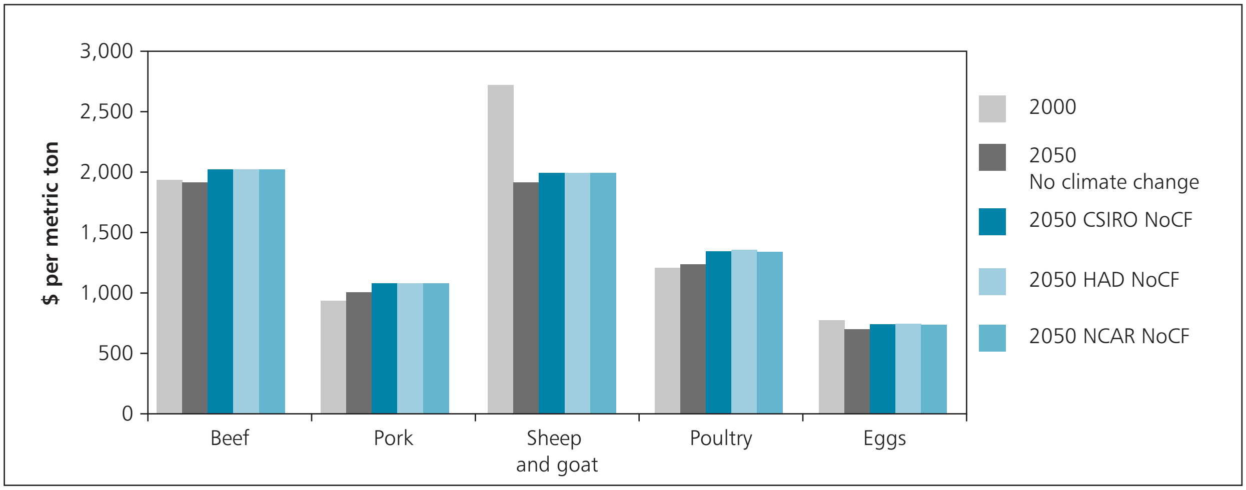
			2050: With Climate Change					
	No Climate Change		No CO$_2$ Fertilization ($/mt)			Difference between No and With CO$_2$ Fertilization (%)		
Product	**2000 ($/mt)**	**2500 ($/mt)**	**NCAR**	**Hadley**	**CSIRO**	**NCAR**	**Hadley**	**CSIRO**
Beef	1,926	1,907	2,017	2,026	2,024	(1.15)	(1.47)	(1.35)
Pork	911	1,009	1,070	1,084	1,074	(1.35)	(1.86)	(1.61)
Sheep and Goat	2,713	1,912	1,977	1,985	1,981	(0.71)	(0.93)	(0.85)
Poultry	1,203	1,228	1,334	1,356	1,342	(1.87)	(2.53)	(2.22)
Rice	190	305	419	392	414	(17.41)	(18.36)	(16.36)
Wheat	113	132	263	239	267	(10.39)	(10.67)	(11.37)
Maize	95	100	158	197	162	(11.41)	(16.64)	(13.50)
Soybeans	209	263	301	392	302	(65.85)	(75.05)	(64.33)

( ) = negative number, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research.

Note: Reference prices are in 2000 $. The last three columns in this table report the percentage difference between the price in 2050 with and without the CO$_2$ fertilization effect. For example, with the NCAR GCM, assuming CO$_2$ fertilization is effective in the field, results in a 17.41% decline in the world rice price. The change in prices of livestock products reflects only the reduced cost of feed.

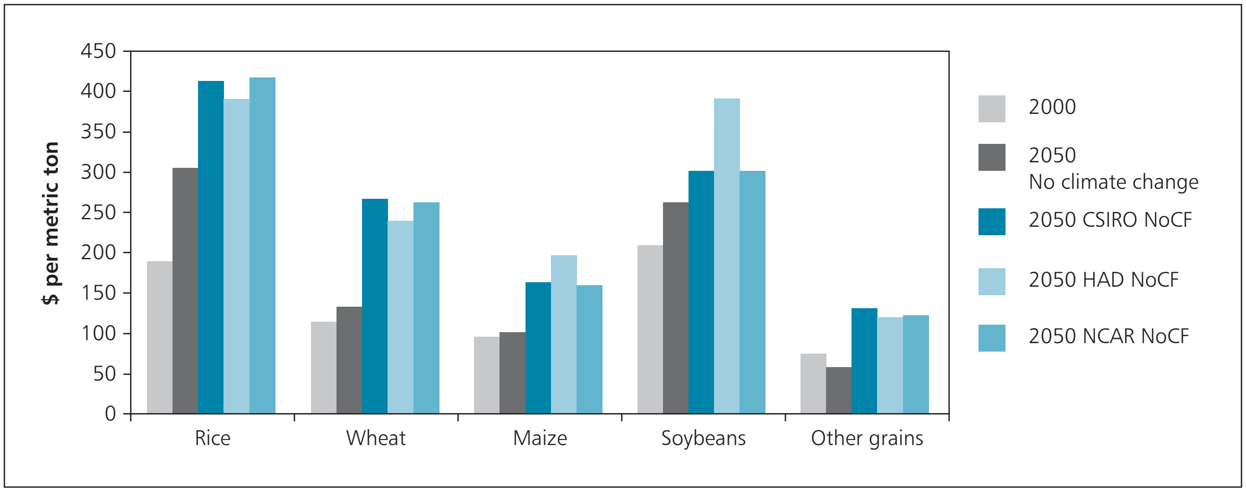
Source: Compiled by authors.

Figure 3.5: World Prices of Major Livestock Products in 2000 and 2050



Source: Authors.

Figure 3.6: World Prices of Major Grains in 2000 and 2050



Source: Authors.

Livestock are not directly affected by climate change in the IMPACT model but the effects of higher feed prices caused by climate change pass through to livestock, resulting in higher meat prices. For example, beef prices decline slightly by 2050 under the no climate change scenario but prices increase by 5% to 6% depending on GCM. With CO_2 fertilization, crop price increases are less so the beef price increase is 1% less than under no CO_2 fertilization.

Table 3.8 combines the biophysical effects of climate change on yields with the indirect effects from water stress on irrigated crops and autonomous adjustments to price effects on yields and on productivity growth.

Table 3.9 reports crop production effects of climate change, accounting for both the changes in yield shown in Table 3.8, and changes in crop area induced by climate change. For each crop, the first row is 2000 production and the second is 2050 production with no climate change. The third to fifth rows are the difference between the GCM production and no climate change production in 2050. For example Southeast Asian maize production would increase by almost 50% with no climate change (from 21.4 million metric tons [mt] to 32.1 million mt). Relative to no climate change the 2050 CSIRO climate results in a 6% decline in production while Hadley results in an 11% increase in production.

The negative effects of climate change are especially pronounced in South Asia; only other grains have production increases under the three GCMs. Central Asia experiences increases in production for all crops except wheat. For East Asia, the results are mixed, and depend on both crop and GCM. Rice is uniformly negative, while wheat is mixed and sorghum production is up under all scenarios. Southeast Asia has mixed results for maize and negative results for rice for all GCMs.

Table 3.8: Combined Biophysical and Economic Yield Effects from Climate Change, No CO_2 Fertilization

Product	Central Asia	PRC	East Asia	India	South Asia	Southeast Asia
Maize						
2000 (kg/ha)	2,860	4,798	4,798	1,869	1,896	2,568
2050 No CC (kg/ha)	5,555	7,824	7,824	2,384	2,002	4,081
CSIRO (%)	11	2	2	(1)	4	1
Hadley (%)	11	9	9	(5)	(1)	1
NCAR (%)	10	7	7	(4)	(1)	(2)
Millet						
2000 (kg/ha)	532	1,717	1,718	801	804	675
2050 No CC (kg/ha)	1,673	3,671	3,676	1,685	1,733	1,136
CSIRO (%)	3	12	11	0	(1)	2
Hadley (%)	3	7	7	(3)	(3)	3
NCAR (%)	2	6	6	(3)	(3)	2
Rice						
2000 (kg/ha)	1,502	4,128	4,117	2,070	2,049	2,316
2050 No CC (kg/ha)	3,982	4,967	4,934	3,151	3,005	3,171
CSIRO (%)	(2)	(6)	(6)	(10)	(7)	(8)
Hadley (%)	(1)	(14)	(14)	(20)	(18)	(10)
NCAR (%)	1	(8)	(8)	(11)	(8)	(10)
Sorghum						
2000 (kg/ha)	3,085	3,243	3,246	799	806	1,693
2050 No CC (kg/ha)	3,296	5,751	5,764	1,407	1,411	4,349
CSIRO (%)	3	11	11	0	0	4
Hadley (%)	4	7	7	(3)	(3)	3
NCAR (%)	3	6	6	(2)	(2)	3
Wheat						
2000 (kg/ha)	1,410	3,797	3,822	2,503	2,683	1,072
2050 No CC (kg/ha)	3,018	5,232	5,251	6,432	4,539	2,527
CSIRO (%)	12	(7)	(7)	(50)	(39)	(22)

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Table 3.8 continued

Product	Central Asia	PRC	East Asia	India	South Asia	Southeast Asia
Hadley (%)	15	4	4	(56)	(48)	(38)
NCAR (%)	9	8	8	(50)	(39)	(25)
Other Grains						
2000 (kg/ha)	1,260	2,496	2,432	1,721	1,927	676
2050 No CC (kg/ha)	2,069	4,778	4,726	3,399	3,610	1,590
CSIRO (%)	8	4	5	5	4	9
Hadley (%)	7	2	3	4	1	8
NCAR (%)	8	3	4	4	2	8

( ) = negative number, kg/ha = kilogram per hectare, CC = climate change, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Source: Compiled by authors.

Table 3.9: Climate Change Effects on Crop Production, No CO_2 Fertilization

Product	Central Asia	PRC	East Asia	India	South Asia	Southeast Asia
Maize						
2000 ('000 mt)	1,300	118,809	118,877	12,567	16,193	21,384
2050 No CC ('000 mt)	2,620	197,648	197,764	10,455	17,196	32,048
CSIRO (%)	7	(14)	(14)	(34)	(23)	(6)
Hadley (%)	5	12	12	(16)	(6)	11
NCAR (%)	5	7	7	(20)	(15)	(9)
Millet						
2000 ('000 mt)	59	2,097	2,098	10,016	10,561	168
2050 No CC ('000 mt)	128	3,040	3,044	11,325	12,220	318
CSIRO (%)	7	1	1	(20)	(19)	7
Hadley (%)	8	6	6	(10)	(9)	7
NCAR (%)	6	4	4	(10)	(10)	6
Rice						
2000 ('000 mt)	337	122,468	127,145	87,889	120,041	97,950
2050 No CC ('000 mt)	933	100,936	104,702	92,975	146,141	122,039

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Table 3.9 continued

Product	Central Asia	PRC	East Asia	India	South Asia	Southeast Asia
CSIRO (%)	(2)	(15)	(14)	(15)	(11)	(10)
Hadley (%)	4	(12)	(12)	(22)	(18)	(7)
NCAR (%)	2	(13)	(13)	(17)	(12)	(13)
Wheat						
2000 ('000 mt)	18,186	101,852	102,003	72,098	96,708	105
2050 No CC ('000 mt)	39,306	93,392	93,625	97,246	185,489	217
CSIRO (%)	(32)	(13)	(13)	(48)	(40)	(43)
Hadley (%)	(19)	3	3	(53)	(45)	(30)
NCAR (%)	(35)	(2)	(2)	(51)	(40)	(45)
Sorghum						
2000 ('000 mt)	19	2,919	2,921	8,179	8,402	147
2050 No CC ('000 mt)	16	3,055	3,059	8,697	9,005	206
CSIRO (%)	7	2	2	(20)	(19)	9
Hadley (%)	10	7	7	(10)	(10)	7
NCAR (%)	9	5	5	(10)	(10)	9
Other Grains						
2000 ('000 mt)	2,921	4,367	4,683	1,478	1,709	5
2050 No CC ('000 mt)	3,997	5,523	5,845	2,166	2,695	12
CSIRO (%)	(4)	5	6	14	9	25
Hadley (%)	(2)	11	12	20	15	22
NCAR (%)	(7)	(1)	0	9	4	22

( ) = negative number, mt = metric ton, CC = climate change, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Source: Compiled by authors.

Trade in agricultural commodities

Climate change has dramatic effects on Asian trade flows, but they differ significantly depending on the GCM (Table 3.10, Figure 3.7). Consider the PRC's net cereal trade—net imports of 22 million mt in 2000 increase to 84 million in 2050 without climate change. If instead, the CSIRO climate results occur, net imports increase to 106 million, an increase of 26% over the no climate change trade. On the other hand, with the Hadley climate in 2050, net imports fall to only 13 million mt, a decline of 85% relative to no climate change. Overall, net cereal imports are expected to increase in East Asia and South Asia under all climate change scenarios. In Southeast Asia, the impact of climate change on trade varies according to the GCM applied.

Table 3.10: Net Cereal Trade in 2000 and 2050

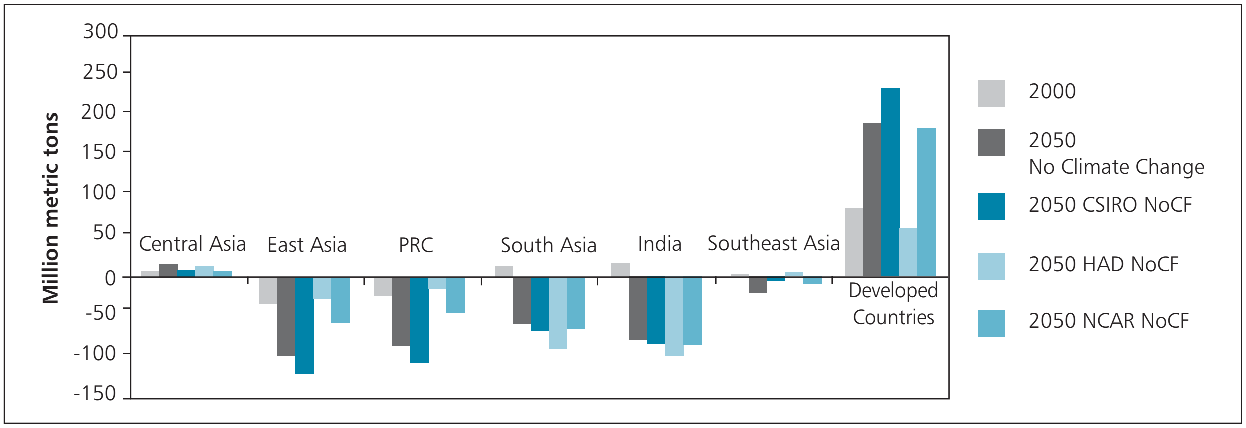
	No Climate Change		**2050: With Climate Change**					
	2000 (million mt)	**2050 (million mt)**	**No CO_2 Fertilization (million mt)**			**Difference between No and With CO_2 Fertilization (%)**		
			CSIRO	**Hadley**	**NCAR**	**CSIRO**	**Hadley**	**NCAR**
Central Asia	7.26	15.80	8.51	13.07	7.24	7.71	10.18	6.16
East Asia	(32.97)	(96.56)	(119.61)	(24.78)	(56.64)	0.23	(2.72)	(35.69)
PRC	(21.64)	(83.93)	(105.60)	(12.66)	(43.21)	(0.85)	(5.73)	(76.12)
South Asia	15.00	(56.13)	(66.32)	(87.20)	(64.06)	3.37	80.50	(9.49)
India	17.48	(78.51)	(84.72)	(97.78)	(85.64)	6.37	25.36	(4.10)
Southeast Asia	2.65	(20.02)	(5.29)	5.98	(9.58)	7.19	7.89	10.79
Developed Countries	84.24	191.07	233.62	59.95	184.40	(10.61)	(14.03)	(82.49)

mt = metric ton, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Note: Negative values indicate net imports. The last three columns in this table report the percentage difference between the net imports in 2050 with and without the CO_2 fertilization effect. For example, with the NCAR GCM, assuming CO_2 fertilization is effective in the field, results in a 76.12% increase in PRC net imports relative to the no CO_2 effect. Cereals include rice, wheat, maize, millet, sorghum, and other grains.

Source: Compiled by authors.

Figure 3.7: Net Cereal Trade in 2000 and 2050



mt = metric ton.

Note: Cereals include rice, wheat, maize, millet, sorghum, and other grains.

Source: Authors.

Food demand

The level of food available for consumption is determined by the interaction of supply, demand, and the resulting prices with individual preferences and income. Table 3.11 shows average consumption of cereals and meat products in 2000 and projected for 2050 under various climate change scenarios. With the exception of Central Asia, human consumption of cereals as food is expected to drop between 2000 and 2050 under no climate change. For East Asia, the

Table 3.11: Capita Food Demand for Cereals and Meats in 2000 and 2050
(kg/cap/year)

Product and Subregion	No Climate Change		2050: With Climate Change		
	2000	2050	CSIRO	Hadley	NCAR
CEREALS					
Central Asia	174	194	146	153	147
East Asia	185	171	128	133	128
PRC	186	172	128	133	129
Other East Asia	152	129	106	107	107
South Asia	164	159	124	128	124
India	162	158	123	127	124
Other South Asia	172	161	126	130	126
Southeast Asia	183	155	126	127	126
World: Developing	164	155	120	123	121
World: Developed	116	123	91	95	92
MEAT					
Central Asia	26	25	25	25	25
East Asia	49	77	74	74	74
PRC	49	78	75	75	76
Other East Asia	16	16	15	15	15
South Asia	6	15	14	14	14
India	5	14	14	14	14
Other South Asia	8	16	15	15	15
Southeast Asia	18	31	31	31	31
World: Developing	28	34	33	33	33
World: Developed	86	94	92	91	92

kg/year = kilogram per year, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Source: Compiled by authors.

decline is over 7%; for South Asia, it is 3%; and for Southeast Asia, it is over 15%. These declines are driven by changing diets due to continued rapid growth in per capita income. As a result, meat consumption increases by 57% in East Asia, 150% in South Asia (albeit from a low base), and 72% in Southeast Asia.

Climate change has significant negative impacts on cereal consumption. With higher prices from climate change, per capita food demand declines dramatically throughout Asia. Central Asian consumption falls by 21% to 25% relative to the 2050 no climate change consumption. For East Asia, the decline is 22% to 25%; South Asia is 19% to 22%; and Southeast Asia is 18% to 19%. Meat consumption, on the other hand, is almost unchanged because climate change has only a small effect on meat prices.

The results for demand for cereals and meats translate into similarly large declines in calorie availability. Results are presented in Table 3.12 and Figure 3.8. Without climate change, calorie availability increases throughout Asia and the Pacific between 2000 and 2050. The largest increase, 17.4%, is in Central Asia, but East Asian consumers also consume more—over 7%. Under climate change, calorie availability in 2050 is not only lower than the no climate change scenario in 2050; calorie availability actually declines relative to 2000 levels. Higher food prices lead to declines in total demand for cereal and other crops and a reduction in calorie availability across all Asian subregions, by 13%–15% on average. The subregion hardest hit is Central Asia, with projected declines in calorie availability of 15%–18%, given their combination of low levels of calories at the outset and the strong impact from climate change.

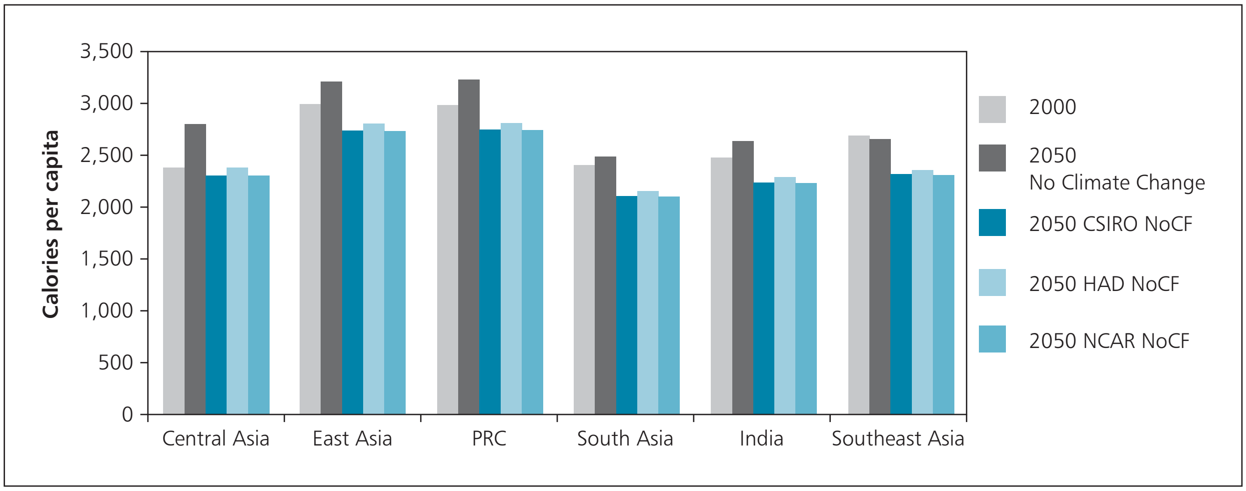
Table 3.12: Daily Per Capita Calorie Availability in 2000 and 2050

Subregion and Country	No Climate Change		2050: With Climate Change					
			No CO_2 Fertilization (Kcal/person/day)			Difference between No and With CO_2 Fertilization (%)		
	2000 (Kcals/person/day)	2050 (Kcals/person/day)	NCAR	Hadley	CSIRO	NCAR	Hadley	CSIRO
Central Asia	2,365	2,777	2,284	2,360	2,281	3	3	3
East Asia	2,970	3,190	2,718	2,782	2,718	4	4	4
PRC	2,968	3,194	2,719	2,783	2,719	4	4	4
South Asia	2,381	2,464	2,089	2,142	2,088	4	5	4
India	2,453	2,613	2,214	2,270	2,213	4	5	4
Southeast Asia	2,669	2,632	2,290	2,339	2,296	5	6	5
Developing countries	2,677	2,750	2,318	2,372	2,315	4	5	4
Developed countries	3,438	3,606	3,213	3,269	3,213	2	2	2

CO_2 = carbon dioxide, Kcal = kilocalorie, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Source: Compiled by authors.

Figure 3.8: Daily Per Capita Calorie Availability in 2000 and 2050



PRC = People's Republic of China.

Source: Authors.

Welfare effects

Our primary measure of the welfare effects of climate change is the change in the estimated number of malnourished children between 2000 and 2050 without climate change and under various climate change scenarios. Table 3.13 provides country by country estimates of the number of malnourished children and how these estimates change under the various climate change scenarios.

Table 3.14 reports summary statistics for the subregions in Asia and the Pacific and Figure 3.9 presents results for India and the PRC. With no climate change, all parts of Asia see relatively large declines in the number of malnourished children, driven by rapid income and agricultural productivity growth. Climate change eliminates much of that improvement. In East Asia, instead of 2.3 million malnourished children in 2050, we find 4.9 million to 5.3 million. In South Asia, instead of 52.3 million malnourished children in 2050, we find between 57.2 million and 58.2 million. If CO_2 fertilization is in fact effective in the field, the negative effect of climate change on child malnutrition is reduced somewhat. Overall, childhood malnutrition in the region is projected to increase dramatically under climate change by between 9 to 11 million children, in addition to the 65 million children projected to remain malnourished in 2050 even under current climate conditions.

The Costs of Adaptation

To assess the costs of adaptation, we need to identify investments that reduce child malnutrition with climate change to the levels with no climate change. There are two types of investments examined here that influence malnutrition—those that increase agricultural productivity and nonagricultural investments in maternal education

Table 3.13: Number of Malnourished Children in Developing Asia in 2000 and 2050

(‘000 of children under 5 years of age)

			2050: Additional Number, With Climate Change					
	No Climate Change		No CO_2 Fertilization			With CO_2 Fertilization		
Country	**2000**	**2050**	**CSIRO**	**Hadley**	**NCAR**	**CSIRO**	**Hadley**	**NCAR**
Asia	100,407	64,898	10,538	8,968	10,564	7,717	5,886	7,755
Bangladesh	9,055	7,813	637	529	648	389	253	390
Cambodia and Lao PDR	1,085	1,159	78	66	80	40	23	40
China, People’s Republic of	9,586	1,998	2,920	2,501	2,919	2,199	1,714	2,206
India	56,431	37,488	4,055	3,436	4,042	3,036	2,337	3,038
Indonesia	5,323	3,561	680	617	690	435	337	442
Kazakhstan	48	42	43	35	43	36	28	36
Korea, Republic of	591	321	50	42	51	39	29	39
Kyrgyz Republic	31	7	23	19	23	19	15	19
Malaysia	520	304	62	51	63	48	35	49
Mongolia	34	9	10	9	10	9	7	9
Myanmar	957	688	103	84	107	49	21	49
Nepal	1,760	1,505	195	187	192	139	124	138
Pakistan	7,162	5,398	869	730	868	709	563	717
Philippines	1,889	1,134	286	226	294	206	136	211
Sri Lanka	316	170	40	33	41	30	22	31
Tajikistan	167	64	40	33	40	33	26	34
Thailand	968	703	77	62	79	54	36	56
Turkmenistan	58	46	21	18	21	17	14	18
Uzbekistan	540	404	104	86	103	86	68	86
Viet Nam	2,754	2,086	236	203	243	143	97	145

CSIRO = Commonwealth Scientific and Industrial Research Organization, Lao PDR = Lao People’s Democratic Republic, NCAR = National Center for Atmospheric Research.

Note: Results are not reported for a few small countries.

Source: Compiled by authors.

Table 3.14: Total Number of Malnourished Children in Developing Asia in 2000 and 2050

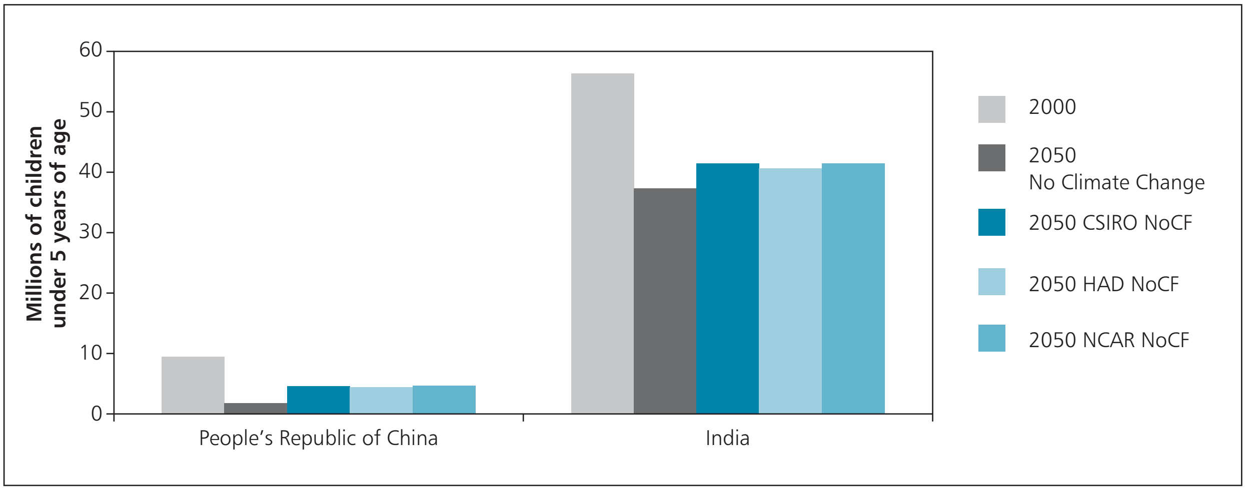
	No Climate Change ('000 of children under 5 years of age)		2050: With Climate Change					
			No CO_2 Fertilization ('000 of children under 5 years of age)			Difference between No and With CO_2 Fertilization (%)		
Subregion	**2000**	**2050**	**NCAR**	**Hadley**	**CSIRO**	**NCAR**	**Hadley**	**CSIRO**
Central Asia	912	562	800	754	798	(5.76)	(5.28)	(5.43)
East Asia	10,210	2,328	5,309	4,880	5,309	(13.83)	(16.43)	(13.69)
South Asia	75,621	52,374	58,170	57,289	58,165	(2.57)	(2.82)	(2.54)
Southeast Asia	13,505	9,634	11,157	10,945	11,190	(4.91)	(5.71)	(5.03)
Total	100,248	64,898	75,436	73,867	75,462	(3.74)	(4.17)	(3.72)

( ) = negative number, CO_2 = carbon dioxide, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research.

Note: The last three columns in this table report the percentage difference between the number of malnourished children in 2050 with and without the CO_2 fertilization effect. For example, using the Hadley GCM and assuming CO_2 fertilization is effective in the field, the result is a 2.82% decline in the number of malnourished children in South Asia relative to the climate change outcome without CO_2 fertilization.

Source: Compiled by authors.

Figure 3.9: Total Number of Malnourished Children in the People's Republic of China and India in 2000 and 2050



Source: Authors.

and clean water. The maximum realistic productivity increases for agriculture investments in Asia and the Pacific alone were insufficient to meet our malnutrition target.

Table 3.15 reports the types of investments needed to reduce malnutrition rates to those without climate change through intermediate channels. Table 3.16 reports the effects on child malnutrition for the three climate scenarios relative to the no climate change scenario. The effects of climate change increase child malnutrition and reduce calorie consumption. Aggressive agricultural productivity investments raise calorie consumption significantly and cut two-thirds of the increase in childhood malnutrition due to climate change. Nonagricultural investments for clean water and maternal education reduce child malnutrition further but do not contribute directly to calorie consumption.

The additional investments needed to reach the child malnutrition numbers shown in Table 3.16 and the daily calorie availability per capita in Table 3.17 are reported in Table 3.18. Overall, spending across all sectors needs to increase through 2050 by more than 50% from baseline investment assumptions of $4.9 to $5.8 billion per year, to adapt to climate change and reduce child malnutrition to the levels under no climate change. The total expenditure in the agriculture sector increases by two-thirds over the entire period to 2050, with the most sizeable increases occurring in South Asia, in terms of both irrigation and rural roads. The spending on agriculture in India, alone, increases by more than 50% and even Southeast Asia makes sizeable increases across all sectors. The most dramatic changes are seen in terms of improvements in irrigation efficiency across most subregions.

Table 3.15: Investment and Productivity Scenarios for Climate Change Adaptation

Investment Type	Result
Agriculture sector investments	• 60% increase in crop (all crops) yield growth over baseline (baseline = intrinsic) • 30% increase in animal numbers growth • 40% increase in production growth of oils and meals • 25% increase in irrigated area growth • 15% decrease in rainfed area growth • Increase of 0.15 by 2050 in basin water efficiency
Nonagricultural investments	• 30% increase in the growth of female secondary school enrollment rates (subject to 100% maximum) • 30% increase in the growth rates of access to clean water (subject to 100% maximum)

Source: Authors.

Table 3.16: Number of Malnourished Children, with Adaptive Investments
(millions)

Scenario and Subregion	2000	2010	2020	2030	2040	2050
No climate change						
Central Asia	0.91	0.84	0.80	0.67	0.63	0.56
East Asia	10.21	7.11	5.57	3.25	2.47	2.33
People's Republic of China	9.59	6.65	5.14	2.86	2.13	2.00
South Asia	75.62	72.13	68.15	60.92	56.48	52.37
India	56.43	53.30	49.16	43.01	39.95	37.49
Southeast Asia	13.51	13.58	12.39	11.57	10.62	9.63
Asia and the Pacific	100.25	93.66	86.91	76.42	70.20	64.90
Hadley with agricultural investments						
Central Asia	0.91	0.91	0.90	0.76	0.72	0.64
East Asia	10.21	7.76	6.45	4.10	3.32	3.06
People's Republic of China	9.59	7.28	6.00	3.70	2.96	2.72
South Asia	75.62	73.48	69.99	62.90	58.49	54.16
India	56.43	54.29	50.48	44.41	41.38	38.78
Southeast Asia	13.51	13.94	12.82	12.04	11.07	10.02
Asia and the Pacific	100.25	96.08	90.15	79.81	73.60	67.89
Hadley with agricultural + nonagricultural investments						
Central Asia	0.91	0.91	0.87	0.74	0.70	0.63
East Asia	10.21	7.76	5.41	2.89	1.87	1.77
People's Republic of China	9.59	7.28	4.97	2.48	1.51	1.42
South Asia	75.62	73.48	67.34	59.42	54.01	48.86
India	56.43	54.29	48.37	41.72	37.93	34.68
Southeast Asia	13.51	13.94	12.43	11.52	10.47	9.50
Asia and the Pacific	100.25	96.08	86.05	74.56	67.06	60.76
NCAR with agricultural investments						
Central Asia	0.91	0.92	0.92	0.79	0.75	0.68
East Asia	10.21	7.83	6.60	4.32	3.60	3.41
People's Republic of China	9.59	7.36	6.15	3.91	3.24	3.06
South Asia	75.62	73.68	70.39	63.47	59.15	54.89

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Table 3.16 continued

Scenario and Subregion	2000	2010	2020	2030	2040	2050
India	56.43	54.45	50.77	44.82	41.84	39.28
Southeast Asia	13.51	13.99	12.92	12.19	11.25	10.23
Asia and the Pacific	100.25	96.42	90.83	80.77	74.75	69.20
NCAR with agricultural + nonagricultural investments						
Central Asia	0.91	0.92	0.89	0.76	0.73	0.67
East Asia	10.21	7.83	5.57	3.10	2.15	2.12
People’s Republic of China	9.59	7.36	5.12	2.69	1.79	1.77
South Asia	75.62	73.68	67.74	59.99	54.67	49.59
India	56.43	54.45	48.66	42.12	38.40	35.18
Southeast Asia	13.51	13.99	12.53	11.67	10.65	9.70
Asia and the Pacific	100.25	96.42	86.73	75.52	68.20	62.07
CSIRO with agricultural investments						
Central Asia	0.91	0.92	0.92	0.79	0.75	0.67
East Asia	10.21	7.84	6.60	4.31	3.58	3.36
People’s Republic of China	9.59	7.36	6.15	3.90	3.22	3.01
South Asia	75.62	73.69	70.37	63.44	59.10	54.79
India	56.43	54.45	50.76	44.81	41.81	39.23
Southeast Asia	13.51	13.98	12.90	12.16	11.20	10.17
Asia and the Pacific	100.25	96.43	90.79	80.71	74.63	68.99
CSIRO with agricultural + nonagricultural investments						
Central Asia	0.91	0.92	0.89	0.76	0.73	0.66
East Asia	10.21	7.84	5.56	3.10	2.13	2.07
People’s Republic of China	9.59	7.36	5.12	2.69	1.77	1.72
South Asia	75.62	73.69	67.72	59.96	54.62	49.49
India	56.43	54.45	48.65	42.11	38.37	35.13
Southeast Asia	13.51	13.98	12.51	11.64	10.61	9.64
Asia and the Pacific	100.25	96.43	86.69	75.46	68.08	61.86

CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research.

Note: The climate change results presented in this table assume no CO_2 fertilization effects.

Source: Calculated by authors.

Table 3.17: Daily Calorie Per Capita Availability in 2000 and 2050, with Adaptive Investments (Kcals/person/day)

Scenario and Subregion	2000	2010	2020	2030	2040	2050
No climate change						
Central Asia	2,365	2,459	2,500	2,563	2,672	2,777
East Asia	2,970	3,101	3,170	3,227	3,264	3,190
People's Republic of China	2,968	3,104	3,175	3,234	3,272	3,194
South Asia	2,381	2,392	2,403	2,427	2,468	2,464
India	2,453	2,496	2,531	2,573	2,625	2,613
Southeast Asia	2,669	2,596	2,554	2,550	2,589	2,632
Asia and the Pacific	2,660	2,694	2,705	2,724	2,751	2,722
Hadley						
Central Asia	2,365	2,366	2,319	2,299	2,327	2,360
East Asia	2,970	3,002	2,978	2,948	2,911	2,782
People's Republic of China	2,968	3,004	2,981	2,952	2,915	2,783
South Asia	2,381	2,313	2,253	2,209	2,192	2,142
India	2,453	2,413	2,371	2,341	2,330	2,270
Southeast Asia	2,669	2,527	2,425	2,365	2,349	2,339
Asia and the Pacific	2,660	2,608	2,542	2,489	2,454	2,376
Hadley with investments						
Central Asia	2,365	2,372	2,368	2,396	2,478	2,580
East Asia	2,970	3,013	3,051	3,092	3,127	3,067
People's Republic of China	2,968	3,015	3,055	3,097	3,133	3,070
South Asia	2,381	2,316	2,299	2,303	2,336	2,341
India	2,453	2,416	2,420	2,441	2,483	2,478
Southeast Asia	2,669	2,529	2,468	2,455	2,491	2,540
Asia and the Pacific	2,660	2,614	2,598	2,600	2,622	2,603
NCAR						
Central Asia	2,365	2,352	2,290	2,253	2,267	2,284
East Asia	2,970	2,990	2,953	2,909	2,859	2,718
People's Republic of China	2,968	2,992	2,956	2,913	2,863	2,719
South Asia	2,381	2,301	2,228	2,171	2,145	2,089

continued on next page

Table 3.17 continued

Scenario and Subregion	2000	2010	2020	2030	2040	2050
India	2,453	2,400	2,344	2,301	2,280	2,214
Southeast Asia	2,669	2,514	2,400	2,330	2,307	2,290
Asia and the Pacific	2,660	2,596	2,517	2,452	2,406	2,320
NCAR with investments						
Central Asia	2,365	2,357	2,339	2,353	2,425	2,510
East Asia	2,970	3,002	3,031	3,058	3,082	3,010
People's Republic of China	2,968	3,004	3,034	3,064	3,088	3,013
South Asia	2,381	2,305	2,277	2,269	2,295	2,293
India	2,453	2,404	2,396	2,405	2,439	2,428
Southeast Asia	2,669	2,519	2,449	2,425	2,453	2,496
Asia and the Pacific	2,660	2,603	2,577	2,567	2,580	2,552
CSIRO						
Central Asia	2,365	2,350	2,287	2,248	2,262	2,281
East Asia	2,953	2,974	2,937	2,892	2,842	2,702
People's Republic of China	2,968	2,992	2,954	2,910	2,861	2,719
South Asia	2,381	2,301	2,226	2,170	2,143	2,088
India	2,453	2,399	2,342	2,298	2,278	2,213
Southeast Asia	2,662	2,508	2,392	2,321	2,296	2,278
Asia and the Pacific	2,660	2,596	2,516	2,451	2,405	2,321
CSIRO with investments						
Central Asia	2,365	2,357	2,339	2,352	2,425	2,516
East Asia	2,970	3,002	3,031	3,059	3,086	3,018
People's Republic of China	2,968	3,004	3,035	3,065	3,092	3,021
South Asia	2,381	2,304	2,277	2,271	2,298	2,299
India	2,453	2,403	2,397	2,406	2,441	2,433
Southeast Asia	2,669	2,520	2,453	2,432	2,463	2,509
Asia and the Pacific	2,660	2,603	2,578	2,569	2,584	2,560

Kcal = kilocalorie, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Source: Authors.

Table 3.18: Additional Annual Investment Expenditure Needed Across Asia and the Pacific to Counteract the Effects of Climate Change on Nutrition
($ million/year in constant 2000 values)

Scenario and Subregion	Agricultural Research	Clean Water	Education	Irrigation Expansion	Irrigation Efficiency	Roads	Total
Hadley							
Central Asia	0	0	3	2	69	6	81
East Asia	284	58	255	59	539	1	1,196
People's Republic of China	150	57	255	59	538	1	1,061
East Asia minus PRC	133	1	1	0	0	0	135
South Asia	347	46	737	413	889	532	2,963
India	189	0	544	303	593	1	1,629
South Asia minus India	158	46	193	110	296	531	1,334
Southeast Asia	177	8	107	36	186	281	795
Asia and the Pacific	807	112	1,102	510	1,683	820	5,035
NCAR							
Central Asia	0	0	3	2	63	0	69
East Asia	357	58	255	22	505	2	1,199
People's Republic of China	204	57	255	22	504	2	1,045
East Asia minus PRC	152	1	1	0	0	0	154
South Asia	275	46	737	381	831	62	2,332
India	126	0	544	287	569	1	1,526
South Asia minus India	149	46	193	94	262	62	806
Southeast Asia	161	8	107	9	170	154	609
Asia and the Pacific	793	112	1,102	415	1,569	218	4,209
CSIRO							
Central Asia	0	0	3	1	63	0	67
East Asia	362	58	255	40	503	2	1,220
People's Republic of China	188	57	255	40	502	2	1,044
East Asia minus PRC	174	1	1	0	0	0	176
South Asia	329	46	737	310	823	66	2,311
India	134	0	544	271	574	1	1,524
South Asia minus India	195	46	193	39	249	65	787
Southeast Asia	171	8	107	8	170	184	648
Asia and the Pacific	863	112	1,102	360	1,558	251	4,246

CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research, PRC = People's Republic of China.

Note: These results are based on crop model yield changes that do not include the CO_2 fertilization effect.

Source: Calculated by authors.

The nonagriculture sector that sees the biggest increases in investment spending needs is that of education, which almost doubles in magnitude across all of Asia. The magnitude of spending needs in India alone, nearly triples, and that for South Asia more than doubles. The magnitude of spending in East Asia also rises by more than 75%, and almost all of that increase occurs in the PRC. The importance of female schooling as a determinant of child malnutrition is reflected in these results, and argues strongly in favor of support for continued attention to the important linkages that this sector creates to human well-being outcomes. The overall increase in spending on clean water access is relatively small, by comparison, and represents less than a 5% overall increase across Asia. Nonetheless, there is some appreciable increase in spending needs in East Asia, and the rest of South Asia, outside India.

For Asia and the Pacific, the overall increase in annual spending (including agriculture and nonagriculture sectors) to adapt to climate change exceeds $5 billion constant dollars per year for the Hadley results and over $4 billion constant dollars per year for the NCAR and CSIRO results. Within the agriculture sector, the largest annual spending need is for irrigation efficiency enhancements. This has a large component in South Asia—which is hardest hit by climate change and where possibilities for water supply enhancement are limited, even under a no climate change case, and where the imperative for demand management and efficiency improvements is vital for the future viability of agriculture. The needs for additional agricultural research expenditure are also sizable, and are largest in South Asia, closely followed in magnitude by those in the PRC, where an extensive network of public and private agricultural research institutions already exists. In terms of the nonagriculture sectors, education stands out and in an order of magnitude above the additional annual needs for clean water access, across the region. As before, the largest annual spending is needed for South Asia, which is more than double that for East Asia—even accounting for just those needs within India. The need for additional resources to maintain levels of female schooling that can bring down levels of child malnutrition in the rest of South Asia sufficiently to counteract climate change is almost twice that of Southeast Asia, as a whole.

The key messages embodied in these results speak of the importance of improving the productivity of agriculture as a means of meeting the future challenges that climate change represents. These results also show the importance of strengthening the provision of clean water and education for rural populations, and shows that these should not be ignored when deciding how to allocate resources and political priorities in the future, as part of planning for a climate-proof path to development, growth, and the improvement of human welfare.

Effects of Trade Liberalization and Increased Protection

As we have seen above, agricultural trade flows alter significantly with climate change. An important issue is whether trade liberalization could partially compensate for the negative effects of climate change. This position has been argued by much of the early literature on the effects of climate change on agriculture. For example, a widely cited 2004 publication (Parry et al. 2004) based on modeling of both climate and agriculture using the AR3 results was still relatively sanguine about global food production, showing increased production in the developed world, declines in the developing world, and more open trade to match the changes in production.

Table 3.19 shows our experiments with complete elimination of trade barriers (the argument for reduced protection) and an across-the-board doubling of trade barriers (the counter-argument for increased protection). Trade liberalization reduces childhood malnutrition in Asia and the Pacific, while increased protectionism results in higher levels of malnutrition for all scenarios.

Impacts of Sea-Level Rise on Crop Area in Asia and the Pacific

Potential impacts of sea-level rise on crop production for key Asia and Pacific countries were calculated, overlaying detailed elevation data with IFPRI's Spatial Allocation Model for cultivated crops for sea-level rise of 1 meter and 3 meters,

Table 3.19: Changes in Childhood Malnutrition under Alternative Trade Scenarios ('000 children)

Scenario	Asia and the Pacific
2000	100,407
No climate change	
2050	64,898
2050 increased protection	318
2050 reduced protection	(330)
Hadley	
2050	73,867
2050 increased protection	307
2050 reduced protection	(343)
NCAR	
2050	75,462
2050 increased protection	288
2050 reduced protection	(323)
CSIRO	
2050	75,436
2050 increased protection	281
2050 reduced protection	(317)

( ) = negative number, CSIRO = Commonwealth Scientific and Industrial Research Organization, NCAR = National Center for Atmospheric Research

Source: Calculated by authors.

respectively. These sea-level rise assumptions are higher than IPCC predictions for 2050 and 2100. However, analysis of less than 1-meter sea-level rise requires Digital Elevation Model data with higher vertical resolution than is currently available in the public domain. Moreover, IPCC (2007) predictions have underestimated the level and speed of recent Arctic ice melting, which gives more credence to the possibility of levels above the 0.5–0.6 meter range than generally anticipated.

Results are available for those countries in Asia and the Pacific that are included in IFPRI's Spatial Allocation Model (ISPAM) and that have coastal areas. This excludes 12 countries in the Pacific, for which no spatial crop allocation data was available as well as 13 landlocked member countries in the region.

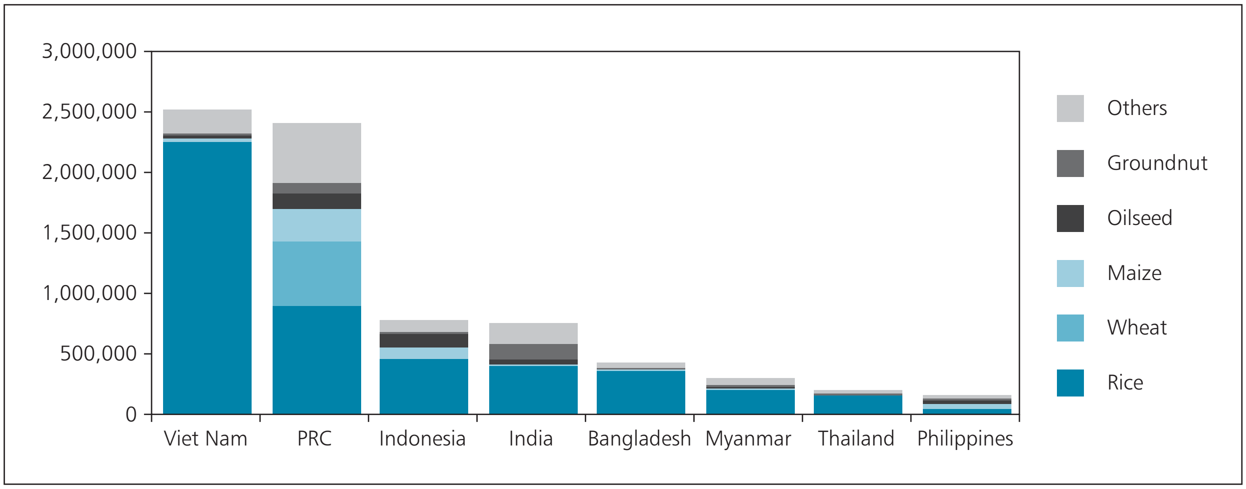
In the case of a 1-meter sea-level rise, a total of 7.7 million hectares (ha) of crop land is submerged, while under a potential 3-meter sea-level rise, the area submerged more than doubles to 16.1 million ha. Rice is by far the most affected crop, losing 4.9 million ha and 10.5 million ha, respectively. This is followed by wheat and maize, losing 0.6–1.2 million ha and 0.5–0.9 million ha under the two sea-level rise scenarios in Asia and the Pacific. Current rice harvested area is about 150 million ha; assuming a harvest index for rice of around 1.5, sea-level rise impacts for Asia and the Pacific alone could account for losing between 5% and 11% of global rice cultivated area, respectively, which would create significant upward pressures on world rice prices. Also significantly affected, but not brought into the calculation here, would be large negative impacts on aquaculture production in Asia and the Pacific with secondary impacts on prices of livestock products.

Figures 3.10 and 3.11 present countries in the region with crop land submergence in excess of 100,000 ha under sea-level rise of 1 meter and 3 meters, respectively. The PRC and Viet Nam are the two countries most affected by sea-level rise in terms of total crop land area, followed by Bangladesh, India, and Indonesia. While rice is the key crop affected in Viet Nam, considerable areas of wheat and maize would be affected in the PRC. Figure 3.12 presents maps of the main affected countries in Asia and the Pacific, highlighting key areas submerged under the alternative sea-level rise scenarios. In Viet Nam, these would be the Mekong Delta, but also parts of the Red River Delta; while in the PRC, the Pearl River delta, the Yangtze River delta, coastal areas of Jiangshu Province and the coastal areas along the west rim of the Bo Hai Sea, where the Yellow River delta is located, are affected.

Limitations

As has been described in Chapter I, there are several limitations to this report in terms of climate change impacts that cannot currently be modeled due to data limitations. Incorporation of these effects would make the climate change outcomes significantly worse than the already negative picture shown here. First, direct effects on livestock are not included. These range from less productive pastures for ruminants because of heat and precipitation changes to increased stress in livestock confinement systems. Second, pests and diseases, from traditional weeds that are more robust to larger insect populations to more infectious diseases, might be a more serious problem with higher temperatures and in locations with more precipitation. Third, the analysis in this chapter does not take into account the effect of sea-level rise on coastal agricultural resources. Coastal rice paddies might see saline intrusion, coastal seafood pens might be lost, and marine fisheries made less productive as mangrove swamps are affected. Fourth, some parts of the world, in particular, the

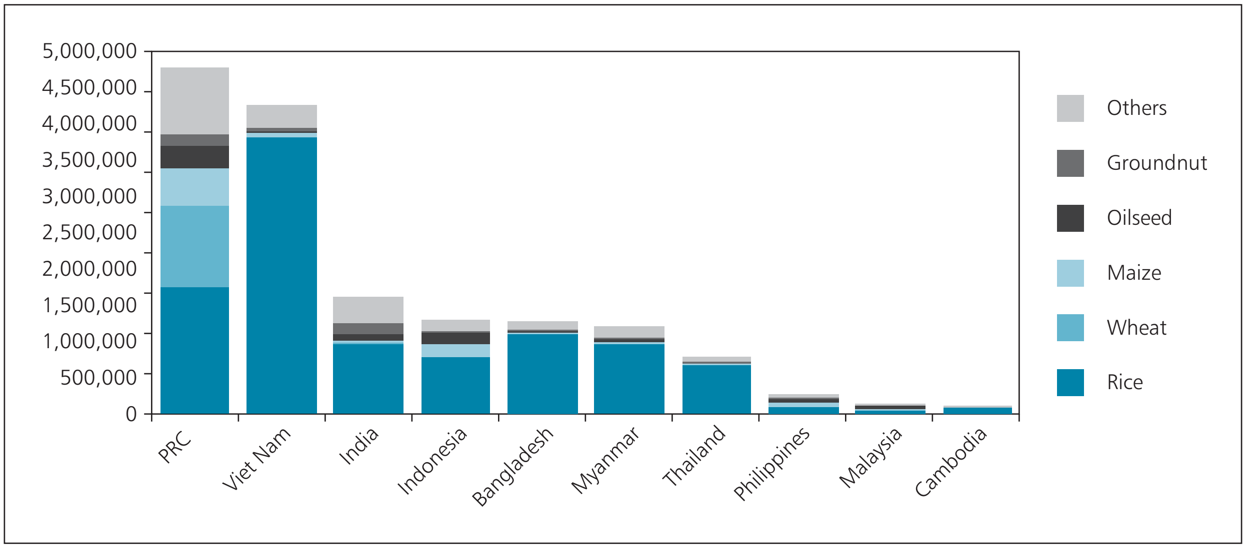
Figure 3.10: Countries in Asia and the Pacific with Cultivated Crop Areas Lost in Excess of 100,000 Hectares, 1-Meter Sea-Level Rise



PRC= People's Republic of China.

Source: Authors.

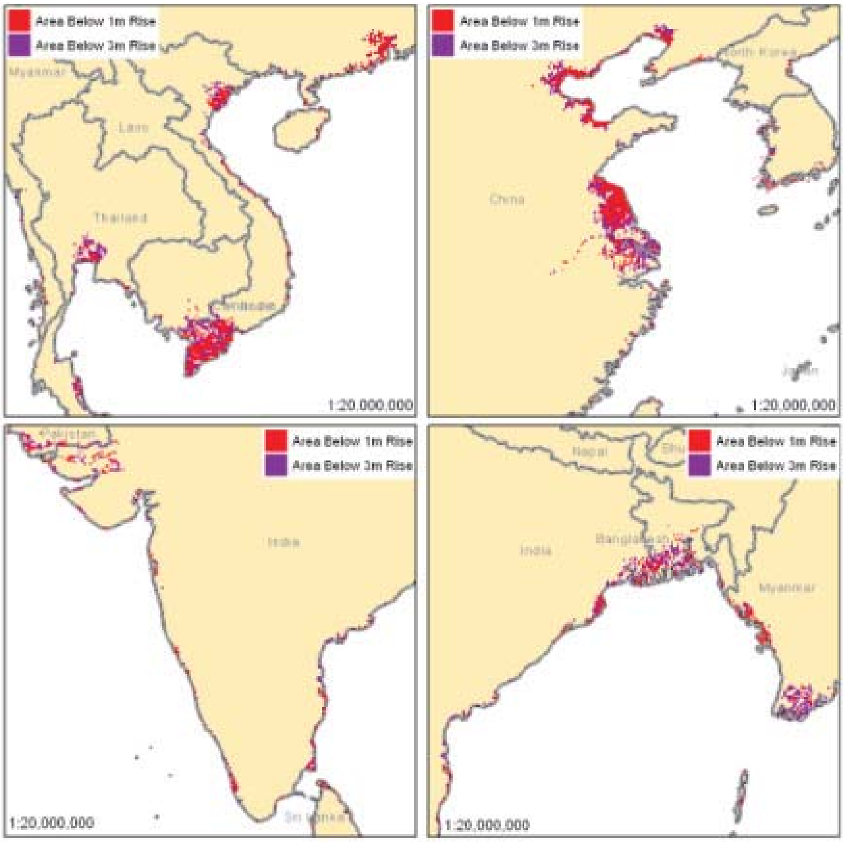
Figure 3.11: Countries in Asia and the Pacific with Cultivated Crop Areas Lost in Excess of 100,000 Ha, 3-Meter Sea-Level Rise



PRC= People's Republic of China.

Source: Authors.

Figure 3.12: Cropland Areas Under Sea-Level Rise of 1 and 3 Meters, Respectively, in Key Affected Countries in Asia and the Pacific



Source: Authors.

rivers that derive from glaciers in the mountains of Asia, might see more varied flows with effects on irrigated agriculture and fisheries based on water sourced from rivers. Finally, we have not included the effect of extreme weather events as current GCM scenarios do not account for such events. In time, regional climate models should account for extreme weather events.

Summary

This analysis brings together, for the first time, detailed modeling of crop growth under climate change with insights from global partial agriculture equilibrium trade models. Several important conclusions can be drawn from this chapter. First, regardless of climate change scenario, agriculture in Asia and the Pacific, overall, will be negatively affected by climate change.

When biophysical impacts of climate change are integrated into the IMPACT economic modeling framework, food prices increase sharply for key crops, with adverse consequences for the poor. Rice prices are projected to be 29%–37% higher in 2050 compared to a no climate change case, wheat prices at 81%–102% higher, maize prices rise by 58%–97%, and soybean prices increase by 14%–49%. Price increases due to climate change are lower if carbon fertilization is considered, but the recent insights from field experiments suggest that benefits from carbon fertilization are much less than previously estimated. Higher food prices as a result of lower crop yields mean reduced food availability and more malnourished children.

There remains great uncertainty about where the particular impacts will occur and the resulting production, consumption, and trade flow effects exhibit considerable differences depending on the climate scenario.

Increases in investments to increase agricultural productivity, including agricultural research, improvements in irrigation efficiency and expansion of irrigated area, and rural road construction, can compensate for much of the effects of climate change. Investments in complementary sectors, such as education and health, can further reduce adverse impacts from climate change in Asia and the Pacific. Adaptation costs are not small, however. We estimate these costs to be in the range of $3.0–$3.8 billion for direct agriculture and related investments (public agricultural research and development, irrigation efficiency and expansion, and rural roads), plus $1.2 billion for investments in complementary sectors above and beyond projected investments of $4.9–$5.8 billion per year in these areas.

Higher food prices as a result of the effects of highly negative biophysical crop yield (and to some extent area) induce lower food demand. However, higher crop production, with secondary impacts on crop yields, significantly reduce direct biophysical impacts of climate change—but at the cost of higher malnutrition.

Changes in the volume and direction of international trade in agricultural commodities is another important avenue to compensate for the differential impacts of climate change, which is also taken into account in our modeling framework. Thus, more open international trade should continue to be promoted to partially offset adverse effects and uncertainty, from climate change.

The largest potential food crop impact from sea-level rise in Asia and the Pacific is for rice. The PRC and Viet Nam are the two countries most affected from sea-level rise in terms of total crop land area, followed by Bangladesh, India, and Indonesia.

CHAPTER IV

Adaptation Policies, Investments, and Institutional Reforms

Introduction

The current scientific consensus holds that greenhouse gas (GHG) emissions and atmospheric concentrations are set to increase for some decades to come, and that global mean surface temperature (and hence climate change with the impacts described in Chapter III) will continue to increase long after the peak of emissions is passed. Even with an aggressive mitigation strategy, global surface warming will continue up to and beyond the end of the 21st century. There is room for debate and uncertainty about how much warming will occur and at what rate it will unfold, but there is no doubt about the general trend of the curve. To maintain their present levels of prosperity and continue to develop, all countries have no alternative but to adapt to climate change. In the face of this adaptation imperative—and current insufficient capacity to adapt—the purpose of this chapter is to answer the following question:

Given the likely effects of climate change, the varied economies in developing countries in Asia and the Pacific, and the highly complex and dynamic socioeconomic and political environments within those countries, what initiatives should different development actors implement to build resilience and promote adaptation, while at the same time contributing to the achievement of the Millenium Development Goals (MDG) on poverty and hunger?

Decisions about which adaptation measures to adopt are not made in isolation by rural and agricultural individuals, households, or communities, but in the context of the wider society and political economy (Burton and Lim 2005). The choices are thus shaped by public policy, which can either support or at times act as a barrier or disincentive to adaptation. Possible supporting policies to stimulate adaptation measures are shown in Table 4.1.

Adaptation policy should be an extension of development policy designed to eradicate the structural causes of poverty and food insecurity. The complementarities between the two goals enable a streamlined approach toward achieving both. General policies that should be supported include (i) promoting economic growth and diversification; (ii) strengthening institutions; (iii) protecting natural resources; (iv) creating markets in water and environmental services; (v) improving the international trade system; (vi) enhancing resilience to disasters and improving disaster management; (vii) promoting risk sharing such as social safety nets and weather insurance; and (viii) investing in research and development, education, and health. However, as will be described below, adaptation must also go beyond good development policy.

Table 4.1: Examples of Adaptation Measures, by Sector

Sector	Examples of Adaptation Measures
Water	• Harvesting groundwater and rainwater • Increasing desalination • Protecting water catchment areas • Improving systems of water management • Developing flood controls and drought monitoring • Developing early warning systems
Agriculture and food security	• Changing agricultural practices, such as planting and harvesting times, fertilizer use, pest control, and so on • Improving irrigation techniques • Diversifying crops and income sources • Developing tolerant crop varieties • Improving extension services
Infrastructure and settlement, including coastal zones	• Strengthening coastal defenses • Improving key coastal infrastructure and human settlements • Integrating coastal zone management • Improving coastal planning and land use legislation • Supporting the relocation of high-risk populations
Human health	• Improving disease surveillance systems • Developing early warning systems • Improving preparedness and emergency response
Terrestrial and marine ecosystems	• Improving natural resource management systems • Protecting coral reefs and coastal vegetation • Improving species monitoring and identification • Creating protected areas and biodiversity corridors • Developing and maintaining seed banks

Source: Adger et al. (2007).

Adaptation options and their supporting policies should be adopted by the appropriate level of government and implemented by institutions in direct contact with beneficiaries. For example, adaptation responses such as changing planting dates and tillage practices will be implemented by farmers but might be facilitated through the provision of technical services such as local extension agents and regional universities and research institutions. Agricultural research, including crop breeding to develop drought- and heat-tolerant crop varieties, will require both public and private investment. Structural adaptation measures, such as creating water markets and price incentives, will need to be implemented on a national level, most likely in partnership with user organizations.

The challenge facing the global poor and those who would provide assistance is not solely a matter of finding ways of improving adaptation to anthropogenic climate change. Many communities, not necessarily limited to the poor, are not even well adapted to their current climate. The losses from floods, droughts, coastal storms, and other impacts are already unacceptably large and increasing. These impacts can be attributed to anthropogenic climate change only to a relatively minor degree. People are now suffering, and economic development is being impeded by extreme weather events because their level of adaptation is below what it could be given the "availability" of adaptation measures. There is, quite simply, an adaptation deficit in relation to the existing climate (Burton 2004). It follows that any efforts to improve current and future capacity to adapt to climate change has to be built on the present circumstances and state of vulnerability. This challenge thus includes reducing the adaptation deficit even as we proceed to address adaptation to future and growing risks (Burton 2006a, b).

How can the current adaptation deficit be eliminated and then adaptation policies and strategies extended to meet the challenges of climate change? As discussed in Chapter I, adaptation responses can be categorized according to the level of ownership of the adaptation measure or strategy. "Autonomous" adaptations are those that take place—invariably as a reactive response to climatic stimuli (that is, after the initial manifestation of impacts)—without the directed intervention of a public agency and assuming efficient markets (Smit and Pilifosova 2001; Leary 1999; Mendelsohn 2006). Policy-driven or "planned" adaptation is the result of a deliberate policy decision by a public agency, based on an awareness that conditions are about to change or have changed and that action is required to minimize losses or benefit from opportunities (Pittock and Jones 2000). Thus, autonomous and planned adaptation largely correspond with private and public adaptation, respectively (Smit and Pilifosova 2001). Table 4.2 provides examples of autonomous and planned adaptation strategies for agriculture.

Autonomous adaptation responses will be evaluated by individual farmers in terms of costs and benefits. It is argued that farmers will adapt "efficiently" and that markets alone can encourage efficient adaptation in traded agricultural goods (Mendelsohn 2006). Yet in situations where market imperfections exist—such as in the absence of information about climate change and the presence of environmental externalities and land tenure insecurity—climate change will further reduce the capacity of individual farmers to manage risk effectively. As a result, an appropriate balance needs to be struck between public sector efforts and incentives (such as capacity building and the creation of risk insurance) and private investment, so that the burden can be shifted away from poor producers.

Table 4.2: Examples of Autonomous and Planned Agricultural Adaptation Strategies

Type of response	Autonomous	Planned
Short run	• Crop choice, crop area, planting date • Risk-pooling insurance	• Improved forecasting • Research for improved understanding of climate risk
Long run	• Private investment (on-farm irrigation) • Private crop research	• Large-scale public investment (water, storage, roads) • Crop research

Source: Rosegrant et al. (2008b).

Achieving enhanced resilience in the face of climate change will require strengthening the adaptive capacity of countries in the region, as well as implementing appropriate adaptation investments, policies, and institutions. Moreover, mitigation measures can support adaptation options and provide much-needed funds for further adaptation (Bryan et al. 2008; FAO 2009b). Adaptation measures should be targeted at the countries, sectors, and people most vulnerable to the adverse impacts of climate change—that is, those most exposed, and most sensitive to the adverse impacts of climate change, as well as those with the least adaptive capacity (Figure 1.1).

In sum, to reduce vulnerability to climate change, important ongoing development initiatives need to be strengthened. These include developing agricultural markets, reducing distortions and subsidies in agricultural policies, continuing to pursue trade liberalization policies, enhancing social protection and microfinance, preparing for disasters, and—most critically—mainstreaming climate change in agricultural policies. Nevertheless, neither development policies nor autonomous adaptation measures will be sufficient to enable the developing countries in Asia and the Pacific to adapt to climate change. Adaptation will also require improvements that take existing development policies above and beyond their current capacity. Innovative policies include:

- changing investment allocation within agriculture and across sectors of importance to agriculture, including education and health;
- increasing the focus on risk-sharing and risk-reducing investments;
- improving spatial targeting of investments;
- eliminating existing detrimental policies that will exacerbate climate change impacts; and
- increasing the value of sustainable farming practices through the valuation of carbon.

Key components of new and innovative adaptation measures to climate change include:

- changes in agricultural practices;
- changes in agricultural water management for more efficient water use;
- agricultural diversification to enhance climate resilience;
- agricultural science and technology development, agricultural advisory services, and information systems; and
- risk management and crop insurance.

Countries in Asia and the Pacific can draw on a long history of coping with climate vagaries that will be useful in developing longer-term adaptation strategies. In fact, coping and adaptation are part of a continuum and lessons for adaptation policy can be drawn from examining how the rural poor are coping with increased climate variability. Understanding these existing coping strategies for risk reduction can help strengthen planning strategies for adaptation to climate change.

Local Coping Strategies

Despite the commonalities among the natural disasters occurring in the various subregions of Asia, coping strategies and indigenous knowledge used to deal with extreme weather events vary by subregion, country, and sometimes provinces within countries. The variations in coping mechanisms may be due to geographical differences, social acceptability, farmers' capacity (such as the knowledge and materials needed), and availability of government support. The local coping strategies presented here, according to areas applied, will benefit countries within subregions or those in separate subregions that experience the same natural disturbances. Further details of these and other local coping strategies are provided in Table A1.4.

Central Asia

Mountainous areas in Central Asia experience extreme cold, which affects crop production—a condition also experienced in the Himalayas of South Asia and similar zones of East Asia. As a response to the extreme cold, farmers in Tajikistan practice an alternative cultivation method that involves the use of cold frames to allow earlier seeding of plants (UNFCCC 2008a). This practice ensures continuous production of key crops despite extreme weather events, thus assuring farmers' income and even providing the potential for higher income. Another coping strategy applied by households in Tajikistan, and normally undertaken by women, is food preservation (UNFCCC 2008b). Before the onset of cold weather, women cure and can raw vegetables to ensure available food for the family during winter. This option is equally relevant in Nepal, where green leafy vegetables are processed during extremely cold conditions. The practice has the added benefit of promoting local enterprise among women (Manandhar 1998).

Central Asia faces extreme coldness, flooding, land degradation, soil erosion, and deforestation. Community-based approaches to both disaster and natural resource management, as well as government interventions, are important to address these impacts. Managing disaster risk through community-based management projects was found to be effective in Viet Nam (Francisco 2008, see also Box 4.7) and thus may be applied to countries in Central Asia as well. Aside from the solidarity it creates within the community and with the government, this approach has the added benefit of disseminating knowledge on coping with natural disasters, thus reducing risks in communities and ultimately saving lives. Other local coping measures adopted by communities in Tajikistan that can be applied in similar areas or countries in Central Asia are presented in Table A1.4.

East Asia

In the loess highlands of western and northern PRC, farmers control soil erosion through a series of dams or dam-fields (UNFCCC 2008c). The dams control floods and retain water, while the dam-fields are used to receive mud flows from erosion and thus create new land for cultivation. This strategy, however, has potential maladaptation effects, including the inability to control soil erosion over the entire watershed, particularly at the sides and top of the hills, and salinization of the dam-fields (UNFCCC 2008c).

On the Tibetan Plateau, extreme cold reduces the productivity and survival of livestock. In western Sichuan in southwestern PRC, livestock breeders select *jiulong* (valley-type) and *maiwa* (plateau-type) yak during extremely cold weather (Wu 1998). This strategy ensures continuous production of yak and thus provides a source of food and income for farmers. It might be practical for other Asian farmers to check the feasibility of livestock breeding in areas affected by extreme coldness, or extreme heat, for that matter.

South Asia

Changes in climatic conditions will result in flooding, erratic rainfall, drought or aridity, and rising sea levels in the countries of South Asia. In Bangladesh, there are two types of flooding; *barsha,* or moderate flooding that brings silt to agricultural land and thus increases soil fertility, and *bonna,* or high-intensity flooding (UNFCCC 2008d) that causes damage to agricultural crops, low survival or productivity of livestock, waterlogging, loss of livelihood, and —in extreme cases— destruction of settlements and loss of lives. Farmers have devised a number of coping strategies at the farm level as a means of survival during the *bonna* floods. Farmers in Jamalpur District and other coastal areas such as the Brahmaputra/Indo-Gangetic River Basin have established community rice/fish farms, a practice known as integrated agriculture–aquaculture (IAA), in floodplains or during the flood season (Dey and Prein 2005; FAO 2001). This system ensures food and nutrition availability, increases incomes, improves use of resources, and promotes community cooperation.

Another adaptation strategy common to most South Asian countries is appropriate crop selection as a response to flooding. To avoid the impact of floods, farmers in Bangladesh adjust their transplanting of *aman* (a wet season rice variety) (UNFCCC 2008e). The farmers transplant early or late varieties of *aman* to avoid crop losses due to variations in the recurrence of floods. The early production of rice encourages the growing of other additional crops. This practice enhances incomes not only from rice production, but also from other crops as well. Farmers in Uttar Pradesh, India, may benefit from this kind of coping strategy given that flooding in this area is similar to that in Bangladesh.

Hydroponics is another method of cultivating crops during the flood season, especially in waterlogged areas (UNFCCC 2008f). Crops (mostly vegetables) are grown in floating gardens. This practice ensures subsistence food during flooding and may be a potential source of additional income. Duck raising may also be exploited as part of livestock production during the monsoon period. Mallick (2006) explains that raising ducks and diversifying the diets of communities are coping strategies for the flood season in Bangladesh. Hydroponic vegetable farming might be an option for the Mekong Delta as well.

Rising sea levels result in flooding, which causes waterlogging. In Goa, India, farmers in waterlogged areas practice *khazan*—a traditionally community-managed IAA system. Aside from establishing cooperation within the community, the practice promotes a mutually beneficial relationship between rich and poor constituents by generating employment and labor sharing (TERI n.d.).

Another natural disaster of significance in South Asia is drought or aridity. In general, the most common adaptation strategy consists of sustainable water management through tanks and dams.

In Sindh, Pakistan, temporary structures, 1–3 meters deep known as *laths* are used for traditional flood irrigation (UNFCCC 2008g). In India, *anicuts* (small to medium-sized dams) are used to harvest rainwater and serve as reservoirs (Narain, Khan, and Singh 2005). Other rainwater-harvesting techniques include underground tanks or *kunds* in the Thar Desert of India (UNFCCC 2008h); gutters and pipes to collect rooftop rainwater in Bangladesh (UNEP DTIE 2000); bamboo stems for drip irrigation in Bhutan (UNFCCC 2008i); ground barriers (such as contour bunds, *nallan* bunds, or gabions) and shallow excavations (such as contour trenches, farm ponds, and reservoirs in bedrock) in Maharashtra, India (Sivanappan 1997); and cascading tanks in Sri Lanka (Herath 2001).

Other coping strategies involve appropriate crop selection. In the Barind Tract[11] of Bangladesh, farmers plant drought-resistant fruit trees, such as mangoes, or engage in jujube gardening (Selvaraju et al. 2006). Domesticating indigenous varieties of cereals and fruit trees promotes local enterprises for women in several northeastern states in India. Alternative cultivation methods such as seedbed methods for transplanting seedlings (UNEP DTIE 2000), home gardening (UNFCCC 2008j), and rotational cropping (Verma 1998) are also helpful in increasing crop production, as well as ensuring food availability during adverse climatic conditions.

Erratic rain can result in soil erosion and land degradation. Methods of controlling soil erosion in the Himalayas include terracing, field leveling, plowing, sheet erosion control, and biofencing (Verma 1998). Application of manure or ash from organic manure, crop residues, or kitchen ash can enhance soil fertility (Verma 1998).

Southeast Asia and the Mekong Subregion

As in the IAA system in South Asia, farmers in West Java, Indonesia, grow fish in *huma* or dry swidden fields during drought conditions and in *sawah* or wet fields during flooding (FAO 2001). This alternative cultivation method encourages the generation of cash income and the availability of food for farmers during times of extreme weather conditions like drought and flood. To overcome drought conditions, farmers in the Philippines are encouraged to (i) change cropping schedules to lessen demand for irrigation or adjust the cropping calendar according to water availability; (ii) line canals to reduce water losses; (iii) maximize the use of available water during abundant periods by constructing reservoir-type projects; (iv) redesign irrigation facilities to reuse return flows; and (v) introduce other water-saving techniques (Lansigan 2003). Some traditional farming practices such as drip irrigation, mulching, and other improved irrigation methods, as well as windbreaks to minimize wind speed and evapotranspiration, can improve the use of dwindling irrigation water (Baradas and Mina 1996 in Jose and Cruz 1999). Drought-tolerant crop varieties and efficient farming practices should likewise be considered. Boer (2009) presented the same strategic options found in the Philippines to farmers in Indonesia. Aside from improved crop technologies and water efficiency, Boer suggested the creation of climate field schools (CFSs) to develop farmers' capacity in terms of information on climate forecasting and risk management. Boer (2009) further clarified that CFSs go beyond the farm level. Off-farm programs on agribusiness can help farmers estimate production periods for agricultural commodities based on climate forecasts and thus can help them take advantage of expected price changes for these

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[11] The Barind Tract includes Dinajpur, Rangpur, Pabna, Rajshahi, Bogra, and Joypurhat of Rajshahi Division, Bangladesh.

commodities. Furthermore, such programs can increase farmers' bargaining power by enhancing collaboration with the government, private sector, farmers' organizations, and other groups.

In the Mekong Delta, communities in Attapeu Province, Lao People's Democratic Republic (Lao PDR), diversify their diets during the flood season from rice-based diets to edible aquatic resources such as fish, crabs, and other food from the Delta. Prolonged food shortages, however, threaten wetland and forest resources in the Delta (Meusch et al. 2003). Viet Nam illustrated a successful community-based adaptation strategy in response to climatic changes in Quang Dien and Phu Vang Districts, Thua Thien Hue Province, along the country's north–central coast (Francisco 2008). Affected communities and the government worked together to build capacity for adaptation to climate change. The critical steps in this effort were building scenarios, then planning and implementing projects. The main objectives were to help build communities' adaptive strategies in the face of recurrent climatic catastrophes and to minimize the loss of lives and property (Francisco 2008).

Innovative Adaptation to Climate Change

Major components of new and innovative adaptation measures to climate change include (i) changing agricultural practices; (ii) changing agricultural water management to promote more efficient water use; (iii) diversifying agricultural practices to enhance climate resilience; (iv) developing agricultural science and technology, agricultural advisory services, and information systems; and (v) introducing risk management practices and crop insurance. Moreover, innovation will be a key for investment allocation, including changing the allocation of investments within and across sectors, increasing the focus on risk-sharing and risk-reducing investments, and improving spatial targeting of investments (these issues are discussed in the section on investments for adaptation). Other important adaptation strategies include eliminating existing detrimental policies that will exacerbate climate change impacts (which is discussed in the section on strengthening existing development policies), and increasing the value of sustainable farming practices through the valuation of carbon (which is discussed in Chapter V). Table 4.3 lists key innovative adaptation policies.

Changes in Agricultural Practices

Key changes in farm management practices include land use changes to maximize yields under new conditions; the application of new technologies and changes in input use including organic and low external-input agriculture; the application of new land-management techniques, such as zero till (Box 4.1); changes in crop and livestock varieties; changes in planting dates; and the introduction of water-use efficiency techniques. Changes in agricultural water-management practices will be discussed in succeeding paragraphs. Adaptive agricultural management practices include effective use of pest-, disease-, and weed-management systems through wider application of integrated pest and pathogen management techniques and development and use of crop varieties resistant to pests and diseases, as well as efficient quarantine capabilities and monitoring programs. Changes in location or timing of cropping activities are very simple, but also very effective techniques. Matthews et al. (1997) found that changing the planting time can lessen the negative impacts of extreme temperatures. Farmers in the Mekong Delta of Viet Nam are using a shorter cycle rice seed variety to adapt to climate risks (Oxfam 2008).

Table 4.3: Innovative Adaptation to Climate Change in Asia and the Pacific

Area of Adaptation	Implementation Level				Scope for Mitigation	Institutional Support	Existing Experience in Asia and the Pacific
	Farm	Community	National	Global			
Changes in agricultural practices	Zero till, no till, organic agriculture, low input agriculture, changing planting dates, crop varieties, soil and water conservation techniques, integrated pest and pathogen management techniques, supplementary livestock feeds	Integrated pest management, Transfer of indigenous knowledge	Strong extension services, functioning credit markets, market information system, climate information system	Integration of agriculture into carbon markets, efficient quarantine capabilities and monitoring programs	Sustainable land management, pasture and grazing land management, restoration of degraded soils, livestock management, agroforestry practices, biofuels, nutrient management programs, promotion of low-input and/or no-till agriculture	Functioning markets and information services facilitating efficient use of resources and access to information	Alternative wetting and drying for rice production (the PRC); zero and/or low till (Indo-Gangetic Plains); nitrogen fertilizer added to soils only after soil nitrogen testing (the PRC); shorter cycle rice seeds in the Mekong Delta (Viet Nam)
Changes in agricultural water management	Water harvesting, on-farm irrigation, soil and water conservation, drip and sprinkler systems, groundwater use, treadle pumps	Small reservoirs, watershed management, water trading	Investment in large-scale systems, reservoirs	Support for funding	Water quality legislation limiting nonpoint source pollution from agriculture; groundwater development might increase CO_2 emissions as might irrigation expansion	Credit availability, monitoring and enforcement of water quality standards	Small tanks for dry-season irrigation (Tamil Nadu and/or Sri Lanka); pilot water trading (northern PRC), carbon credits for treadle pumps (India); water quality programs that control nonpoint source pollution (the PRC)

continued on next page

Table 4.3 continued

Area of Adaptation	Implementation Level				Scope for Mitigation	Institutional Support	Existing Experience in Asia and the Pacific
	Farm	Community	National	Global			
Agricultural diversification	Shrimp and/or rice farming in coastal areas with rising sea levels, migration, off-farm work					Strong extension services	Flexible water control structures supporting shrimp and rice production (Viet Nam's Mekong Delta)
Agricultural science and technology development		Participatory crop breeding	Drought-and/or heat-resistant crops; salinity-tolerant varieties, water-conserving crops, animal breeds	Support for funding, strengthening research for sustained agricultural biodiversity	Breeding for higher fertilizer use efficiency	Capacity building of scientists (curricula at BSc, MSc, and PhD levels, on-the-job training), public–private partnerships, appropriate intellectual property rights and/or biosafety systems, strong international agricultural research centers and national agricultural research systems	Aerobic rice (northern PRC)

continued on next page

Table 4.3 continued

Area of Adaptation	Implementation Level				Scope for Mitigation	Institutional Support	Existing Experience in Asia and the Pacific
	Farm	Community	National	Global			
Agricultural advisory service and information systems		Farmer-to-farmer training	Support dissemination of climate-resilient varieties, technologies, and practices; disseminate (seasonal) climate forecasts		Link farmers to carbon markets; disseminate information on mitigation technologies and practices; build capacity on certification, monitoring, and obtaining carbon credits	Pluralistic, demand-driven, decentralized advisory service; strong research-extension-farmer linkages	
Risk management and crop insurance	Crop insurance	Contract farming, weather index insurance, futures and option contracts	Weather index insurance	Global climate insurance		Appropriate agricultural advisory service, hydrometeorological infrastructure, functioning financial markets and institutions	Various type of contract farming arrangements for crab and shrimp farmers (Indonesia)

Source: Compiled by authors.

Box 4.1: Zero Tillage—An Effective Mitigation and Adaptation Strategy in South Asia

In the past decade, many farmers in the rice-wheat farming system in the Indo-Gangetic plain of Bangladesh, India, and Pakistan have adopted minimum-tillage practices, which conserve resources under climate change. Since being introduced by researchers from a consortium of international agricultural research centers and national agricultural research systems in the late 1990s, zero tillage for wheat has been adopted rapidly, reaching more than one million farmers on an estimated 5.6 million hectares (Rice-Wheat Consortium 2005). Such rapid and widespread adoption of a natural resource management innovation is rare, although zero or minimum tillage has been adopted on a large scale in intensive mechanized farming systems elsewhere, with global adoption estimated to be as high as 90 million hectares (Murray et al. 2005). Farmers' wheat yields have reportedly improved, and production costs have decreased by an average of $65 per hectare with additional benefits for water conservation and

Organic agriculture deals with management of natural cycles to enhance critical nutrients like nitrogen, increase soil organic matter, and protect the soil from erosion (Boron 2006). Leguminous plants fix atmospheric nitrogen, and manure from livestock increases the nutrient content of the soil and minimizes the need to apply synthetic fertilizer (enabling low external inputs). This reduces—and in some cases completely eliminates—greenhouse gas (GHG) emissions, particularly nitrous oxide (N_2O) (Kotschi and Muller-Samann 2004). The drop in N_2O emissions may be further enhanced by diversifying crop rotations with green manure to improve soil structure. This is also beneficial because organic techniques aerate the soil so that it significantly lowers mobile nitrogen concentrations (ITC, UNCTAD, and WTO 2007). In addition, organic agriculture offers potential for carbon sequestration via the organic matter, although rates of sequestration depend on the soil's texture and structure, as well as rainfall, temperature, the farming system, and soil management practices used (Hepperly and Setboonsarng 2009).

The practices described above utilize farmers' indigenous knowledge of local farming, which itself is an important aspect of adapting to climate change (Tengo and Belfrage 2004; Salinger, Sivakumar and Motha 2005; Stigter et al. 2005; FAO 2008g). The traditional knowledge, identities, and practices of indigenous and local communities embody ways of life relevant for conservation and sustainable use of natural resources and biodiversity, and encompass all aspects of farming systems (Boron 2006). Farm practices, such as planting times, crop varieties, crop rotation, and others are all based on farmers' extensive knowledge about local ecosystems. Collaboration in the conservation, development and use of local and traditional biological materials; incentives for and development of capacity among scientists and formal research organizations to work with local and indigenous people and their organizations; a higher profile in scientific education for indigenous and local knowledge as well as for professional and community-based archiving and assessment of such knowledge and practices will all contribute to enhanced adaptation to climate change (McIntyre et al. 2009).

Furthermore, organic agriculture reduces farmers' vulnerability to climatic variability by encouraging highly diverse farming systems, thus improving income diversity (Muller 2009). Promotion of low-risk farming strategies with reduced input costs, lowers the risks of crop failure due to extreme weather (Eyhorn 2007). Setboonsarng (2009) assessed the relative impacts of organic agriculture on the Millennium Development Goals (MDG) based on 11 case studies in six Asian countries. Results showed that organic agriculture has positive impacts on MDG goals 1, 7, and 8, focusing on income and food security, the environment, and global development partnerships, respectively. Other relevant outcomes are related to farmer's health, sanitation, and education. A comparison of profits resulting from organic and conventional agricultural practices is presented in Table 4.4.

Table 4.4: Organic Versus Conventional Agricultural Practices: A Profit Comparison

Crop/Year/Source	Local Currency/Unit of Area	Number of Households	Difference (organic agricultural profit–conventional agricultural profit)	P-Value
Rice				
2003	Thailand (baht/rai)	443	8,887	0.00
2005	Thailand (baht/rai)	243	90	0.72
2006	Thailand (baht/rai)	626	1,127	0.04
Bananas	Thailand (baht/rai)	110	5,387	0.12
Asparagus	Thailand (baht/rai)	148	9,720	0.12
Tea				
Chinese	PRC (yuan/ha)	240	837	0.00
Sri Lankan	Sri Lanka (rupee/ha)	200	6,129	0.25
Horticulture	PRC (yuan/ha)	220	1,101	0.00
Lemongrass	Bhutan (1,000 Nu)	96	23	*Data not given*
Rice				
Cambodia	Cambodia (1,000 riel/ha)	615	179	0.14
Lao PDR	Lao PDR (1,000 kip/ha)	368	1,296	0.03

ha = hectare, PRC = People's Republic of China, Lao PDR = Lao People's Democratic Republic.

Note: Organic products from Cambodia and Lao PDR are noncertified. Data for Cambodia are for cash profit only. Data for Bhutan are simple averages. One rai is equivalent to 1,600 m^2.

Source: Setboonsarng (2009).

Additionally, greater diversity was observed in organic farms where farmers applied more agroecological practices and adapted more soil carbon sequestration methods, such as applying mulch and green manure, and recycling organic matter through composting (Setboonsarng 2009).

Changes in climatic conditions influence intensive livestock production. During warm weather, there is less need for winter housing and feed concentrates. On the other hand, warm weather requires increased management and infrastructure to lessen the detrimental effects of heat-related stresses on productivity, fertility, and fatality (Howden et al. 2007). Heat-tolerant livestock breeds have lower levels of productivity (Howden et al. 2007), suggesting a need for additional research into higher yielding, heat-tolerant breeds.

Field-based livestock systems require extra attention in implementing adaptation measures (Howden et al. 2007), including matching stock rates with pasture production, rotating pastures, and changing grazing times and production periods. Additional measures include integrating mixed crop and livestock systems using adapted forage crops, reassessing fertilizer applications, ensuring plentiful water supplies, and utilizing supplementary feeds and concentrates (Daepp, Nösberger, and Lüscher 2001; Adger et al. 2003; Batima et al. 2005).

In any given situation or context, the choice of adaptation measures may be difficult and constrained by traditional beliefs and cultural practices, lack of knowledge about implementation, or excessive costs. Notwithstanding these impediments, farmers and others at risk from climate change can receive several forms of external help. Possibilities include technical information and advice or guidance, weather and seasonal climate forecasts and warnings, drought or flood relief, and insurance or other forms of financial assistance and risk spreading. These actions can be taken to reduce exposure or vulnerability to risk where the poor agriculture- or resource-dependent population lives. Poor farmers are not passive recipients of external assistance. They can and do take other initiatives, such as diversifying their sources of income by beginning other enterprises at the village level or by migrating temporarily or permanently to towns or cities in search of other kinds of employment.

A combination of these suggested adaptation measures for cropping systems will have substantial potential to reduce the destructive effects of climate change in agriculture. Other types of support are also required, however, because farmers cannot adequately adapt to climate change and variability on their own (Box 4.2).

Changes in Agricultural Water Management

Water management adaptation measures that are being applied by farmers include the wider use of practical technologies, such as water harvesting, soil moisture conservation techniques (for example, crop residue retention), and effective use and transport of water during drought periods (Howden et al. 2007). Some of these water management practices can prevent waterlogging, erosion, and nutrient leaching when rainfall increases.

Climate variability is increasing in places where it is already greatest. The reduced storage of precipitation as snow, as well as the earlier melting of winter snow, is leading to shifts in peak runoff away from the summer season when demand is high in parts of Asia and elsewhere. Low-lying coastal areas affected by rising sea levels are experiencing inundation and increased damage, with storm surges and increased saline intrusion into vulnerable freshwater aquifers. Nonrenewable groundwater resources are being

Box 4.2: Coping Versus Adapting: Examples from South Asia

Smallholder farmers in the semi-arid Jhalawar District in Rajasthan, India, are highly vulnerable to climate variability, such as consecutive droughts. In 2002, Jhalawar experienced its fourth consecutive year of drought. To cope with climate variability, farmers have shifted from traditional crops, such as sorghum and pearl millet, to soybeans, which earn higher market prices and yield quick returns due to their shorter life cycle (Kelkar and Bhadwal 2007). In the Lakhakheri Umat village, where nearly all of the farmers have small or marginal landholdings, farmers use a variety of coping mechanisms, such as selling cattle, shifting to other types of crops and labor, and undertaking seasonal migration (Jhalawar, Rajasthan, India; TERI 2003).

In addition, female farmers in flood-prone areas of Bangladesh are building “floating gardens” made of hyacinth rafts in order to grow vegetables during the flood season (UNDP 2007). These options are temporary coping measures, however, that do not prepare farmers for future climate problems. As a result of lack of awareness, procedural complexities, and stringent eligibility criteria, farmers do not use options that improve long-term adaptive capacity, such as institutional credit, crop insurance, and drought-resistant varieties (Kelkar and Bhadwal 2007).

Muhammed (2004) reports on coping strategies practiced in vulnerable areas of South Asia. During drought periods, farmers in India and Pakistan borrow money from lenders and banks, and some migrate to search for alternative livelihoods. Other adaptation options include buying or saving fodder for livestock, given changing feeding patterns of livestock, selling livestock and other belongings, shifting livestock to other areas, planting less water-intensive crops, selling or mortgaging property, and—if available—working in government-sponsored food- or cash-for-work programs.

Furthermore, farmers in Bangladesh, India, and Nepal cope with flooding by migrating to look for alternative livelihoods, engaging in off-farm activities, protecting livestock, applying for insurance for local crop varieties, harvesting and trading premature fish to avoid escape and loss, spending savings, and securing loans from the informal sector.

To move beyond short-term coping mechanisms, effective farm-level adaptation requires access to improved agricultural technologies. Additional information on coping strategies and possibilities for future adaptation are presented in Table A1.4.

depleted. Consequently, increased flexibility in infrastructure and operations of irrigation systems—particularly large irrigation systems—will be crucial. Water-delivery systems need to be (technically and institutionally) flexible so that they can deliver water for multiple uses (that is, agriculture, the environment, urban areas, industry, and the generation of energy). Such systems range from entire river basins down to and within large irrigation systems, and under new ranges of water availability. The modernization of irrigation systems, in particular the establishment of better control systems at key distribution points, can increase farmers’ access and control over irrigation water resources, conserving water resources and enhancing adaptability to climate change (Renault, Facon, and Wahaj 2007). This improvement will be particularly important not only for the large surface irrigation systems fed by glaciers and melting snow in the PRC and India, but also for the large systems found in much of Central Asia.

In fragile upstream watersheds that practice a combination of irrigated agriculture, rainfed agriculture, pasture, and forestry, a holistic approach to watershed management will be important in adapting to more erratic rainfall events, especially in Lao PDR, Nepal, and Viet Nam, as well as in some of the island states.

Water storage will be a key adaptation strategy, taking the form of seasonal storage systems in the monsoon regions where peak flood flows are likely to increase. Water storage comprises much more, however, including a continuum of surface and subsurface water storage options ranging from natural wetlands and water stored *in situ* in the soil, to rainwater-harvesting ponds and small and large reservoirs. Concerns about the negative social and environmental impacts led to reduced investment in large dams in the 1990s. Now, however, given the need to produce more food, provide stable water supplies for growing urban areas, and provide more energy resources, investments in large dams in Asia are once again increasing.

Investments in supplemental irrigation will be important to reduce the consequences of irregular rainfall through short-term interventions to capture and store more soil moisture or runoff. This approach will be particularly important in the semi-arid and arid areas of Central Asia, Afghanistan, parts of India, and some of the Pacific Island states.

Large-scale groundwater development in Asia was undertaken in response to the availability of cheap pumps from the PRC and unreliable or unavailable access to surface water sources, particularly in India and parts of East and Southeast Asia. Groundwater now accounts for 50% of irrigation supply in South Asia and perhaps two-thirds of supply in the grain belts of northern PRC (Giordano and Villholth 2007). Groundwater development can be an effective method of adaptation to climate change, given the just-in-time availability and high efficiency of use of the resource. When extreme weather events turn into disasters, groundwater may play a crucial role in securing safe emergency water supplies. However, this will require increased attention, and creation and sharing of knowledge on groundwater potentials, limitations on continued use, and best management practices at multiple levels. Some of the adaptation benefits of groundwater irrigation may be offset, however, by CO_2 from energy used to deliver the water or from N_2O emissions from higher moisture. Moreover, in coastal areas, groundwater will be affected by saline intrusion as a result of rising sea levels. Conjunctive surface and groundwater management and economic incentives for reducing unsustainable groundwater use are important avenues to sustainably continue groundwater use in India, the PRC, and other parts of Southeast Asia. In South Asia, groundwater over-extraction is due to poor policy, driven by free or quasi-free electricity supply for groundwater extraction. The cost of such policies is expanding dramatically under climate change as the real price of water will rise due to increased volatility of both food prices and water resource availability.

One avenue for both adaptation and mitigation might be treadle pump development. The Energy and Resources Institute (TERI) estimated for International Development Enterprises of India that the operation of one treadle pump annually reduces CO_2 emissions by 477 kilograms (kg) (TERI 2007a). The total emission reduction was quantified at 150,000 tCO_2-eq for treadle pumps sold between April 2001 and March 2004. The entire project is estimated to generate reductions of more than 800,000 tCO_2-eq in its lifetime. Given that water scarcity is expected to increase in parts of Asia as a result of global warming and other drivers, application of water-conserving irrigation technologies will be an important adaptation strategy. TERI (2007b) found that for four study areas in India, micro-drip irrigation saved an average of 54% of water resources and 39% of electricity compared with flood irrigation. This result is equivalent to an average annual CO_2 emission abatement for every acre of drip adoption of 675 kg per acre per year.

Agricultural Diversification

Many adaptation strategies are forms of agricultural diversification, including some of the farm-level adaptation strategies described in Box 4.2. One example of successful farm-level diversification has been alternative rice/shrimp farming in the Mekong Delta of Viet Nam, facilitated by flexible water control structures that allow for both freshwater and brackish water control.

Diversification into off-farm employment and seasonal migration are strategies that have been adopted for many years in a number of Asia and the Pacific countries as a result of resource scarcity, particularly small farm sizes and lack of income opportunities in farming. In Indonesia, 34% of rural employment was in the nonfarm sector, and nonfarm income provided 43% of total rural income in 2002 (SEARCA/IFPRI/CRESECENT 2004).

Organic agriculture and indigenous and traditional knowledge also generally call for agricultural diversification to ensure flexibility and reduce risk under current climate variability, which should also support future climate change.

Agricultural Science and Technology Development

If the challenges of climate change for the agriculture sector are to be met, technological change that increases agricultural productivity growth, saves land and water, and increases the flexibility of cropping systems is essential. In addition to conventional breeding, biotechnology and genetically modified (GM) crops are also likely to become essential tools for adapting to increased climate stress. They have the potential to increase crop adaptation to heat, drought, and salinity stresses, as well as insect and disease resistance, while improving crop productivity, mitigating GHG emissions from fertilizer use, reducing pesticide and herbicide applications, and modifying plants for use as biofuel feedstock. Investments in biotechnology, including GM crops, could provide a transformational approach to addressing the tradeoffs between energy efficiency and agricultural productivity.

Biotechnology tools—including DNA (or deoxyribonucleic acid) sequencers, chip-based gene expression, molecular markers, and many others—are revolutionizing crop improvement. Continued improvements in high throughput technology (a scientific experimentation method allowing scientists to conduct quickly millions of genetic and other types of tests) will make gene discovery for crop improvement routine and inexpensive. Complete or draft genome sequences for rice, poplars, grapes, papayas, and maize are now available; sequences for soybeans, sorghum, and canola will be available this year; and complete genome sequences for all important crop species will be completed by 2015. Moreover, crop cultivars with GM traits have been broadly commercialized in the past 12 years. In 2007, transgenic varieties, most containing traits for insect or herbicide resistance, were grown on 114 million hectares (ha), primarily in Argentina, Brazil, Canada, the PRC, India, and the United States (James 2007). Many more crops and traits are currently in development and are slowly entering the regulatory pipeline (Atanassov et al. 2004). Farmers' experience with GM crops has been largely positive, with increased management options, reduced pesticide use, and in some cases improved yields (Brookes and Barfoot 2005). This experience suggests that GM crops are becoming an established technology in these countries at the early stages of application.

Marker-assisted breeding has clear advantages over conventional breeding practices regarding rates of gain of crop yield and associated traits (Figure 4.1) (Eathington et al. 2007 in Edgerton 2009). Moreover, in aggressive breeding programs, such as Monsanto's corn-breeding program in North America, product half-life is only approximately 4 years, indicating the potential for relatively rapid adjustment to more adverse climate conditions if sufficient funding is made available (Edgerton 2009).

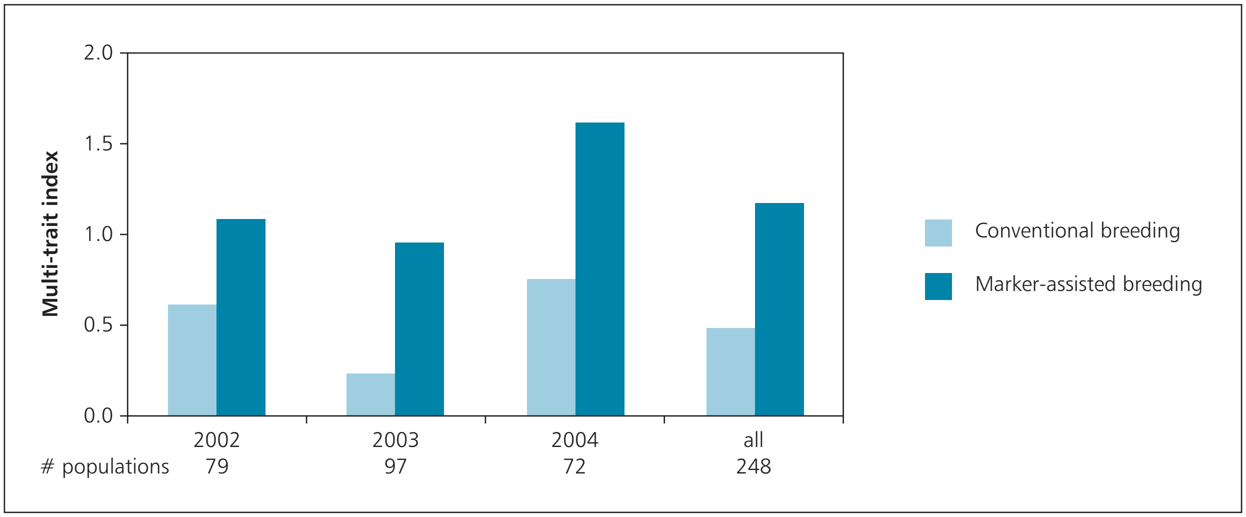
The potential for improved crop varieties to increase nutrient use efficiency and decrease pesticide use

Climate change is projected to increase the pressure on existing crop varieties from both insects and weeds. Breeding programs in developing countries are developing high-yielding seeds in specific biotic and abiotic environments. Recent developments in GM research have produced soybeans, rapeseed, cotton, and maize for herbicide tolerance, and other varieties are being developed to resist various pests and diseases (Phipps and Park 2002).

Pest-resistant and herbicide-tolerant technologies can potentially reduce pesticide and herbicide use,

Figure 4.1: Benefits of Marker-Assisted Breeding

Expressed as Rates of Gain in Multi-Trait Breeding Index Over 3 Years



Note: The multi-trait index is weighted toward yield but also incorporates other agronomic traits, such as grain moisture and stalk strength.

Source: Eathington et al. (2007) in Edgerton (2009).

thus reducing harmful environmental impacts such as water pollution, while also improving yields. The impacts of these technologies are mixed, however. Insect-resistant GM crops—notably *Bt* (or Bacillus thuringiensis) cotton—reduced the amount of pesticide applications by 1.2 million kilograms (kg) between 1996 (when *Bt* cotton was introduced) and 1999. This amount is equivalent to 14% of all insecticides used (James 2000). But the impact of herbicide-tolerant crops on the total amount of herbicides used is ambiguous. Although herbicide-tolerant crops have reduced the number of active ingredients sprayed, the weight of the herbicides used has remained unchanged or may have slightly increased (Benbrook 2001).

Synthetic nitrogen fertilizers aid crop growth but are also major contributors to GHG emissions. More efficient nitrogen use by crops has several important environmental advantages in addition to lowering production costs for farmers in light of high fertilizer prices. Genes have been identified that improve the efficiency with which plants use nitrogen fertilizer, and GM plants with these genes are currently being characterized under field conditions. The reduced need for synthetic nitrogen fertilizers will reduce energy costs and help lower GHG production.

In the longer term, additional fundamental breakthroughs could be made. A crop's ability to produce yields across many different growing environments is complex and can be affected by many different genes. The genes involved in determining yield potential and their importance and expression patterns vary widely depending on the crop and growing environment. Even so, genes that directly affect yield have been identified and are being evaluated in the field. The increase in atmospheric carbon dioxide has a fertilization effect on crops with C3[12] photosynthetic pathway and thus promotes their growth and productivity. On the other hand, C4[13] crops have improved water-use efficiency. Research continues to adapt crops to both higher carbon dioxide and increased water stress, including research into the conversion of C3 crops, such as rice, to C4 plants (Normile 2006). The technical hurdles for this approach are high, but it is realistic to expect that these improved crops will be available in field trials within the next 10 years.

Biotechnology could profoundly affect future demand for freshwater, as well as investment requirements in irrigation and other water sectors. GM crops have the potential to address major water-related stresses under both rainfed and irrigated farming and possibly to offer solutions to important water-quality problems. Breeding crop varieties with high water-use efficiency—a good indicator of the crop's ability to withstand environmental stresses, especially drought and salinity—is one policy option. Many genes associated with adaptation to various types of stress tolerance have been identified and incorporated into crops. These stress-tolerant genes are being field tested in maize, rice, wheat, and soybeans and will be developed in other crops.

Conventional and molecular plant breeding have been and remain important tools for dealing with drought, and this should continue, but GM

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[12] C3 plants are so-called because the CO_2 is first incorporated into a 3-carbon compound. They include many trees and agricultural crops, such as rice, wheat, soybeans, potatoes, and vegetables.

[13] C4 plants are so-called because the CO_2 is first incorporated into a 4-carbon compound; C4 plants photosynthesize faster than C3 plants under high light intensity and high temperatures, and are more water-use efficient. They include mostly tropical plantforms such as grasses and agriculturally important crops like maize, sugar cane, millet, and sorghum.

approaches appear to offer more genetic variations that could lead to further advances. Despite the commercial selection of major crops for drought tolerance over the past 50 years, together with traditional selection over the preceding centuries, adequate water is still the factor that limits crop production more than any other. The use of breeding to improve drought tolerance has been well tested, and the degree of improvement is well understood. Initial experiments and field testing with transgenics suggest that higher levels of drought tolerance appear possible. Most interestingly, progress in drought tolerance may be possible without interfering with yields under good conditions, which is often a tradeoff with conventional breeding.

Condon et al. (2004) discuss three main processes that crop breeders can use to promote high water-use efficiency: (i) moving more of the available water through the crop rather than letting it go to waste by evaporating from the soil surface, draining beyond the root zone, or remaining behind in the root zone during harvesting; (ii) acquiring more carbon (biomass) in exchange for water transpired by the crop (that is, improving crop transpiration efficiency); and (iii) partitioning more of the acquired biomass into the harvested product. These processes are interdependent, and their relevance depends on water availability during the crop cycle. Because these crops are not yet on the market, crop simulation modeling can be used to assess the likely impact of changing the expression of crop traits on water-use efficiency and yields (Condon et al. 2004). Biotechnology's role as a possible substitute for large-scale water investments must be considered in future planning for irrigation and water supply and sanitation investments.

Risks and limitations

Increased confidence in the ability to evaluate the risk of and maintain safe use of GM crop varieties will be necessary if the benefits of these technical advances are to be captured (Rosegrant, Cline, and Valmonte-Santos 2007). Food safety risks are often raised, but no documented case of food safety problems or negative human health impacts from GM food crops has occurred, despite many years of production of GM crops. Potential environmental risks such as the possibility of out-crossing with wild relatives to create resistance to diseases, or the rapid creation of new pest biotypes that are adapted to GM plants must be managed through appropriate safeguards (World Bank 2008b). Similar to the case of other modern crop varieties, if a small number of GM cultivars displace traditional cultivars, crop biodiversity may decrease (FAO 2000). Negative impacts of the introduction of GM crops on crop biodiversity are reduced if traits are introduced in several varieties, as in India, where more than 110 varieties of *Bt* cotton are growing (Gruere, Mehta-Bhatt, and Sengupta 2008).

Implementing GM and other biotechnology

A number of steps need to be taken to improve the adoption and benefits of biotechnology and GM crops. In order for technical advances to be translated into products that can improve crop production under climate change, public- and private-sector organizations need to develop additional capacity to address complicated intellectual property, risk management, and regulatory requirements. Additionally, the emergence of private-sector crop improvement has resulted in opportunities for the private and public sectors to work together, but only if there is suitable understanding of the concerns of both sectors.

In many cases, public–private partnerships (PPPs) will constitute the best mechanism for ensuring broad access to improved cultivars by identifying and encouraging effective plant breeders' rights, intellectual property regimes, and technology transfer mechanisms. Policies that support the development of PPPs will increase access to advanced crop improvement technologies where conditions are not yet adequate to promote private commercial seed companies. Specifically, improvements related to climate change—such as nitrogen- and water-use efficiency—are critical for developing countries.

The potential importance of PPPs to agricultural biotechnology research is well recognized (Spielman, Hartwich, and von Grebmer 2007a, b; Spielman, Cohen, and Zambrano 2006; Pingali and Traxler 2002; Pray 2001). Examples for Asia and the Pacific are presented in Box 4.3.

Policies that favor private-sector investment in crop improvements targeted to climate change in the developing world are particularly beneficial. These policies include (i) decreasing the bureaucratic hurdles to business formation and freedom to operate, (ii) developing infrastructure that enables production and distribution of improved seeds and other agricultural inputs, (iii) developing appropriate regulatory and biosafety protocols for introducing transgenic cultivars, and (iv) reforming intellectual property rights in order to encourage private investment in crop improvement. These policies should be combined with negotiation of seed and technology licensing fees that provide access for small farmers to advanced technology.

Box 4.3: Public–Private Partnerships for Biotechnology Development in Asia and the Pacific

Bt cotton in India. At present, the development and diffusion of *Bt* cotton in India is being driven by a number of close public–private interactions. Key proponents include (i) private-sector leaders in the crop-science industry, namely Monsanto and Maharashtra Hybrid Seed Company (MAHYCO, based in Jalna, India), (ii) public research institutes such as the National Botanical Research Institute in Lucknow and the Indian Institute of Technology in Kharagpur, and (iii) domestic seed companies operating throughout India. Through a complex web of joint research ventures and licensing agreements, *Bt* cotton varieties are being rapidly adopted in India, providing small farmers with new choices and options.

Biofortified rice in Asia. A unique public–private partnership under the auspices of the Golden Rice Humanitarian Board is currently leading the research and development of high beta-carotene rice in Asia. The board's role has been to address the issues of intellectual property rights to enable royalty-free transfer and commercialization of the technology, and it has succeeded largely due to the direct involvement of Syngenta, a Swiss company that negotiated to secure access to key technologies used in the Golden Rice research. These negotiations have enabled the issuance of royalty-free sublicenses to public research institutes in Bangladesh, the PRC, India, and the Philippines so that they can develop locally adapted rice varieties with high beta-carotene content (GRHB 2006).

Bt brinjal (eggplant) in India. A partnership that aims to make *Bt* technology in *brinjal* affordable to farmers in Asia and the Pacific has been developed recently between the public and private sectors. Under the Agricultural Biotechnology Support Project II, an initiative supported by the United States Agency for International Development, MAHYCO is providing the technology to public-sector research institutions in Bangladesh, India, and the Philippines, which will use the MAHYCO material to backcross with their own *brinjal* varieties. No royalties are required to be paid as long as the public institutions are not involved in commercializing the *Bt* varieties, and farmers will be permitted to save seed to cultivate crops in subsequent seasons (Balaji 2005).

Developing countries have chronically underinvested in science, technology, and innovation (Pardey et al. 2006). In most of the developing world, the growth in public investments in research stagnated after the 1980s. Investments in biotechnology and biosafety, especially by the public sector, may be insufficient to address pressing needs in both areas, especially when focused on resolving national constraints. In spite of the limitations, the public sector in many developing countries has invested in agricultural biotechnology research (Atanassov et al. 2004), yet few of its technologies have made it to the commercialization stage (Cohen 2005). Additional regulations, unnecessary procedures, and regulatory time delays tend to increase the costs of developing GM crops and complying with biosafety regulations. Unnecessary costs reduce the present value of GM crops and may even prevent the release of the technology. In most cases, however, the present value is affected more by regulatory time delays than by increased costs. Therefore, cost—in the sense of both time and money—becomes a barrier to entry for private companies, and especially the public sector. What is needed is not necessarily more biosafety regulation, but effective, science-based biosafety regulation.

Agricultural Advisory Services and Information Systems

Effective dissemination of modern technologies is responsible for a considerable share of the success in Asian agriculture. The performance of agricultural extension has declined significantly in the past 2 decades, mainly because of the prevalence of supply-driven public extension services characterized by weak human capacity, limited coverage, and poor financial resources. Involving producer organizations in extension activities helps engage producers in programs that coincide with their own goals. There is a growing consensus that a mature extension system is characterized by pluralistic extension funding and service provision (see Box 4.4 on Indonesia's extension system). Farmers could contribute to the cost of extension services, but there is concern that this step would limit access by small farmers. Hence, a number of studies have concluded that commercial farmers should pay for extension advice, and the government should provide complimentary extension services to small producers. The public sector must continue to be a major player, however, both in funding and in coordinating operations.

Extension policies and strategies need to define an effective division of labor between public extension and other providers and identify overall objectives for public-sector involvement in extension. Another challenge to privatizing extension services is the lack of private providers, especially in remote areas. In countries that have privatized provision of advisory services, many service providers have emerged, with many nongovernment organizations (NGOs), private companies, and semiautonomous bodies delivering extension advice to farmers. The large number of service providers has led to the need for coordination and regulation because different providers have offered conflicting technical recommendations in some cases. A pluralistic agricultural extension system also allows for complementarity of providers. Underscoring the importance of pluralism, one study showed that NGOs tended to promote natural resource conservation more than public advisory service providers.

Successful action in agricultural adaptation requires better and clearer information combined with investment and advisory services to disseminate the information to users, as well as feedback loops to generate bottom-up information from farmers, foresters, and fishers. Information is an important component of all successful management reforms. Improved information systems allow for more

Box 4.4: Extension in Indonesia

Indonesia's experience with decentralizing its extension system has been mixed. Sharp reductions in funding and the removal of centralized guidance have had adverse impacts on extension. There have also been successes, however, in the form of management experimentation, participatory approaches, dissemination of market and upstream information and technology, decentralized services, and some movement toward privatized extension. Indonesia can make use of several relevant avenues for developing extension services, including the following:

- *Expanding the coverage of the Decentralized Agriculture and Forestry Extension Project or similar agricultural extension projects.* These projects were originally funded at the national level but are gradually being taken over by district governments. Such projects could provide necessary guidance and training, while demonstrating to district governments the importance of agricultural extension activities in improving farmer incomes.
- *Implementing farmer field schools using participatory methods to help farmers develop analytical skills, critical thinking, creativity, and decision-making skills.* Participatory extension, however, requires a simple curriculum, short-duration training, and high-quality trainers. Prospects for collective action to improve outcomes are greater when larger groups of farmers within a village are trained.
- *Privatizing parts of extension through contracting, for example, by seed companies.* This approach can introduce incentives for higher efficiency. Success is increased when extension is linked to the delivery of a specific technology (such as hybrid maize or poultry) and to larger, more homogeneous groups of farmers. For commodities where private extension services cannot be self-supporting, the government needs to continue providing assistance and training.
- *Training field extension personnel in a broader range of subjects, not limited to technology.* Personnel should be provided with additional resources as needed to help them advise farmers on diverse issues such as how to obtain credit, add value to their agricultural products, and obtain markets for their products.

Source: SEARCA/IFPRI/CRESECENT (2004).

informed decisions, heightened awareness of the impacts of people's actions, and greater incentives to change crops and adopt practices to enhance management sustainability. As a basis for adaptation planning, developing countries, alongside their international partners, will need to conduct comprehensive climate change monitoring and forecasting. In most cases, these activities will require developing countries to allocate more resources to support the collection of systematic meteorological data and the development of stronger human capacity in climate change analysis and research. Until this capacity is developed, the international research community will remain critical to these efforts.

More advanced information technologies are developing quickly and will become increasingly important. Satellite remote sensing to measure water productivity and spatially disaggregated patterns of land use and geographic information systems have been successfully used and should be expanded dramatically in pursuing land- and water-saving policies in response to climate change. Both policy makers and local communities require a combination of technical expertise and local knowledge. In many cases they will require more effective innovation systems that disseminate information about adaptive land and water management practices—in terms of both new technologies and practices developed by farmers—and about their consequences across both space and time. Participatory land use planning can build on technical models, as well as on systems of problem identification, farmer field schools, and other methods to identify both the constraints and opportunities, especially in the context of climate change.

Risk Management and Crop Insurance

Crop insurance has, historically, been relatively ineffective, even in developed countries, and problems are greater in developing countries. At present, communities and individuals in most developing countries lack insurance coverage against extreme weather events. Index-based insurance and credit may overcome some of the limitations of traditional agricultural insurance, allowing farmers to take the increased risks that tend to be associated with higher-yielding production decisions that can result in increased incomes and agricultural productivity (Tubiello et al. 2008). Rather than basing indemnity payments on individual farm yields, index-based policies determine payments to policyholders based, for example, on regional yields or weather data such as temperature or rainfall. This approach reduces the transaction costs involved in traditional insurance products, and because farmers are paid regardless of their individual yields, this approach also encourages farmers to continue producing if possible (Kryspin-Watson et al. 2006).

The private sector is often reluctant to provide crop insurance because of high implementation costs and the fear of large losses in catastrophic events that are unlikely to be covered by income from insurance premiums. PPPs could overcome these limitations, thus serving three purposes. First, they could perform the classic insurance function of spreading risk. Second, they could ensure continuity of government operations after a severe loss event. Third and most important in the adaptation context, they could help to ensure that adequate adaptation measures are taken. Insurance in this case would be an instrument of public policy and not an end in itself. The objective would be to maximize

Box 4.5: Weather-Based Insurance in India

In 2003, a pilot program for weather insurance was launched in Andhra Pradesh Province, India, to help protect famers against low rainfall. Implemented by BASIX, one of India's largest microfinance institutions, the program began with 250 policies sold to groundnut and castor farmers in the province. The index-based weather insurance relied on rainfall data in the province and made payments to farmers when rainfall fell below a predetermined amount. Based on feedback from farmers, BASIX expanded the project in 2004, selling more than 700 policies. In 2006, BASIX sold rainfall and mixed weather contracts, including temperature and relative humidity insurance, to more than 11,000 farmers in more than six of India's states.

Source: World Bank (2003); Bryla and Syroka (2007).

agricultural productivity in the face of increased climate shocks. Insurance would encourage, facilitate, or even mandate adaptation measures. An innovative approach to a comprehensive insurance program would contribute to these goals (see Box 4.5). Insurance could be made available at concessionary rates (thus contributing to meeting the United Nations Framework Convention on Climate Change [UNFCCC] obligation to help developing countries meet the costs of adaptation), subject to the condition that the insured activity or the property meets certain adaptation or vulnerability reduction requirements.

Strengthening Ongoing Development Initiatives

Part of planned adaptation policy should be an extension of development policy that seeks to eradicate the structural causes of poverty and food insecurity. Important ongoing development initiatives that should be strengthened in Asia and the Pacific include providing secure property rights for farmers, continuing agricultural market development, reforming distorting trade and agricultural input and output price support policies, strengthening environmental policies, enhancing social protection, and providing microfinance and disaster protection.

Secure Property Rights

Meeting the challenges of climate change adaptation in agriculture requires long-term investment by farmers. But long-term investments—such as integrated soil fertility management, tree planting, and water harvesting—require secure property rights to provide people with the incentive and authority to make the investments (Meinzen-Dick et al. 2002). By changing the profitability of land—such as through the potential to generate income from carbon markets and biofuels—climate change may also worsen the position of farmers with insecure property rights, leading to expulsion from their land as landlords seek to increase their share of the new income streams. Improvement in land rights is therefore an essential component of effective and equitable adaptation.

Secure property rights do not necessarily have to take the form of individual or titled land; secure collective or customary tenure can also be sufficient (Bruce and Migot-Adholla 1994; Sjaastad and Cousins 2008). In cases where pressure on land is growing, however, customary tenure may no longer be secure. These cases call for innovative approaches to securing land tenure, which may involve alternatives to titling. These alternatives could range from recognizing customary rights to land, identifying agents to represent customary interests, to formalizing groups and granting them collective rights over resources (Fitzpatrick 2005; Kanji et al. 2005).

Climate change is making water access inherently less secure because water flows are becoming less predictable. The declining availability and increasing variability in rainfall and stream flows in many regions will decrease the security of water access. It is therefore increasingly important to influence other factors that reduce secure access, especially the lack of secure water rights, which empower users by requiring their consent to any reallocation of water and granting users compensation for transferred water. Secure, well-defined water rights give users incentives to invest in water-saving technologies. A system of tradable water rights can also encourage users to consider the full opportunity cost of water, including its value in alternative uses, thus providing incentives to economize water use and gain additional income by selling saved water. Moreover, a properly

Table 4.5: Ongoing Development Initiatives that Support Climate Change Adaptation and Mitigation

Area of Adaptation	Implementation Level				Scope for Mitigation	Institutional Support	Existing Experience in Asia and the Pacific
	Farm	Community	National	Global			
Secure property rights			Legislation for formal rights and acceptance of informal rights systems (legal pluralism)		Significant, as farmer investment increases with increased property rights	Support to the establishment of rights systems	
Agricultural market development		Cooperatives for farm inputs and outputs, information and communication technologies	Infrastructure and market development, one-stop information centers, and extension services		Carbon market development, carbon market information, and support for farmers to access value chains	Public–private partnerships for carbon markets, new market opportunities as a response to global warming, and property rights to land	
Agricultural policies			Mainstream climate change in policies, reduce fertilizer subsidies, phase out subsidies for biofuel promotion, and support research in second- or third-generation technologies	Mainstream climate change in global policies and target climate policies to the poor	Mainstream win-win mitigation–adaptation policies through appropriate incentives, develop policies to ameliorate the adverse impacts of massive expansion of livestock production (including monitoring, regulation, research, and extension)	Capacity building at the government agency and national agricultural research system levels	Regional agricultural development programs (the PRC)
Trade		Cooperative storage, market information	Trade reform, legislation on food safety standards, support for market information systems, and road development	Doha Round of World Trade Organization, food safety standards	Focus on mitigation instruments that support trade	*Codex Alimentarius*, producer organizations, consumer organizations	

continued on next page

Table 4.5 continued

	Implementation Level						
Area of Adaptation	**Farm**	**Community**	**National**	**Global**	**Scope for Mitigation**	**Institutional Support**	**Existing Experience in Asia and the Pacific**
Other environmental policies			Environmental legislation, including afforestation and reforestation; secure property rights for land and water; improve incentives and markets in natural resources; and policies to maintain ecosystem services		Air quality legislation (reducing straw burning), afforestation and reforestation policies, secure property rights to secure carbon financing for mitigation		Reforestation (northern PRC)
Enhanced social protection		Effective rural institutions	Food reserves and storage, social policies (safety nets) targeted toward the poor	Timely, targeted food aid when needed (mostly disaster); government-sponsored food- or cash-for-work programs		Effective targeting, monitoring of targeted support	
Microfinance		Microcredit groups for women	Support to public and private microfinance institutions			Functioning financial markets and institutions (for example, agricultural credit providers), rules and regulations, decentralization, subsidiarity principle	BRAC in facilitating microcredit (Bangladesh; see also Table 4.6)
Disaster preparedness			Climate information system, early warning systems	Support to investments in these systems, international regulations			Tsunami information system (Bangladesh)

BRAC = Bangladesh Rural Advancement Committee.

Source: Compiled by authors.

managed system of tradable water rights will give water users incentives to internalize the social and environmental costs imposed by their water use, reducing the pressure to degrade resources.

Agricultural Market Development

Many highly developed agricultural economies in Asia and the Pacific are thriving as a result of well-developed agricultural markets, with integrated value chains and other mechanisms that include smallholders in food production systems, through information and communication technologies, cooperatives, and responsive extension services.

Agricultural Policies

The costs of subsidy policies are made worse by climate change because it contributes to increased food, energy, and water prices. Improving economic incentives for adaptation thus requires, for example, reducing the existing perverse subsidies on water, energy, and fertilizer that encourage environmentally damaging overuse of these resources and inputs. The resulting savings should then be invested in adaptation activities that boost farm income. Input subsidies have not only distorted production decisions, but also encouraged carbon emissions beyond economically appropriate levels. As the real prices of natural resources rise, market-based approaches to managing environmental services in response to climate change—such as through water pricing, payments for environmental services, and carbon trading—will be increasingly important. Improved definition and protection of land and water property rights will be necessary to effectively implement market-based approaches to climate change policy, including payments for environmental services.

One way to improve on previous payment for environmental services approaches is to involve local communities, allowing them to negotiate the terms of the payments. For example, downstream users in a watershed may try to negotiate with upstream users to protect the water from pollution and sedimentation. The downstream users may offer a payment or reward in exchange for implementing agreed management practices. When the initiative comes from local people who are direct stakeholders, it may be easier to achieve on a sustainable basis because the downstream users will have an interest in continuing to monitor compliance (Pender 2009). Such negotiation and collective agreements are more likely within relatively small and cohesive communities than between communities, and where the ability to ensure that all resource users' benefit is greater. The fact that few such examples exist in practice may be less dependent on local leadership and other idiosyncratic factors, and relate more to the absence of local control over resources.

In addition to eliminating distorting policies, climate change should be mainstreamed to limit policies and investments that inadvertently encourage, rather than minimize, vulnerability to the impacts of climate change. Mainstreaming climate change in agricultural policies would help avoid (i) investments in agricultural research and development (R&D) for crops that are not likely to thrive under global warming in certain environments of Asia and the Pacific; (ii) investments in agricultural water management technologies that perform poorly with increased temperature (such as sprinklers versus drip irrigation); and (iii) investments in livestock expansion in areas expected to experience declines in pastures and grazing lands as a result of climate change, as is the case in Mongolia and Inner Mongolia, the PRC. Similarly, mainstreaming climate change will help focus agricultural policies toward enhancing resilience under extreme weather events and global warming.

Trade Policies

Trade liberalization is an important adaptation strategy because producing food based on local comparative advantages regarding resource availability will help reduce GHG emissions and allow countries to adapt to climate change more effectively and efficiently. Growing scarcity of water, fuel, and land has the potential to drive up food prices, limiting access to food. The experience in 2007–2008, when several countries imposed trade restrictions as a result of higher food prices and increased price volatility, shows how breakdowns in trading systems can increase potential threats and have adverse impacts on food security. Thus, restoring confidence in international trading systems will be crucial (Box 4.6). Effective food trading systems will also require continued advancements in food safety standards, both through the *Codex Alimentarius*, a collection of internationally recognized standards on food quality and safety, and through enhanced risk analysis and risk management.

But will smallholders in Asia and the Pacific be able to benefit from increased trade liberalization? Cooperative storage and contract farming—both for export and for local supermarkets with growing retail shares in developing Asia—are important means of increasing certainty and stability in smallholder agricultural production.

Other Environmental Policies

In addition to secure property rights, farmers as well as land and water managers need not only incentives to make decisions to sustain these resources, but also sufficient flexibility to adapt efficiently to climate change signals. Market solutions that promote sustainable natural resource management and mitigate the negative impacts of climate change are a potential method of

Box 4.6: Restoring Confidence in International Agricultural Trade

The ongoing failure of the Doha Round of the World Trade Organization (WTO), together with the sharp increase in food prices that stimulated export bans and other restrictions of trade by many countries in 2007–2008, has resulted in declining confidence in agricultural trade. The restrictive agricultural trade policies adopted by several developing countries also undermine the benefits of global integration, adding to the distortions already created by rich countries' long-standing trade and subsidy policies. Agricultural globalization is regressing, with adverse effects for the poorest countries. Rule-based, fair, and free international trade is particularly critical in times of crisis, as the export ban problems underline.

A sound global trade system is especially crucial in the context of climate change. As shown in Chapter III, the impacts of climate change on agricultural growth and production will make many Asia and the Pacific countries and subregions increasingly reliant on food imports. To increase confidence in international agricultural trade, the WTO Doha Round should be completed; Organisation of Economic Co-Operation and Development (OECD) countries should reduce or eliminate trade restrictions that limit developing-country export access to markets, and buffering mechanisms should be established to address volatility in world markets more successfully. Alternative or complementary approaches to market stabilization for cereals include a joint pooling of fixed portions of national stocks into an international grain reserve, and/or a financial facility, provided by the International Monetary Fund, for imports by countries in food emergencies.

reducing emissions and improving soil fertility, soil productivity, and water use efficiency, while at the same time improving livelihoods of poor communities in developing countries.

With rising food, energy, and land prices—and in the longer run carbon prices—it is necessary to overcome past constraints and fully implement green markets, including improved design and implementation of carbon trading systems. Under climate change, rising energy prices will change the relative effectiveness of different types of irrigation and water allocation policies. Higher energy prices will increase the cost of distribution systems and increase both fiscal and efficiency costs of water subsidies. This will, in turn, lead to significant pressure and increased incentives to reform water management to improve water-use efficiency, including using water markets or other economic incentives, reducing subsidies, and making targeted investments in efficiency-enhancing technologies (Zilberman et al. 2008).

With rising input and output prices, efficiency pricing of water and markets in tradable water rights is an important component of strengthening climate change adaptation because it improves water-use efficiency across sectors. Large-scale adoption of water markets or efficient pricing of water is challenging, however, and will require innovative designs to protect farm incomes—for example, brokered trading to ensure fair compensation for irrigators who trade water. Appropriate pricing systems in the domestic and industrial sectors can enhance efficiency and equity of use, target subsidies to the poor, cover delivery costs, and generate adequate revenues to finance the needed growth in supply coverage. Pricing policies for the irrigation sector are inherently more difficult to realize because of political concerns, complex design and implementation, and potentially adverse impacts on poor consumers and farmers. Excessively high water prices are likely to severely reduce farm income. Moreover, in much of the developing world, irrigation consists of large systems serving many small farmers. Measuring and monitoring deliveries to this large number of end users—as would be required for volumetric charges—is too costly. Despite these difficulties, water pricing systems, such as a water brokerage system, can be designed to introduce incentives for efficient water use, recover operations and maintenance (O&M) costs and, at the same time, protect or even increase farm incomes. In a brokerage system, a base water right is established at major turnouts to individuals, groups of water users, or water user associations that regulate distribution within the group. A fixed base charge would be applied to an initial (historical) quantity, sufficient to cover O&M and longer term asset replacement (depreciation) costs. The brokerage agency—for example, a river basin authority—would then broker water trades. For demand above the base water right, an efficiency price equal to the value of water in alternative uses would be agreed on; for demand below the base right, users would be compensated at the same price for unused water. Reform of water pricing policy in developing countries faces many technical, administrative, and political constraints, but with increasing water scarcity under climate change, and declining financial resources available for irrigation and water resource development, such reform is essential (Rosegrant and Cline 2002).

Existing markets favor the production of crops or livestock relative to the production of environmental services. Payments for environmental services (PESs) can help reflect the value of environmental services more accurately and thus enhance their production. Payments compensate farmers for the costs they bear in producing these services (FAO 2007b), giving them incentives to invest in land use practices that can increase and diversify their income streams and help them both adapt to and mitigate climate change. It is an important option to consider for several other reasons as well. First, farmers are the largest group of ecosystem managers on earth, and they have an important role to play in improving the management of global and local natural resources. Second, paying farmers for environmental services can be a relatively inexpensive and quick means of responding to some environmental problems. Third, environmental service payments can be a more equitable way of managing environmental problems, particularly when poverty is a cause of environmental degradation. PES provide one option for offsetting pressures to generate biofuel benefits out of agricultural ecosystems at the expense of environmental services. Policies and contract reforms should be implemented to bring smallholder farmers—who have often been bypassed because of property rights issues and high transaction costs—into PES systems (FAO 2007b).

PES approaches may be most effective when local communities are involved in negotiations to determine the terms of the payments (as was discussed in the section on agricultural policies above). The village of Sukhomajri in India is one of the best examples in which the benefits of a locally initiated watershed development effort were broadly shared in the community in return for compliance with grazing restrictions, leading to dramatic improvements in natural resource management, household food production, and livelihoods (Dixon, Gulliver, and Gibbon 2001).

Social Protection

Given the low levels of income and savings in poorer communities, as well as the weak economic position of certain states, developing countries will need to design more robust social protection schemes at the individual and national levels. At the individual level, such measures can include employment programs, cash transfers, and weather- and crop-related insurance. At the national and subnational levels, countries will need to leverage further international financial markets and develop relationships with the financial services sector to pool and transfer their risk to ensure that they will not have to significantly redirect national budgets in cases of climate shock.

Comprehensive social protection initiatives are required to address the risks facing the poor as a result of climate change and increasing climate variability. Appropriate social protection interventions include both protective measures to mitigate short-term risks and preventative measures to preclude long-term negative consequences. By protecting against downside risk, effective social protection also reduces risk aversion in farmers' production decisions, enhancing the potential for adaptive farming systems. Introducing or scaling up these interventions is, however, complex, expensive, and dependent on a country's knowledge base and capacity (IFPRI 2008).

At the core of the protective measures are conditional cash transfer programs, pension systems, and employment programs. These programs exist in many low-income countries and should be scaled up. Where such interventions do not exist, countries should introduce targeted cash transfer programs in the short term. If food markets function poorly or are absent, however, providing food is a better option. Microfinance, which includes both credit and savings, will allow the poor to avoid drastic actions such as distress sales of productive assets that can permanently damage future earning potential. Furthermore, Francisco (2008) has suggested the potential for developing index-based microinsurance schemes in Southeast Asia. Partnerships among international organizations, national governments, nongovernment organizations (NGOs), and the private sector should examine and pilot test schemes that have worked well.

Preventative health and nutrition programs targeted toward vulnerable population groups (such as mothers, young children, and people living with HIV/AIDS) should be strengthened and expanded to ensure universal coverage. This measure is essential to prevent the long-term consequences of malnutrition on lifelong health and economic productivity. In addition, school-feeding programs can play an important role in increasing school enrollment, keeping children in school, and enhancing their academic achievement.

Overall, expected results of social protection programs include preventing long-term adverse consequences of early childhood malnutrition, increasing protection of assets, and maintaining school participation rates. Many of these actions should take place at the national level, but many countries lack the resources to implement them. Donors should expand support for such programs in conjunction with sound public expenditure reviews (IFPRI 2008).

Financial Markets: The Role of Microfinance

Microfinance services (MFSs) can be an important tool in reducing the vulnerability of the poor and, in the context of climate change adaptation, can provide poor people with the means to diversify, accumulate, and manage the assets needed to become less susceptible to shocks and stresses or to better deal with their impacts. Yet, these benefits may not apply to everybody. MFSs typically do not reach the chronically poor, may encourage short-term coping at the expense of longer term reduction in vulnerability, or they may even increase vulnerability. These limitations and risks aside, MFSs can still play an important role in reducing vulnerability and increasing climate change adaptation among some of the poor, provided services match client needs and livelihoods (Hammill, Matthew, and McCarter 2008).

Hammill, Matthew, and McCarter (2008) note that MFSs can be divided into three main types.

i. Microcredit lends funds to poor people so they can exploit their capacities for income production (job creation, enterprise growth, and increased production); it is about asset-building and diversification. Returns are consumed, saved, or reinvested. Loans are also offered for nonproductive purposes that may contribute to reducing vulnerability, such as emergency loans, education loans, and home improvement loans.

ii. Microinsurance (Pierro and Desai 2008) protects poor people against specific perils (such as injury, death, and natural hazards) in exchange for regular premium payments (Churchill 2006). Thus, like the social protection policies already described, it protects assets and gives people the freedom to pursue profit without fear, ideally leading to increased income production and adaptability (Morduch 2006).

iii. Microsavings are small balance deposits for the safe storage of money, allowing people to obtain lump sums to meet both predictable and unpredictable expenses. They can be used as insurance or for investment, yielding the same results for asset bases already described (Hammill, Matthew, and McCarter 2008).

Potential pitfalls need to be avoided. If microfinance is essentially a coping mechanism, it is not likely to be a pathway toward adaptation and could even increase vulnerability. Debt burdens can also increase to unsustainable levels. Furthermore, if governments see microfinance as a substitute for appropriate levels of social protection, the adaptive effects could weaken. If these pitfalls can be avoided, the most powerful case for MFSs with regard to climate change adaptation is their ability to help families build and diversify assets so that they have more than one means of livelihood or more than one skill set to avoid dependency. Green microfinance, through service conditions that provide sustainable resource stewardship, may reinforce longer term vulnerability reduction gains. For example, a partnership between the Self-Employed Women's Association Bank and the Solar Electric Company-India (a social enterprise providing sustainable energy solutions and services) seeks to meet the energy needs of self-employed individuals and microenterprises for processing, agriculture, and other livelihoods (McKee 2008). Although the need for green microfinance is recognized, appropriate terms and modalities need to be developed to make it effective without sacrificing positive social impacts. Balancing quick gains and short-term loan repayment schedules with longer term sustainable management practices will continue to challenge the industry (Hammill, Matthew, and McCarter 2008).

The long-term experience of microfinance institutions in the ADB's developing member countries is detailed in Table 4.6.

Disaster Preparedness

Disaster preparedness or risk reduction (DRR) is an important adaptation measure to combat climate change. The UN International Strategy for Disaster Reduction (UNISDR) is mandated as the UN coordinating mechanism for DRR at the global level (UNISDR 2006). It defines DRR as "...*the concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events*" (UNISDR 2009a). UNISDR promotes four key messages to ensure the integration of DRR into current policies at national to local levels by

(i) making adaptation to climate change a fundamental pillar of any post-Kyoto agreement;
(ii) ensuring that DRR and climate risk management are core elements of adaptation to climate change;
(iii) establishing a mechanism to provide sufficient funding for adaptation to climate change and risk reduction, especially to protect the most vulnerable; and
(iv) taking immediate action to implement adaptation to climate change and risk reduction in vulnerable countries during 2008–2012 (UNISDR 2009b).

The Hyogo Framework for Action is a recognized global guide to facilitate effective implementation of DRR at international, regional, national and local levels (UNISDR 2006). The Framework was adopted by 168 countries in 2005, and will address technical and political agreement on all areas with risk (O'Brien et al. 2008). It has five priorities for action: (i) ensuring that DRR is a national and a local priority with a strong institutional basis for implementation; (ii) identifying, assessing and monitoring disaster risks, and enhancing early warning systems; (iii) using knowledge, innovation, and education to build a culture of safety and resilience at all levels; (iv) reducing the underlying risk factors; and (v) strengthening disaster preparedness for effective response at all levels (O'Brien et al. 2008). Although DRR and climate change adaptation intend to reduce disaster risk, the lack of discussion, coordination of activities, and engagement regarding these two agenda

Table 4.6: Some Experience with Microfinance in the Asian Development Bank's Developing Member Countries

Subregion and country	Bank	Microfinance Program and/or Scheme	Activities	Client	Allowable Loan ($)	Source
South Asia						
Bangladesh	Bangladesh Rural Advancement Committee (BRAC)	Unnoti – Microenterprise development for marginal farmers	Provide financial services to meet the specific needs of small and marginal farmers	Provide support to small and marginal farmers who own more than one acre of land—a group not being targeted by the mainstream microfinance programs in the country, 840,000 borrowers as of 2008	T10,000–T50,000 ($147–$735) T9,569 million disbursed as of 2008	BRAC. 2009. Microfinance. Unnoti. <http://www.brac.net/index.php?nid=220>
India	National Bank for Agriculture and Rural Development	Self-Help Group (SHG) model to contribute to poverty alleviation in rural areas launched in 1992	Facilitating credit flow for the promotion and development of agriculture, small-scale industries, cottage and village industries, handicrafts and other rural crafts Promotion of microfinance by providing bulk loans to microfinance institutions and refinancing the commercial bank loans to the SHG	SHGs program serves 85%–90% of the total SHGs for women More than 48 million poor families are also assisted by this program Increase in the number of banks participating in SHGs linkage program	$1,000 as of March 31, 2007	World Savings Banks Institute (WSBI). 2008. Overview of Microfinance in Asia/Pacific and Selected Experiences from WSBI Members. Brussels. <http://www.wsbi.org>

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Table 4.6 continued

Subregion and country	Bank	Microfinance Program and/or Scheme	Activities	Client	Allowable Loan ($)	Source
			Provides access to finance the poorest among the poor, while most of the poor are women. Enlarges the coverage of microcredit for women in rural areas.			
Sri Lanka	Hatton National Bank	Rural savings mobilization and social development through the Gami Pudubuwa (village awakening) program—Micro, Small and Medium-Scale Enterprises financing in partnership with the German Savings Banks Foundation for International Cooperation launched in 2007.	To reconstruct their business and improve the economic employment activities of the 2006 tsunami victims. 7,055 new employment opportunities were created.	2006 tsunami victims; 9,775 families directly and indirectly	The project allocated loans to wide economic sectors including agriculture, manufacturing, fisheries, transport, and so on. 2007 = 2,720 loans amounting to $7.5 million provided to entrepreneurs.	WSBI. 2008. Overview of Microfinance in Asia/Pacific and Selected Experiences from WSBI Members. Brussels. <http://www.wsbi.org>

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Table 4.6 continued

Subregion and country	Bank	Microfinance Program and/or Scheme	Activities	Client	Allowable Loan ($)	Source
Southeast Asia						
Malaysia	*Amanah Ikhtiar Malaysia* (AIM)	Alleviation of poverty among poor Malays; established in 1987	"To disburse small loans on reasonable terms exclusively to the very poor households to finance additional income-generating activities," but for all practical purposes, has confined its attention to the *Bumiputera*.	1989 = 94,600 households (2.2% of the total population) classified as "hardcore poor" with incomes below half the level of the official poverty line; AIM targeted the poorest among the poor, used the official periodic Household Income Survey as a guide and developed its own means test to identify the hardcore category August 1994 = AIM had some 6,100 Grameen groups in operation; total membership = 30,000 borrowers	Total loans disbursed amounted to RM37.9 million ($14.8 million) • Some 28% of lending for agriculture • 46% for trade • 15% for animal husbandry • 10% for other activities	Conroy, J. D. 2004. The challenges of microfinancing in Southeast Asia. The Foundation for Development Cooperation, Brisbane, Australia.

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Table 4.6 continued

Subregion and country	Bank	Microfinance Program and/or Scheme	Activities	Client	Allowable Loan ($)	Source
Philippines	People's Finance and Credit Corporation (PFCC) established in 1995. Registered finance company. Its articles of incorporation provide for its privatization.	Specialized institution for lending to the poor	PFCC funds microfinance institutions, defined broadly, and includes NGOs, rural banks, cooperatives and other intermediaries as conduits for on-lending to the poor. These intermediary organizations are required to operate in a self-sustaining and operationally viable manner.			Conroy, J. D. 2004. The challenges of microfinancing in Southeast Asia. The Foundation for Development Cooperation, Brisbane, Australia.
Mekong Subregion						
Thailand	Bank for Agriculture and Agricultural Cooperatives (BAAC)	To reach rural areas as financial institution	The penetration of BAAC in rural areas is more significant than any other single rural financial institution in Asia.	Some 4.7 million of the country's over 5 million farm households registered for its services. 1996 = 3.4 million households, 72% registered as individual branch clients, 28% as members of 877 agricultural cooperatives and 295 farmers' associations that borrowed from BAAC directly or indirectly; it reached about 90% of the country's farmers.		Conroy, J. D. 2004. The challenges of microfinancing in Southeast Asia. The Foundation for Development Cooperation, Brisbane, Australia.

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Table 4.6 continued

Subregion and country	Bank	Microfinance Program and/or Scheme	Activities	Client	Allowable Loan ($)	Source
Viet Nam	Viet Nam Bank for Agriculture and Rural Development (VBARD)	Services to rural market	Banking for the poor and granting loans to poor households with favorable interest rates without any collateral. Loosening the lending conditions, increasing the maximum amount of every nonguaranteed loan, diversifying category of loan products and simplifying the lending procedures to promote and expand credit for farming households. Bank has developed network for farming households with 2,200 branches and transaction offices and 700 mobile car-banks giving bank access to people in remote areas.	10 million farming households as of March 2007	Loans without collateral: Farming households = up to $600 (D10 million), Goods and manufacturing households = $1,800 (D30 million), Fishery breeding and husbandry households attacked by epidemics = $3,000 (D50 million), Average outstanding loan: For every producing household = $700 (D11.27 million), For the poor household = $300 (D5 million)	WSBI. 2008. Overview of Microfinance in Asia/Pacific and selected experiences from WSBI members. Brussels.

Source: Compiled by authors.

items impede the fulfillment of the goal. Moreover, any strategies to reduce risk and effect adaptation need to be tailored to the needs of the individual, household, and community (O'Brien et al 2008). One potential solution may be to use a community-centered approach together with an enabling policy environment. Community-based management works well in most developing countries of Asia in responding to natural disasters, but these kind of initiatives require technical and financial assistance and thus the support of the government is vital.

Coastal defense systems will be crucial for disaster preparedness in Bangladesh, Viet Nam, and many of the island states in the Pacific. These investments require attention to financial and human resource capabilities during both development and maintenance. For example, the coastal sea dike defense system in northern Viet Nam degraded significantly following decollectivization, as the management authority for maintenance was shifted from agricultural cooperatives to decentralized communes, which considered aquaculture development a higher priority (Adger 2001). In Viet Nam's Mekong Delta, mangrove replanting has been a key component of the coastal defense system since the late 1990s. Not only do the mangroves provide physical protection and environmental sustainability, but they also generate ecosystem goods and services (Tri, Adger, and Kelly 1998; Adger 1995). According to a review by Kathiresan (2008), a 100-meter wide band of mangrove forest in coastal Viet Nam was sufficient to reduce the amplitude of tidal waves by 20% and the associated energy by up to 90%. A comparison of typhoon impacts (1996 and 2005) found that there were significant improvements as a result of this mangrove forest—no loss of human life, a significant drop of property damage, and improved survival rate for the mangroves (63%).

Implementing Climate Change Adaptation Policies

Mainstreaming Climate Change and Adaptation into Development Planning

Development policies and plans at all levels need to consider the impacts of climate change on the agriculture sector. National and regional policy makers must integrate the effects of climate change and the outcomes from assessments and scenarios into their national plans and policies in the agriculture sector. Advanced planning, or "climate-proofing," will ensure that climate change neither disrupts nor renders ineffective, development plans that are critical to at-risk or vulnerable communities with low levels of development. Moreover, mainstreaming should aim to limit development policies and plans that inadvertently encourage, rather than minimize, vulnerability to the impacts of climate change. Many of the aforementioned adaptation strategies are already part of sound development policy advice, which should make mainstreaming easier. At the same time, adaptation to climate change should be recognized as a critical element of development policy that will require both innovative ideas and additional funding commitments, and this reality should not be lost in mainstreaming efforts.

Although the interdependence of climate change adaptation and sustainable development should be self-evident, it has been difficult to combine them in practice. A significant adaptation deficit exists in many developing countries, particularly those populated by the rural poor who rely on agriculture for their very subsistence. Although the UNFCCC includes clearly defined objectives, measures, costs, and instruments for mitigation, it does not do so for adaptation. Agrawala (2005) reports that much less attention has been paid to how development could be made more resilient to the impact of climate change and identifies a number of barriers to mainstreaming climate change adaptation within development activities. These barriers include segmentation and lack of coordination within governments and donor agencies, the lack of relevant climate information for development-related decisions, and perceived tradeoffs between climate and development activities.

Despite these barriers, the development community recognizes the linkages between development and climate change adaptation. Schipper and Pelling (2006) note that climate change has been identified as a serious risk to poverty reduction in developing countries, particularly because these countries have a limited capacity to cope with current climate variability and extreme weather events, not to mention future climate change. Adaptation measures will need to be integrated into poverty reduction strategies to ensure sustainable development, and this goal will require improving governance, mainstreaming climate change measures, and integrating information on climate change impacts into national economic projections. Based on case studies of natural resources management in Bangladesh, Fiji Islands, and Nepal, Agrawala (2005) recommends several priority actions for overcoming barriers to mainstreaming, such as screening projects for climate-related risk, including climate impacts in environmental impact assessments, and shifting the emphasis from creating new plans to better implementation of existing development measures and policies.

To mainstream climate change adaptation, countries will need to undertake multifaceted risk assessments that incorporate not only climate risk, but also existing vulnerabilities, such as low levels of development, poor governance, political instability, and expected future trends, such as population growth, rapid urbanization, and increasing water scarcity. Qualitative and quantitative scenarios will need to be developed at the country level and potentially at the subnational level. Combined with detailed economic analysis of adaptation options, these multifaceted risk assessments and scenarios should serve as the basis for developing comprehensive and robust adaptation plans. With the financial support of the UNFCCC, acting through the Global Environment Facility (GEF), national adaptation programs of action (NAPAs) could be key mechanisms for mainstreaming climate change into development planning, but progress on NAPAs has been slow.

OECD (2009) provides good discussion on integrating climate change responses into budgetary processes, and adaptation strategies into the World Bank's poverty reduction strategy papers, as well as how to implement the proposed plans. The report suggests multi-year budgeting as a key opportunity to mainstream climate change concerns at the country level. Transparent inclusion of planned climate change expenditures provides a level playing field for various sectors to compete for fiscal resources. Multi-year budgetary processes also provide stability for long-term investments. Doing this effectively in developing countries in Asia and the Pacific will require capacity strengthening in the area of cost–benefit analysis of investments related to climate change.

Many developing countries in Asia and the Pacific have poverty reduction strategies spanning a 3–5 year timeframe. This is relatively short given the long-term concerns of climate change. Nevertheless, it is important that the potential impacts of climate change on current and planned efforts to reduce poverty are explicitly assessed to avoid maladaptation and to strengthen those development efforts that support both poverty alleviation and climate change adaptation. Asia has made significant strides in recognizing the importance of climate-related developments for poverty reduction, given the large negative impacts of natural disasters on livelihoods in the region (Table 4.7). However, such explicit linkages need to be developed for all key elements of climate change.

Financing Adaptation

In recent years, new mechanisms have been established to support adaptation, including the Least Developed Country Fund (LDCF), Special Climate Change Fund (SCCF), and Adaptation Fund, the evolution of which are traced by Huq (2002); Desanker (2004); Huq (2006); and Huq, Reid, and Mussay (2006). These mechanisms have provided the opportunity to mainstream adaptation into local and regional development activities, but a critical problem with integrating climate change adaptation into existing development assistance has come to light. The boundary between existing development assistance and the additional adaptation funds promised under the UNFCCC is vague. This ambiguity may mean that difficult decisions have to be made as to how much of the funding for an adaptation project should be allocated to "regular" development, and how much should be targeted specifically to climate change adaptation. This distinction is important because it carries implications about the distribution or allocation of costs for particular actions within UNFCCC mechanisms such as the GEF. For example, Burton (2004) and Huq and Reid (2004) note that calculating the costs of adapting to future climate change (as opposed to current climate variability), as well as the local nature of resulting benefits, are both problematic vis-à-vis the GEF requirement to calibrate global environmental benefits.

Guidance provided by the UNFCCC's Conference of the Parties—the 15th meeting of which will be held in Copenhagen in December 2009—identifies three stages of GEF support for adaptation. Stage I provides support for the national communications process, a portion of which is vulnerability and adaptation assessment. Stage II provides further assistance for other capacity-building efforts for

Table 4.7: Poverty Reduction Strategy Papers—Recognition of Disaster Risk Reduction as a Poverty Reduction Tool (% of papers)

Level of Recognition	Total	Africa	Asia	Europe	Latin America and the Caribbean
Disaster risk reduction not mentioned	25	23	20	33	14
Disaster risk reduction mentioned	55	54	65	67	57
Whole section and/or chapter on disaster risk reduction	20	23	15	0	29

Source: UNISDR (2009c).

adaptation. Stage III provides support for actual adaptation activities, including insurance, and has been implemented in the form of the GEF's Strategic Priority on Adaptation, under which $50 million has been allocated. Of that amount, $5 million has been allocated to piloting community adaptation initiatives through the Small Grants Program.

The community component of the GEF is being piloted by the Community-Based Adaptation Program and provides the basis on which the GEF and other stakeholders can effectively support small-scale adaptation activities. This goal will be realized through three immediate objectives: (i) developing a framework—including new knowledge and capacity spanning local to intergovernmental levels—to respond to unique community-based adaptation needs; (ii) identifying and financing diverse community-based adaptation projects in a number of selected countries; and (iii) capturing and disseminating to all stakeholders (including governments) information on lessons learned at the community level.

The LDCF was established to support the preparation and implementation of NAPA. The operational aspects and procedures have been finalized, and one project in Bhutan has already been approved under this fund. As of mid-2009, the LDCF has approximately $115 million to fund priority activities in 48 least developed countries under the UNFCCC. Bangladesh, Bhutan, Cambodia, Kiribati, Samoa, Tuvalu, and Vanuatu are 7 of the 48 official countries that have prepared NAPA and are therefore currently eligible for funds (GEF 2008). Cambodia, however, is the only country receiving funds—approximately $1.9 million from the LDCF specifically in the agriculture sector (GEF 2008). The Special Climate Change Fund was established to finance developing-country activities in adaptation, technology transfer, key sectors (energy, transport, industry, agriculture, forestry, and waste management), and economic diversification in countries dependent on the fossil fuel sector. The Adaptation Fund is intended to support concrete adaptation initiatives in developing countries that are particularly vulnerable to the adverse effects of climate change. The funding is generated through a 2% levy on Clean Development Mechanism (CDM) proceeds (excluding those undertaken in least developed countries), as well as "other sources." The extent of the Adaptation Fund will therefore depend on the volume of CDM activity.

Although a great deal of attention has been paid to this issue recently, much of the related activity by international actors has focused on the first type of adaptation action—mainstreaming climate change into existing program portfolios. According to the Organisation for Economic Co-operation and Development (OECD), however, there has been little concrete progress even in this area. Although awareness of climate change impacts has increased significantly, and several tools have been developed to support "climate proofing," few development programs have integrated the impacts of climate change into their plans. Beyond the efforts being undertaken to "climate proof" existing portfolios, most international development and humanitarian agencies have only recently developed or begun to develop their own strategies for new activities in the area of adaptation. Though initiatives have recently proliferated, few concrete activities are underway, especially at the national level or below. Notable exceptions include impact analysis undertaken by research institutes such as the Columbia University Earth Institute and The Energy and Resources Institute (TERI); country-level support by the United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), and other UN agencies; the economic case for adaptation and engagement with the insurance industry being developed by the World Bank; and the $70 million Climate Change Initiative financed by the Rockefeller Foundation.

In Asia and the Pacific specifically, ADB is supporting the creation of regional funding modalities. The main regional mechanism available for both adaptation and mitigation is the Climate Change Fund, with an initial contribution of $40 million (Sharan 2008). Two smaller funding sources have also been created: the Water Financing Partnership Facility (WFPF) and Poverty and Environment Fund (PEF) (see succeeding sections). The WFPF has secured donor commitments totaling $26 million, while the PEF has a more modest $3.6 million budget (Sharan 2008).

In addition, the private sector—in particular, the insurance and reinsurance industries—has begun to engage in adaptation activities in developing countries. The most advanced initiatives have been developed by two global reinsurance companies, Munich Re and Swiss Re. These initiatives focus on developing new risk-transfer products such as microinsurance, weather and crop insurance, and other mechanisms such as risk pooling and disaster-related bonds. A set of pilot programs is currently underway in various developing countries, and implementing partners are assessing their efficacy.

The Role of the CGIAR in Climate Change

The Consultative Group on International Agricultural Research (CGIAR) is a partnership of 15 international research centers and five major collaborative programs. The scientists of the CG partner with governments, civil society organizations, and private firms in over 100 countries. The research institutions of the CGIAR are widely known for their contributions to sustainable agricultural growth with benefits for the poor through greater food security, better human nutrition and health, higher incomes, and improved management of natural resources. The new crop varieties, management technologies, policies, and other knowledge products resulting from CGIAR's collaborative research are made available to all.

The CGIAR has the experience and scope to lead global research efforts needed to enable agriculture in the developing world to adapt to climate change and to contribute to mitigation. Much of the ongoing work of the CGIAR is already directly applicable: breeding crops for stress tolerance, developing better practices for sustainable crop and environmental management; gauging the vulnerability of agriculture, natural resources, and rural communities; and supporting the development of policies that are conducive to sustainable agricultural growth. But much more can and must be done.

The CGIAR has already established a coalition of agricultural research facilities around the world. These can form the core of a network of test fields in all of the earth's agroclimatic zones of today to test existing germplasm under widely varying conditions, and to explore the potential for new management systems for tomorrow's climate. Coordinating these efforts with national research sites using a common set of data management protocols will provide unprecedented ability to assess the challenges and possible solutions to the wide variety of possible climate futures.

Much data and genetic material are already in the hands of individual researchers, research institutions, and gene banks around the world. These existing resources are much more valuable when shared in a systematic way with the world. A variety that performs well in one location today might be critical to farmers half way around the world in 20 years with climate change. Open and shared data make it much easier to identify critical data gaps and improve analysis. Collection and harmonization of critical supporting information on land use, soil and water characteristics, and agricultural infrastructure is essential. And recognizing and supporting the willingness of people around the world to contribute information from global positioning system units, cell phones, and digital cameras, to support and extend traditional data gathering methods, can provide significant cost savings if exploited effectively.

Agriculture is an intensely local activity. It requires good knowledge of local biophysical and socioeconomic conditions. In too many parts of the world, national research and extension systems have had to deal with reduced resources, both human and physical, for too long. But lessons learned in one system can be shared with others. The CGIAR is unique in its wide-ranging experience with national research and extension systems. Together with other national and international organizations, and in partnership with local farmers, input suppliers, traders, and consumer groups, it can be a model for effective and efficient development and dissemination of locally appropriate techniques and cultivars to help revitalize the communications among farmers, scientists, and society to meet the challenges of the 21st century.

Significant New Investments

Significant adaptation can be implemented in the agriculture sector without huge new investments, but some key initiatives, such as agricultural research, will require large, new investments.

Changing investment allocation within and across sectors

Developing countries have chronically underinvested in science, technology, and innovation. However, crop breeding—using biotechnology and genetic modification—will be an essential component of adapting to key biotic and abiotic stresses under climate change, including drought, heat, salinity, pests, and disease.

In much of Asia, growth in public investments in research slowed from the end of the 1980s, but investments in GM crops have started to expand. However, few crops have entered the field trial stage (see section on Agricultural Science and Technology Development). In terms of irrigation and water resources, investments may be needed to expand large-scale storage to deal with the increased variability of rainfall and runoff. On the other hand, in subregions where changes in precipitation are highly uncertain, investments might be better distributed among a variety of small catchments. Climate change and variability in water supply, together with potential long-term changes in the cost of energy, could also dramatically change the cost–benefit calculus for big dams for storage, irrigation, and hydropower, making these investments more attractive despite the environmental and human relocation issues that dams raise. The appropriate level and location of future irrigation investments could also change dramatically.

In addition to investing in agricultural adaptation strategies directly, it is important to ensure that sufficient funds are made available for clean drinking water, education, and public health services in rural areas. Without these services, adequate food supply will not translate into adequate nutrition and enhanced livelihoods. In particular, female secondary education and clean drinking water access are crucial for malnutrition rates to decline in developing countries, and will be under further pressure from higher food prices. For additional discussion on investments across sectors to combat food insecurity, see the adaptation investment cost discussion in Chapter III.

Increasing the focus on risk-sharing and risk-reducing investments

Greater variability in weather and production outcomes will require enhanced attention to risk-sharing and risk-reducing investments. Such investments include financial market innovations, weather-based crop insurance, and broad-based social safety nets, which both protect against the negative impacts of increased risk and induce farmers to make decisions that are not excessively risk-averse. International agricultural trade is an important mechanism for sharing climate change risk, so open trading regimes should be supported. Appropriate agricultural advisory services, hydrometeorological infrastructure, functioning financial markets, and effective institutions are necessary to minimize the risks to farmers as they make decisions about agricultural production. Also directly related to managing risk is the need to upgrade the efficiency and sophistication of infrastructure and other investments, including modernizing instead of just rehabilitating irrigation, and investing in paved, rather than dirt, roads. More sophisticated agricultural practices, such as integrated pest management, are also needed, requiring improved human capacity in agricultural management. Strengthening women's roles in household and agricultural production, as well as their rights to and control over assets, would improve the effectiveness of risk management.

An existing mechanism to reduce risk and improve disaster preparedness is the Indian Ocean Tsunami Warning and Mitigation System (IOTWS), which is funded by the UN Economic and Social Commission for Asia and the Pacific (ESCAP). The fund aims to strengthen early warning tsunami capabilities by building institutional, technical, and system-wide capacity in the countries of the region. The fund will be administered by governments, which will identify their own priorities and design and implement projects. At the end of 2008, the fund had approved 11 projects in the region with a budget of $9.2 million (UNESCAP 2007). Although at a relatively small scale currently, this initiative shows the potential for regional cooperation.

Improved spatial targeting of investments

Broad-based investment in adaptation is needed, but funds should also be targeted on the margin to those areas most vulnerable to climate change—that is, areas with the largest climate change signal and highest sensitivity to climate change, those depending on rainfed agriculture or in low-lying delta areas. Rising sea levels will increase the concentration of salt in farm areas, which may require retooling of production systems. In some areas, for example, instead of producing crops, farmers may be better off pursuing alternative livelihoods, such as raising livestock or practicing aquaculture, as is the case in the southwestern coastal areas of Bangladesh during the flood season. More and better spatial analysis is needed to reduce uncertainty about where climate change will have impacts.

Cost of Adaptation

Adaptation measures should be context-and project-specific. Criteria to consider include net economic benefits; timing of benefits; distribution of benefits; consistency with development objectives; consistency with other government policy expenditures; environmental impacts; spillover effects; implementation capacity; and social, economic, and technical barriers (Leary et al. 2007). Once the adaptation strategy has been evaluated, the measure that yields the greatest net benefit should be chosen. Methods presented by Fankhauser (1997); Callaway, Ringius, and Ness (1999); and Callaway (2003) have been integral in developing the cost–benefit analysis of adaptation strategies. The technical capability to change or improve agricultural practices can be assessed by determining their agronomic potential. Therefore, multiple criteria should be used to make judicious selections of adaptation measures from environmental, technical, social, and economic standpoints.

Global Adaptation Costs

Despite the proliferation of adaptation funding windows, most of the activities funded relate to mitigation rather than adaptation. For example, through its operational climate change program, the GEF has funded mitigation activities valued at nearly $1 billion, but it has only funded a small number of adaptation activities (Huq and Burton 2003). TERI (2006) discusses some difficulties in implementing adaptation activities. First, it is difficult to obtain baseline information for incremental cost calculation. Second, funding agencies often require the presentation of "global environmental benefits," but such benefits from adaptation projects can be expressed only at local and sometimes regional levels. Moreover, adaptation to future climate change must be separated from activities that enhance adaptation to climate variability; and most often, adaptation activities are closely linked to other aspects of development, making it difficult to determine a project's adaptation component.

Furthermore, considering the uncertainty that revolves around the future impacts of climate change, a comprehensive assessment of adaptation costs would have to take into account different climate scenarios. Such uncertainty and other limitations make it challenging to estimate adaptation costs at the global level precisely. Recently, six assessments have been published with estimates varying from $4 billion per year (the lower bound) to $166 billion per year (the upper bound) (Table 4.8).

Table 4.8: Estimates of Adaptation Costs on a Global Scale

Assessment	Cost of Adaptation	Timeframe	Countries Included	Sectors	Comments on Methods and/or Sources
World Bank (2006)	$9–$41 billion per year	Present	Developing countries	Unspecified, but presumably all sectors where overseas development assistance (ODA), Foreign Direct Investment (FDI), and Gross Domestic Investment (GDI) are directed.	Estimate based on OECD and World Bank analysis of official flows exposed to climate risk. Costs of "climate-proofing" are assumed in the analysis.
Stern Review (2006)	$4–$37 billion per year	Present	Developing countries	Unspecified (presumably all sectors where ODA, FDI, and GDI are directed)	Update, with slight modifications of the World Bank study

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Table 4.8 continued

Assessment	Cost of Adaptation	Timeframe	Countries Included	Sectors	Comments on Methods and/or Sources
Oxfam (2007)	At least $50 billion per year	Present	Developing countries	Unspecified (presumably all sectors where ODA, FDI, and GDI are directed)	World Bank study, plus extrapolation of cost estimates from National Adaptation Plans of Action and projects undertaken by nongovernment organizations.
UNDP (2007)	$86–$109 billion per year	2015	Developing countries	Unspecified (presumably all sectors where ODA, FDI, and GDI are directed)	World Bank study, plus costing of targets for adapting poverty reduction programs and strengthening disaster response systems.
UNFCC (2007)	$28–$67 billion per year	2030	Developing countries	Agriculture, forestry and fisheries, water supply, human health, coastal zones, and infrastructure	In-depth costing of specific adaptations in water, health, and coastal zones; less detailed costing for agriculture, infrastructure, and ecosystems (infrastructure more abstract).
UNFCC (2007)	$44–$166 billion per year	2030	Global	Agriculture, forestry and fisheries, water supply, human health, coastal zones, and infrastructure	Infrastructure adaptation costs overlap with costing in coastal zones and water resources.

OECD = Organisation of Economic Co-operation and Development, UNDP = United Nations Development Programme, UNFCC = United Nations Framework Convention on Climate Change.

Source: Agrawala and Fankhauser (2008).

The UNDP's Human Development Report 2007/08 (UNDP 2007) focused on three main categories of financing requirements, estimating that the following new (lower bound) financial flows will be required on an annual basis in 2015, as follows:

- climate-proofing development investments: $44 billion,
- adapting poverty reduction to climate change: $40 billion, and
- strengthening disaster responses: $2 billion.

The UNFCCC estimated the annual investment flows needed on a sectoral level for adaptation in 2030, as follows:

- agriculture, forestry, and fisheries: $14 billion;
- water resources: $11 billion;
- human health: $4–$5 billion;
- coastal zones: $11 billion; and
- infrastructure: $8–$130 billion.

To put both these estimates in perspective, the OECD calculated that a total of $103.7 billion was spent on official overseas development assistance (ODA) in 2007. While the UNDP (2007) estimate of $86 billion and the UNFCCC rough estimate of $110 billion are within range of this figure, this would require that all ODA be used for climate change adaptation. Irrespective of the accuracy of these figures, adaptation clearly requires moving beyond the traditional development aid paradigm and necessitates the development of new and innovative financing solutions. In addition, adaptation needs and poverty reduction goals will need to be integrated into broader economic development to make the best use of scarce funds.

Alongside the ongoing work under the auspices of the UNFCCC, most actors in the international development and humanitarian community, as well as select private firms, have begun their own adaptation efforts. These efforts are of two distinct types: (i) mainstreaming climate change impacts into existing program portfolios, and (ii) developing new and additional activities in the area of adaptation.

UNFCCC assessment for the agriculture, forestry, and fisheries sectors

Only one single study (by the UNFCCC) provides a quantification of future investment and financial flows necessary to meet climate change adaptation needs in agriculture, forestry, and fisheries. About $14 billion in investment and financial flows are estimated to be needed for agriculture, forestry, and fisheries (AFF) during 2000–2030, including $11 billion for production and processing, most of which is expected to be financed by domestic private sources; and $3 billion needed for research and development and extension, which is expected to be met by public sources. If converted into annual values, developing country needs for adaptation research are estimated at a very low $47 million per year and extension needs at $2 million per year up to 2030 (Table 4.9).

A recent report mentions the challenges of estimating a global cost for adaptation in the agriculture sector (Wheeler and Tiffin 2009). According to the authors, the UNFCCC (2007) estimates—the only report available—is likely to be underestimating costs as only irrigation, i.e., a single adaptation option, is likely to cost more than half of the global value by 2030 ($8 billion).

UNFCCC recognizes the limited literature on adaptation costs in the AFF sectors and as a result it "*...relies on subjective statements about the current degree to which research expenditures are directed*

Table 4.9: UNFCCC's Assessment of Global Costs in Agriculture, Forestry, and Fisheries

(a) Expenditures in agriculture, forestry, and fisheries ($ million)

Type of Expenditure	Amount
Research in developing countries*	15,422
Research in high-income countries*	25,111
Extension in developing countries*	3,083
Extension in high-income countries*	4,161
Capital formation in developing countries**	190,102
Capital formation in high-income countries**	354,017
Total in developing countries	208,608
Total in high-income countries	383,288
Total	591,896

UNFCC = United Nations Framework Convention on Climate Change.

*Data are estimated for 2000.

**Data are estimated for 2005.

(b) Investment and financial flows needed in 2030 for economic and population growth and for adaptation to the adverse impacts of climate change ($ million)

Type of Expenditure	Additional Investment and Financial Flows Needed due to Economic and Population Growth	Additional Investment and Financial Flows Needed for Adaptation to the Adverse Impacts of Climate Change
Research in developing countries	13,526	1,353
Research in high-income countries	20,374	2,037
Extension in developing countries	617	62
Extension in high-income countries	0	0
Capital formation in developing countries	291,093	5,822
Capital formation in high-income countries	248,001	4,960
Total developing countries	305,236	7,237
Total high-income countries	268,375	6,997
Total	573,611	14,234

Source: UNFCCC (2007).

at climate-related issues and a broad assumption about how capital formation might be affected" (UNFCCC 2007: 101). Some other limitations of the report are mentioned by Agrawala and Fankhauser (2008). The UNFCCC assessment is based on assumed percentages of what adaptation might cost, which are then applied to very large numbers of baseline investments to yield dollar amounts of adaptation costs. The authors also mention that there might be undercounting due to the narrow scope of impacts and adaptations that have been considered, as well as potential double-counting of investments. For example, infrastructure costs are estimated separately as well as being integral components of coastal, water sector, and agricultural adaptations (Agrawala and Fankhauser 2008). Furthermore, as UNFCCC emphasizes, the investment and financial flows calculated are not estimates of the cost of mitigating or adapting to climate change, given that operating and maintenance costs, and offsetting savings, such as reduced energy costs, are excluded (UNFCCC 2007).

National Adaptation Programs of Action

All countries, as part of their responsibilities under the UNFCCC, should create national adaptation programs of action (NAPAs). These plans would take a broad strategic view of the future development path of a given country and consider how it could best be designed or modified in light of expected changes in climate. Within such a strategic view, policies for sectors and regions could be examined and adjusted to account for climate change. Sectoral policies would likely include those for agriculture, forestry, fisheries, water and other natural resources, health, infrastructure, and ecosystems. In addition, the policy review could include the management of extreme weather events such as droughts, storms, and floods and areas of particular risk such as exposed coastal zones and steep mountain slopes. Specific adaptation measures could then be evaluated and selected within the context of a climate-sensitive strategy and set of policies.

Financing these plans, however, is limited to least-developed countries. Furthermore, NAPAs are not comprehensive adaptation plans; they are confined to urgent or priority measures. A common concern of the developing countries has been that their participation in multilateral environmental agreements imposes new costs as they undertake new obligations to address global environmental problems—to a large extent, created by the industrialized countries. It seems realistic therefore to suggest that the developed countries, acting collectively through the GEF, should support the preparation of NAPAs. This step would not only help ensure that climate is adequately considered in national development plans and sectoral policies, but would also reassure donors and investors that climate change adaptation measures are well conceived and represent sound expenditures.

The aggregation of adaptation costs provided by NAPAs in order to estimate global costs is not accurate because many countries have yet to complete their plans and methods, and simplifications used to estimate costs vary considerably among the submitted plans. Nevertheless, although they might not be a reliable guide to the actual implementation costs, they are very useful in revealing the adaptation needs of the countries, and they might help to define relative priorities for stakeholders (Agrawala and Fankhauser 2008).

NAPAs show that (with the exclusion of a $700 million multisectoral project in the Genale–Dawa basin proposed by Ethiopia) the largest requests and costs of implementation of adaptation activities are in the agricultural, livestock, and fisheries sectors (Table 4.10).

Table 4.10: Projects Identified in National Adaptation Programs of Action, by Sector

Sector	Number	Total Cost ($)
Agriculture, livestock, fisheries	104	269,692,234
Water resources	57	140,960,970
Coastal zone and/or marine ecosystems	34	95,671,300
Forestry	33	53,494,730
Health	31	40,043,000
Cross-sectoral	27	740,227,240
Terrestrial ecosystems and/or biodiversity	21	24,908,592
Early warning and forecasting	15	37,423,063
Energy	15	27,964,120
Fisheries	14	35,375,500
Infrastructure	13	16,881,631
Education	10	9,005,000
Disaster management	8	12,953,597
Tourism	2	1,250,000
Insurance	1	225,000
Total	385	1,506,075,977

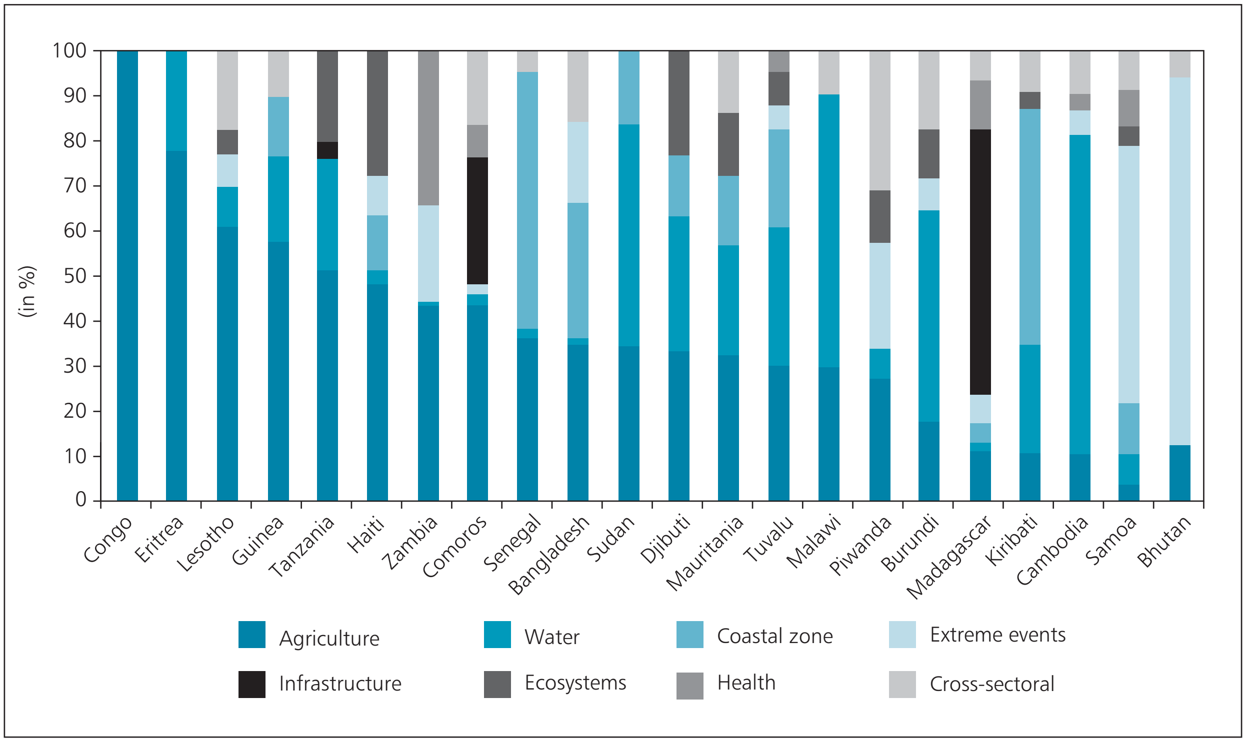
Source: UNFCCC (2007).

An assessment of NAPAs for 22 countries showed that in 14 countries, the agriculture sector represents at least 30% of total adaptation costs, or 60% if the water sector is included (Agrawala and Fankhauser 2008). Among the countries assessed, the highest national cost of priority projects has been identified in Cambodia ($128.9 million, mostly in the water sector), followed by Bangladesh ($77.4 million) (Figure 4.2). Such high adaptation demands in Cambodia and Bangladesh are not surprising considering the high sensitivity and low adaptive capacity of these countries, as discussed in Chapter II.

The finding that agriculture will face high costs in adapting to climate change contradicts many modeling studies that assume that increases in crop productivity can be obtained from low-cost adaptation measures (Agrawala and Fankhauser 2008). Furthermore, in their NAPAs, countries identified priorities relating to soil erosion reduction and improving soil fertility, activities not considered in modeling studies. Adaptation measures such as soil management will also require significant financial outlays (Agrawala and Fankhauser 2008).

The preparation of NAPAs is an early step in moving countries toward effective adaptation responses. The plans need to be implemented, and further support for this implementation will clearly be required. Most of the present funding for adaptation has been on a voluntary basis.

Figure 4.2: Distribution of Adaptation Costs, by Sector for Each Country



Source: Agrawala and Fankhauser (2008).

The GEF has established funds or "windows" to which developed countries make contributions and from which developing countries can obtain funds indirectly through one of three implementing agencies (UNDP, UNEP, and the World Bank). The growth in these funds has been slow, partly because the donor countries seem to lack sufficient confidence that the modalities for the effective use of the funds exist. Negotiating the details of the preparation of the plans will be time consuming, and thus action must be taken if such ideas are to be included in post-2012 agreements. It may be appropriate to proceed slowly in developing NAPAs, however. If they are to be truly comprehensive and part of the mainstreaming process, it may be more effective to incorporate them into poverty reduction strategy papers (PRSPs) or other national development plans currently coordinated by multiple donors. Without this integration, NAPA may simply add another layer of planning rather than aid the process of mainstreaming.

Adaptation Costs for Asia and the Pacific

For Asia and the Pacific, adaptation costs for combating rising sea levels are expected to be particularly high. Protecting South and Southeast Asia from rising sea levels (of greater than

Table 4.11: Impact of Coastal Protection on Damage from Rising Sea Levels

Global Vulnerability Assessment (GVA): Case Countries	People at Risk without Measures	People at Risk with Additional Measures	Cost of Measures (% of gross national product per year)
North America	170,000	90,000	0.02
Central America	56,000	6,000	0.23
Caribbean islands	110,000	20,000	0.21
South America, Atlantic coast	410,000	48,000	0.25
South America, Pacific coast	100,000	11,000	0.01
North and west Europe	130,000	130,000	0.02
North Mediterranean	37,000	31,000	0.02
South Mediterranean	2,100,000	250,000	0.07
Africa, Atlantic coast	2,000,000	220,000	0.25
Gulf States	14,000	3,000	0.05
Asia, Indian Ocean coast	27,360,000	3,040,000	0.52
Indian Ocean, small islands	100,000	12,000	0.72
Southeast Asia	7,800,000	880,000	0.20
East Asia	17,100,000	2,200,000	0.06
Pacific Ocean, large islands	17,000	4,000	0.17
Pacific Ocean, small islands	34,000	4,000	0.77
World	61,300,000	7,380,000	0.056 (average)

Note: Data are based on the number of people at risk from a 1-meter rise in sea level. People at risk are calculated as the number of people living in the risk zone, multiplied by the probability of flooding per year. The cost of measures is undiscounted, assuming 100 years' lifetime—that is, an annual cost is 1% of the total cost.

Source: Fankhauser et al. (1998); Delft Hydraulics (1993) cited in Fankhauser (2006); Francisco (2008).

50 centimeters) could cost $305 billion alone (in 2002). Table 4.11 presents estimates of costs as a percentage of gross national product (GNP) per year for global regions. Small island nations in the Pacific Ocean and Indian Ocean will face the largest burden (approximately 0.75% of GNP per year), followed by coastal communities along the Indian coast of Asia (0.52% of GNP per year) (Francisco 2008). Over 27 million people who live along the Indian coast would be at risk, but the adaptation investments discussed above are estimated to reduce this figure to 3 million people (Francisco 2008).

Table 4.12 shows the costs of priority activities of adaptation in selected least developed countries

Table 4.12: Costs of Priority Adaptation Activities in Selected Least Developed Countries in Asia and the Pacific

Country	Adaptation Measure	Cost ($ millions)
Bangladesh	• Constructing flood shelters and information and assistance centers to cope with more frequent and intense floods in major floodplains,	5.00
	• Enhancing the resilience of urban infrastructure and industries to the impacts of climate change,	2.00
	• Promoting adaptation of coastal crop agriculture to salinity, and	6.50
	• Adapting fisheries in areas prone to enhanced flooding in the northeast and central areas through adaptive and diversified fish culture practices.	4.50
Bhutan	• Managing landslides and preventing floods,	0.89
	• Establishing a weather forecasting system to serve farmers,	0.42
	• Introducing flood protection in downstream industrial and agricultural areas, and	0.45
	• Harvesting rainwater.	0.90
Cambodia	• Rehabilitating upper Mekong and provincial waterways to reduce flood risks, improve fisheries resources, and supply sufficient water for irrigation and domestic uses;	30.00
	• Undertaking vegetation planning for flood and windstorm protection;	4.00
	• Developing and improving community irrigation systems; and	4.00
	• Restoring community mangroves and using natural resources sustainably.	1.00
Samoa	• Undertaking reforestation, rehabilitation, and a community forestry fire prevention project;	0.42
	• Undertaking an early warning climate system project to implement effective early warnings and emergency response measures to climate changes and extreme weather events;	4.50
	• Developing coastal infrastructure management plans for highly vulnerable districts; and	0.45
	• Promoting sustainable tourism that takes into account climate change and climate variability.	0.25
Tuvalu	• Increasing resilience of coastal areas and settlements to climate change;	1.90
	• Increasing pit-grown pulaka productivity by introducing a salt-tolerant pulaka species; and	2.20
	• Adapting to frequent water shortages by increasing household water capacity, water collection accessories, and water conservation techniques.	2.70

Source: Adapted from NAPAs submitted to the UNFCCC (IGES 2008).

in Asia and the Pacific. The projects in the five countries listed—Bangladesh, Bhutan, Cambodia, Samoa, and Tuvalu—are estimated to cost $72 million, which would be double the regional Funds currently available in the Climate Change Fund. Rehabilitating the upper Mekong to reduce flooding risks is the most expensive measure, amounting to at least five times the average costs of other projects and totaling $30 million. Maintaining water resources, including flood protection, rainwater harvesting, and irrigation, is a priority activity for most of the countries listed.

In summary, global assessments of adaptation costs have several limitations, considering the high level of uncertainty in the science of climate change. As NAPA show, adaptation strategies in the agriculture sector not only encompass a large variety of activities but some are also likely to be very costly. In a region such as Asia and the Pacific, where climate change impacts and adaptation costs will be widespread and heterogeneous (especially taking into account extreme weather events), it is also important that assessments of costs and requirements are made at the local level so that resources can be delivered effectively.

Reforming Climate Change-Related Governance and Institutions

Both mitigation and adaptation response options need to be implemented by a variety of actors at local, community, national, and global levels. To decide who is best equipped to implement a particular measure, it is useful to look at the spatial and temporal dimensions of the activity in question. Farm-level adaptation measures, such as changing a crop variety or building a farm pond, generally do not require much in the way of institutions for coordination, although coordination at higher levels may be needed to produce new varieties and develop seed systems that distribute them. Coordination becomes more important to implement response options that operate at the group or community level, such as a pond or small reservoir. Collective action institutions, such as farmer organizations, might be most appropriate for these types of adaptation measures, but some state institutions may also be relevant—for example, to provide technical advice to a group of farmers constructing or operating the reservoir. For larger scale adaptations, such as investments in large-scale irrigation or climate information systems, local government or other state agencies become increasingly important for coordination. Ultimately, the scale of policies and actions becomes global, requiring international institutions—either existing ones, such as the UN agencies, or new institutions, such as the carbon credit exchanges formed after the Kyoto Protocol in 1997.

The timeframe for action also provides insight into the nature of institutional arrangements needed. Although climate change response schemes arguably need to be set in motion as soon as possible, some will show results in the short term (a year or two), others will have lagged results developing over the medium term (2–10 years), and still others will produce results over a much longer time horizon. The longer the time span between actions taken and results seen, the more difficult it will be to gain and maintain support and to monitor progress. Some actions, such as responses to crises like drought or flooding, will be intermittent. These actions call for institutional structures for preparedness and rapid response. The temporal scale may also indicate the relevance of property rights issues when there is a significant lag between an action and its consequences, especially between investments and returns such as for planting trees (Meinzen-Dick and Moore 2009).

If solutions in the long run are to be sustainable, it will be essential to involve local people, consider context-specific issues in local policies, and recognize the increasing role of international institutions in multi-country agreements. At all levels, scaling up adaptation or mitigation policies requires the involvement of the private sector because available funds are primarily in private agencies, and it is important to build on their successful strategies. Coordination among institutions becomes increasingly important, especially with high demand for better cross-sectoral planning tools and flexible and adaptive management systems.

Markets also play a coordination function. The question of when market (rather than state or collective action) institutions work best depends not so much on scale but on issues of transaction costs and attitudes toward markets. Working with many small suppliers of carbon "services" entails higher transaction costs than working with a few large-scale suppliers, which means that markets, for example, tend to favor plantations, over smallholder agriculture or forest communities. Asymmetrical information, either about the actions of farmers or the benefit streams they could tap, will also hinder market-based coordination. Finally, the acceptability of market approaches will depend on values and attitudes toward resources and markets. For example, certain groups representing indigenous peoples have objected to the commoditization of their land and its carbon, which they feel has heritage value, whereas other groups may see markets as an opportunity.

In practice, many issues require policies and action at all levels and across all sectors. For example, effective agreements on reduced emissions from deforestation and degradation will require (i) international market mechanisms to match those interested in paying to offset their emissions with those interested in being paid to sequester carbon, (ii) national governments that will broker agreements—for example, through a designated national authority as currently employed for CDM agreements, and (iii) collective action groups to monitor compliance among local smallholders. Although local collective action can provide an effective means of measuring and ensuring compliance, the groups' motivation to execute this role on an ongoing basis will depend on whether the incentives exist. Continued participation is more likely if the group has been involved in the negotiations, has had a say in setting the rules, and receives a substantial benefit, either for the group or for its members.

Experience with collective action in other types of natural resource management suggests that systems that are developed in a top-down manner and do not engage local people in designing them are unlikely to create viable institutions that operate at the local level in the long run. This experience serves as a warning against focusing only on national-level negotiations and systems for climate change mitigation or adaptation because they are unlikely to create effective institutions to execute the programs, especially among smallholders (Meinzen-Dick and Moore 2009). A range of national and local (public and private) institutions is therefore needed. Rather than focusing exclusively on any single type of institution, policies need to develop polycentric governance arrangements within which multiple institutions play a role (Ostrom 1999). This situation also calls for coordination among different institutions.

Civil Society

Farmers and villagers are likely to be affected by adverse climatic changes, and thus they may voluntarily collaborate to develop and apply adaptation measures by contributing their time and resources (Francisco 2008). This kind of risk-sharing practice constitutes community-based adaptation activity, one example of which is the adaptation project implemented in the Thua Thien Hue Province of Viet Nam (Box 4.7) In that project, communities worked together from the planning to implementation stages, so the resulting adaptation strategies fit their needs well. The project also shows that empowering civil society to participate in the assessment process, including identifying adaptation strategies and implementing the activities based on the plan, reduces the vulnerability of communities to climate change (Francisco 2008; Sperling 2003). Similar types of adaptation schemes should be tested in other countries subject to annual flooding. Furthermore, in Cox Bazar, in eastern Bangladesh, when women became fully involved in disaster preparedness for cyclones, as well as other support activities such as education, reproductive health, self-help groups, and small and medium-sized enterprises, the number of women killed or affected by cyclones fell dramatically (IFRC-RCS 2002 in Sperling 2003). Finally, community-based work is not new in South and Southeast Asia. A number of community-based fisheries and natural resource management projects have been implemented in these subregions. Note, however, that the strong involvement of local and national governments is required in implementing these types of initiatives.

Government Institutions

The effective planning and implementing of climate change adaptation measures for agriculture will require the engagement of a core ministry, such as the Ministry of Finance or Planning, alongside the Ministry of Agriculture, to ensure strong government support (Stern 2006). Such engagement has been developed in many cases for climate change mitigation, but it has not often extended to adaptation. Second, the core capacities of developing country governments will need to be further developed. Such capacity building is required across a number of areas, including technical subjects such as climate forecasting and scenario planning, as well as general development topics such as governance, accountability, and empowerment of local communities. Third, adaptive and flexible management will be essential, including the capacity to monitor the results of managers' decisions and to modify actions as needed. The broadening nature and increasing severity of potential climate impacts in a given area and the unavoidable uncertainties associated with predicting these impacts require innovative approaches to management and development that go beyond centralized prediction and control practices (Nelson et al. 2008; Pahl-Wostl 2007a). One approach—adaptive management, or adaptive governance—has received attention because it enables decision makers and resource managers to work with the inherent uncertainty associated with climate change (Pahl-Wostl 2007b; Brunner et al. 2005; Tompkins and Adger 2004; Folke et al. 2002).

Although interpretations of adaptive management and governing institutions often differ across disciplines (Stankey et al. 2005), such institutions have several defining characteristics. First, the management scale is often realigned with the scale of ecological processes; for example, the watershed or the ecosystem (Cumming et al. 2006). Second, they are founded on a local or regional community-based management system (Olsson et al. 2004). Third, they involve collaboration and integration of various organizations and institutional arrangements at all levels of decision making to foster flexibility, balance divergent interests, and promote coordination and deliberation among

Box 4.7: Community-Based Adaptation to Climate Change in Viet Nam

This project was implemented in four communes and eight villages in Quang Dien and Phu Vang Districts, Thua Thien Hue Province, in the north–central coast of Viet Nam in 2002. These villages experience about 30 days of flooding each year. In 1999, one of the worst floods resulted in the loss of hundreds of lives, along with property and other economic losses. This severe incident attracted international support for the Government of Viet Nam. During the relief operations, an initiative on "capacity building for adaptation to climate change" began. The main objective was to help build adaptive strategies to enable communities to deal with recurrent climatic catastrophes and to minimize the loss of lives and property. This process involves three major steps for each participating community:

1. Scenario building includes identifying and analyzing the hazards, vulnerability to climate change, and existing and required adaptive capacity of the respective village. Interviews, focus group discussions, field surveys, historical profiling, and mapping of vulnerable sites are some of the methods applied to describe the current situation and future scenarios related to climate change. Adaptation mechanisms at the household and community levels, as well as social institutions that could contribute to hazard and disaster management strategies are identified at this stage.

2. Planning involves discussions among the leaders of the social groups or organizations, such as those for farmers, fishers, women, youth, and other village political associations. Deliberations on threats and potential impacts arising from climate change and possible measures to address these issues are carried out at this stage. These measures can be livelihood improvements in agriculture and aquaculture, disaster management protocols, and other strategies. The participation of local government officials is critical during this process to ensure acceptance and implementation of the plan at the commune and district levels, as well as increase the likelihood that the government will co-fund some subprojects identified. The main output at this stage is a "safer village plan" that will increase the resilience of the community to the negative impacts of climate change.

3. Project implementation of some subprojects identified in the plan is made possible through in-kind and cash contributions to the community's adaptation funds. These subprojects involve measures to ensure the safety of the people, infrastructure, and livelihoods of the village. Construction of an intercommune road, multipurpose school (as an emergency shelter), and technical support for agriculture and fisheries are provided. Training on the use of early warning devices, and rescue and relief operations are extended to representatives of various social groups. Critical equipment in giving timely warnings of impending disasters, including boats, life jackets, and megaphones, are made available to representatives of the social groups.

Source: Francisco (2008).

diverse stakeholders (Folke et al. 2005; Dietz et al. 2003). And fourth, an adaptive governance approach requires that managers be knowledgeable about scientific and local information as well as the implementation of policy experiments that develop understanding, prioritize learning as an objective, and improve the ability to manage uncertainty (Lee 1999; Holling 1978). This experimental approach goes beyond trial and error because it takes an explicitly scientific approach to testing and subsequently learning from empirically informed management decisions (Arvai et al. 2006).

Government institutions play a significant role in ensuring the safety of the public, particularly during extreme natural disasters such as flooding. Such institutions served as channels in responding to past environmental events and thus will similarly provide assistance to the local communities, especially the most vulnerable groups, in adapting to climate change (Agrawal, McSweeney, and Perrin 2008). The ability of local institutions to influence the impact of climate change in communities depends on the structure of local governance and local institutional arrangements. For example, households belonging to a lower caste in western India have limited access to the communal pastures compared with richer, upper caste households that can secure much of the available forage from the common pasture areas (Agrawal 1999).

Discussions between government organizations and civil service institutions are important in identifying and implementing adaptation strategies for climate change. Furthermore, accountability of public institutions to the local society ensures good governance through responsive, participative, and accountable actions (Sperling 2003) (Box 4.8). Governments serve as intermediaries for external support to adaptation (Agrawal, McSweeney, and Perrin 2008) and must be creative in finding ways to support activities with limited budgets. In addition, they must encourage collaboration with the private sector in developing climate change adaptation schemes, such as weather insurance.

Regional Organizations

Cooperation among governments in Asia and the Pacific is necessary to ensure effective implementation of adaptation and mitigation strategies in their respective countries, as well as to explore the financial means for addressing climate change. Funding modalities related to climate change (and accessibility of these funds to the vulnerable people), such as carbon trading, payment for environmental services, or other mechanisms to mitigate GHGs, must be implemented by Asian development planners and policy makers coordinating with each other.

Formal organizations such as the Association of Southeast Asian Nations or the South Asian Association for Regional Cooperation could help such coordination efforts. The Indian Ocean Tsunami Warning and Mitigation System is a good example of how coordination can work for disaster preparedness in the region. Work done in various agricultural and economic development sectors under the Greater Mekong Subregion initiative is another example of how investment and knowledge transfer can be facilitated across the various countries in Asia and the Pacific.

Development Agencies and Donors

The core programs of international development agencies and donors must encompass the impacts of climate change as it affects poverty, food security, and economic development in developing countries. Development agencies must ensure that climate issues are internalized in their poverty reduction programs. This approach requires developing tools and methodologies, training, and

Box 4.8: Government Accountability Related to Flooding in Bangladesh

Flooding in Bangladesh is an annual incident, with one-third of cultivated land flooded in a normal monsoon year. In the northeastern part of the country, communities living near the Haor Basin have learned to cope with flooding. The Haor Basin was considered one of the most productive fishery resources in the floodplains, along with a food surplus that provided 10% of national grain supplies. The food system was unstable, however, and food shortages thus affected communities where often 80% of workers are sharecroppers or landless laborers, and a powerful elite controls the land and fishing rights. Although expected floods are manageable, flash floods can cause severe damage to homes and crops.

As a response to this threat, the Water Development Board built more than 800 kilometers of embankments, the maintenance of which is the responsibility of the government and communities. Despite the flood control, a flash flood that hit the communities in 2002 damaged one-third of the embankment and 20% of crops, resulting in food shortages affecting an estimated 1.4 million people. Since then, the communities have complained about the lack of repairs to embankments, construction mismanagement, lack of monitoring, and corruption. As a result, the state Minister for Disaster Management announced that, for the first time, elected officials would be engaged in embankment construction and maintenance. Since the local government lacks adequate capacity, HUNO—a local NGO—is working with it and with the Water Development Board to develop a citizen-based monitoring system.

Source: Sashankar (2002); DFID (2002) in Sperling (2003).

raising awareness of senior management and staff. It may also involve modifying their own institutional processes to ensure that climate change vulnerability in developing countries is addressed in all of their development work (Sperling 2003). Although funds for climate change adaptation and mitigation strategies for developing countries are already available, securing access to these funds poses a challenge for developing countries.

The Private Sector

Risk sharing or risk transfer is critical in implementing adaptation measures. Weather insurance markets, normally developed by the private sector, are a form of risk transfer (Francisco 2008). The insurance and reinsurance industries in particular have started to engage in adaptation activities in developing countries focusing on the provision of new risk-transfer products such as microinsurance, weather and crop insurance, and other mechanisms such as risk pooling and disaster-related bonds.

The important role of private-sector involvement in crop (and livestock) breeding has been described in the section on Agricultural Science and Technology Development and Box 4.3.

Private investment has also taken off in the irrigation sector, with much of the increase in irrigation in Asia coming from farmer investments in irrigation pumps. Private groundwater irrigation has grown rapidly since the 1980s, propelled by the availability of cheap drilling technology, rural electrification, and inexpensive small pumps, mostly imported from the People’s Republic of China. In Viet Nam, rapid dissemination of small private pumps has provided many farmers with an alternative for improving management and water control and increasing water productivity. Privately owned pumps facilitated the shift from rice to higher-value crops, and the drainage of excess floodwater in the deltas. Moreover, in the highlands, groundwater development has been vital for the development of cash crops, particularly coffee and pepper (Barker et al. 2004).

Adaptation Policy Recommendations

At the center of agricultural adaptation are innovative responses to climate change, which are already in development but have not been implemented on a wide scale. These responses include changes in agricultural practices for crop and livestock systems. Enhancing the ability of farmers to respond to climate variability and climate change will require significant improvements in developing and disseminating agricultural technologies targeted toward the major evolving biotic and abiotic stresses generated by climate change. But new technologies, by themselves, are insufficient to address successfully the challenges climate change poses for agriculture, including increased risks to production and household income.

To protect against the devastating outcomes of agricultural failures due to weather and climate, and to reduce risk aversion in farmers' production decisions and thus enhance the potential for adoption of adaptive farming systems, programs and policies should be implemented to improve risk management and crop insurance, including weather index-based insurance. A stable and supportive policy environment that makes those programs available and profitable is also a critical factor. Such a policy environment requires strengthening important ongoing development initiatives that have been implemented in varying degrees throughout the developing world in support of climate change adaptation. These initiatives include secure property rights; improved economic incentives and green markets; improved information collection, use, and dissemination; extension services; and enhanced social protection and fiscal resilience. These adaptation areas need to be supported by local coping strategies and indigenous knowledge employed by farmers for many years, and in some cases, for centuries.

Finally, effective implementation of an agenda for climate change adaptation will require mainstreaming climate change and adaptation into development planning, reforming climate-related governance and institutions, and undertaking massive new investments.

Given regional shifts in the volume of rainfall, increased temperatures, and rising sea levels, investments focusing on enhanced water control, management, and efficiency will be crucial for adaptation to climate change, particularly in Bangladesh, Bhutan, India, Nepal, Viet Nam, and the Pacific Islands. Knowledge and information-sharing among farmers, government implementing agencies, and researchers should be given an enabling environment that supports adaptive management.

While it is difficult to prioritize among adaptation strategies, given the uncertainty of future climate change impacts and the impediments to comprehensive cost–benefit analysis, Hallegatte (2009) put together a series of prioritization criteria in the absence of cost–benefit analysis. His findings indicate that the strategies that should be prioritized are as follows:

1. Strategies for which there will be no-regrets in that they will yield benefits even in the absence of climate change—for example, reversing trade-distorting and other policies that increase wastage of natural resources, such as water;

2. Strategies that are reversible, if necessary, which are preferable to those that are irreversible—for example, insurance and early warning systems, as well as farm-level adaptation options, such as changing planting dates or varieties;

3. Strategies that introduce new safety margins, which reduce vulnerability at low cost—for example, dikes built with higher walls to cope with future rising sea levels;

4. Strategies that reduce decision-making time horizons—for example, those that allow decisions to be taken at a future time, such as phasing in shorter term investments in lieu of long-term investments, or small-scale irrigation systems using groundwater or rainwater as opposed to requiring the construction of irrigation dams and associated investments; and

5. Strategies that take into account or reduce conflicts or enhance synergies among strategies—for example, those that also promote mitigation or reduce poverty (Table 4.13).

However, such an approach—by focusing on costs of adaptation and not the benefits of such investments—undervalues high-risk and (likely) high-payoff strategies, such as investments in rural infrastructure, crop breeding, focusing on no-regrets options. As such, it is a useful second-best approach to assess alternative adaptation strategies and expected rates of return remain the first-best way of choosing among adaptation strategies and options—even under increased uncertainty. Such an analysis was presented in Chapter III.

Table 4.13: Prioritizing Adaptation Strategies

Type	Strategy	No Regret	Reversible and/or Flexible	Cheap Safety Margins	Reduced Decision Horizon	Soft and/or Reduced Conflict Strategies	Synergies with Mitigation
Change in agricultural practices							
Farm level	• Changing planting dates	1	1	1	1	1	1
	• Changing crop varieties, crop diversification	1	1	1	1	1	1
	• Soil and water conservation techniques, conservation tillage	1	1	1	1	1	1
	• Supplementary livestock feeds	1	1	1	1	1	1
Farm and community levels	• Integrated pest management	1	1	1	1	1	1
National level	• Strong extension services	1	1	1	1	1	1
	• Market and climate information system	1	1		1	1	1
Change in agricultural water management							
Farm level	• Water harvesting		1	1	1		1
	• On-farm irrigation						1
	• Soil and water conservation	1	1	1	1	1	1
Community level	• Small reservoirs				1		
	• Watershed management	1			1	1	1
	• Water trading		1		1	1	1

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Table 4.13 continued

Type	Strategy	No Regret	Reversible and/or Flexible	Cheap Safety Margins	Reduced Decision Horizon	Soft and/or Reduced Conflict Strategies	Synergies with Mitigation
National level	• Investment in large-scale systems, reservoirs						
	• Coastal zone management		Depends		1		
Agricultural diversification							
Farm level	• Shrimp/rice farming in coastal areas with rising sea levels		Depends				
	• Migration						
	• Off-farm work	1					
Risk management and crop insurance							
Farm level	• Crop insurance	1	1	1	1	1	
Community level	• Contract farming	1	1	1	1	1	
	• Future and option contracts	1	1	1	1	1	
Community and national levels	• Weather index insurance	1	1	1	1	1	
Agricultural science and technology development							
Community level	• Participatory crop breeding	1		1			1
National level	• Drought and/or heat-resistant crops	1		1			1
	• Animal breeds	1		1			1
Agricultural advisory service and information systems							
Community level	• Farmer-to-farmer training	1	1	1		1	1

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Table 4.13 continued

Type	Strategy	No Regret	Reversible and/or Flexible	Cheap Safety Margins	Reduced Decision Horizon	Soft and/or Reduced Conflict Strategies	Synergies with Mitigation
National level	• Support dissemination of climate-resilient varieties, technologies, and practices • Disseminate (seasonal) climate forecasts	1	1	1		1	1
Agricultural market development							
Community level	• Cooperatives for farm inputs and outputs, information and communications technologies	1	1	1		1	
National level	• Infrastructure and market development	1					
	• Extension service	1	1	1		1	
Agricultural policies							
National level	• Eliminating existing detrimental policies that will exacerbate climate change impacts (phasing out biofuel promotion, reducing fertilizer subsidies, and so on)	1				1	1

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Table 4.13 continued

Type	Strategy	No Regret	Reversible and/or Flexible	Cheap Safety Margins	Reduced Decision Horizon	Soft and/or Reduced Conflict Strategies	Synergies with Mitigation
	• Mainstreaming climate change	1				1	1
	• Increasing the value of sustainable farming practices through the valuation of carbon		1		1	1	1
Trade							
Community level	• Cooperative storage	1	1	1	1	1	
	• Market information	1	1	1	1	1	1
National level	• Trade reform	1	1			1	
	• Legislation on food safety standards					1	
	• Support for market information systems	1	1		1	1	1
Enhanced social protection and microfinance							
Community level	• Effective rural institutions	1				1	
	• Microcredit groups for women	1				1	

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Table 4.13 continued

Type	Strategy	No Regret	Reversible and/or Flexible	Cheap Safety Margins	Reduced Decision Horizon	Soft and/or Reduced Conflict Strategies	Synergies with Mitigation
National level	• Food reserves and storage	1				1	
	• Social policies (safety nets) targeted to the poor	1				1	
Changing investments							
National level	• Changing investment allocations within and across sectors			1		1	1
National and district levels	• Improved spatial targeting of investments		1	1		1	1
National and district levels	• Increasing the focus on risk-sharing and risk-reducing investments			1		1	1
Disaster preparedness							
Community and national levels	• Climate information systems	1	1		1	1	1
	• Early warning systems	1	1		1	1	1

Note: Table columns/rows are filled as an example; "1" means that it "is important." No final ranking was suggested.

Source: Compiled by authors based on Hallegatte (2009).

CHAPTER V

Opportunities for Mitigation and Synergies with Adaptation and Sustainable Development

Introduction

Mitigation and adaptation are both essential aspects of dealing with climate change, but adaptation becomes costlier and less effective as the magnitude of climate change grows. Consequently, when mitigation objectives are affordably achieved, adaptation requirements are reduced and the ultimate result is less stress. As discussed in Chapter II, scenarios that incorporate both mitigation and adaptation in modeling the future effects of climate change result in lower levels of vulnerability compared with scenarios that include either mitigation or adaptation alone. Therefore, pursuing synergies between mitigation and adaptation in the context of reducing poverty will be particularly important in building resilience to the effects of climate change.

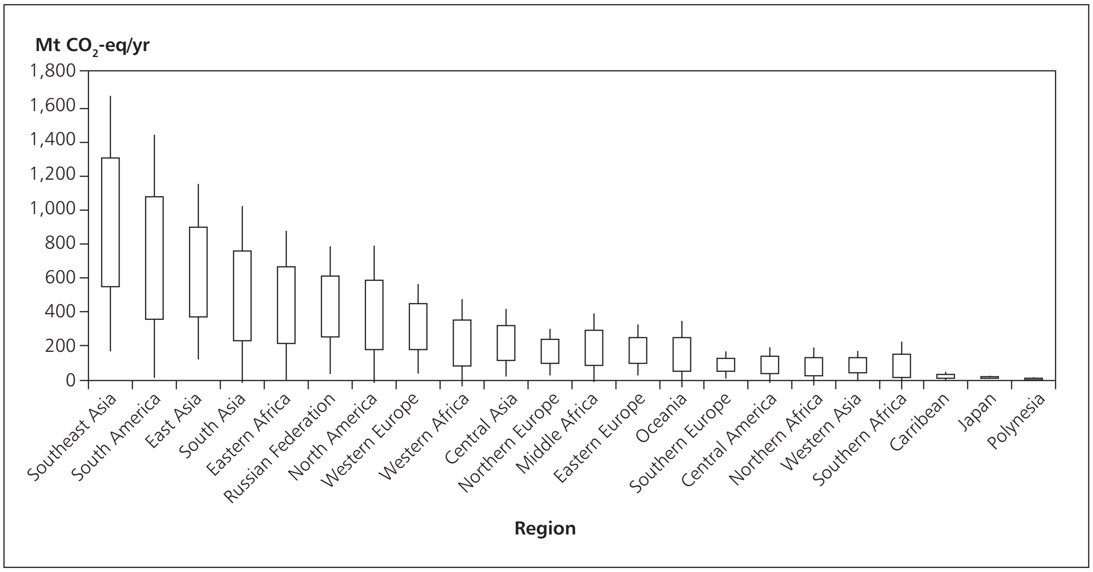
Global technical mitigation potential in the agriculture sector is high—estimated at between 5.5 and 6.0 gigatons (Gt) of carbon dioxide equivalent per year (CO_2-eq/yr) by 2030—with a potential for Asia to contribute up to 50% of theoretical reductions (Smith et al. 2007a, calculated from Figure 5.1). The majority of these emission reductions can be achieved through effective changes in agricultural management practices that increase soil carbon, reduce methane emissions from flooded rice fields, and improve nitrogen fertilizer usage (Figure 5.1; see also Box 5.1, which explains the difference between technical mitigation potential and economic mitigation potential).

Nearly 60% of the population of Asia and the Pacific depend on agriculture and, therefore, have the potential to contribute to effective emission reduction strategies. Moreover, adopting effective management practices that reduce greenhouse gas (GHG) emissions will have significant co-benefits with adaptation, and provide additional livelihood strategies (FAO 2009b; Bryan et al. 2008). Finally, with the establishment of functioning carbon markets, mitigation strategies in the agriculture sector have the potential to generate financial flows to the region, potentially creating income in rural areas and thereby increasing adaptive capacity.

Global and Regional Emission Trends and Sources

Agricultural activities release significant amounts of GHGs into the atmosphere. Agriculture's share of total GHG emissions was 13% in 2000,

Figure 5.1: Total Technical Mitigation Potential for Each Region by 2030
(all practices, all greenhouse gases)



Note: Mt CO_2-eq/yr indicates megatons of carbon dioxide equivalent per year. The boxes show one standard deviation above and below the mean estimate for mitigation potential per area, and the bars show the 95% confidence interval about the mean. The projection of technical mitigation potential is based on emissions scenarios developed by the International Panel on Climate Change (Nakicenovic and Swart 2000). The pattern displayed above is the same for all emissions scenarios considered.

Source: Smith (2007a), drawn from data in Smith et al. (2007b).

Box 5.1: Technical Versus Economic Mitigation Potential

"Technical mitigation potential" is the theoretical amount of emissions that can be reduced, and the amounts of carbon that can be sequestered, given the full application of current technologies without considering the costs of implementation. It describes the order of magnitude that current methods of mitigation may allow, instead of providing realistic estimates of the amount of carbon that will be reduced under current policy and economic conditions.

"Economic mitigation potential," on the other hand, considers the costs of each mitigation technology, as well as the cost of carbon, over a price range. The economic mitigation potential of technologies can be analyzed by determining the marginal abatement cost or the cost of reducing emissions by one unit. These costs can be plotted over varying price levels in order to show the relationship between carbon price and the percentage reduction in emissions.

Estimates of both technical and economic mitigation potential need to be treated with some caution. In general, they do not consider trade-offs with other goals, such as income generation or food security, nor do they consider the heterogeneity in management capacity or cultural appropriateness.

Source: Adapted from Smith et al. (2007a).

and if land use change is considered, agriculture contributes 30% upwards of global emissions (Figure 5.2). Emissions from this sector are primarily methane (CH_4) and nitrous oxide (N_2O), making the agriculture sector the largest producer of non-CO_2 emissions (60% of the world total in 2000) (WRI 2008). Although agricultural lands also generate large CO_2 fluxes both to and from the atmosphere through photosynthesis and respiration, this flux is nearly balanced on existing agricultural lands. Significant carbon release, however, results from the conversion of forested land, which is included in the category of land use, land use change, and forestry (LULUCF).[14] Finally, other agricultural activities related to GHG emissions are included in other sectors, such as the upstream manufacture of equipment, fertilizers, and pesticides; the on-farm use of fuels; and the transport of agricultural products.

Regional variations in emissions from agricultural sources (non-CO_2) indicate that countries outside the Organisation for Economic Co-operation and Development (OECD) emit nearly 75% of global emissions (WRI 2008). As a result, the theoretical potential for mitigation in the agriculture sector is greater in developing countries than in industrial countries. Asian countries account for 37% of the

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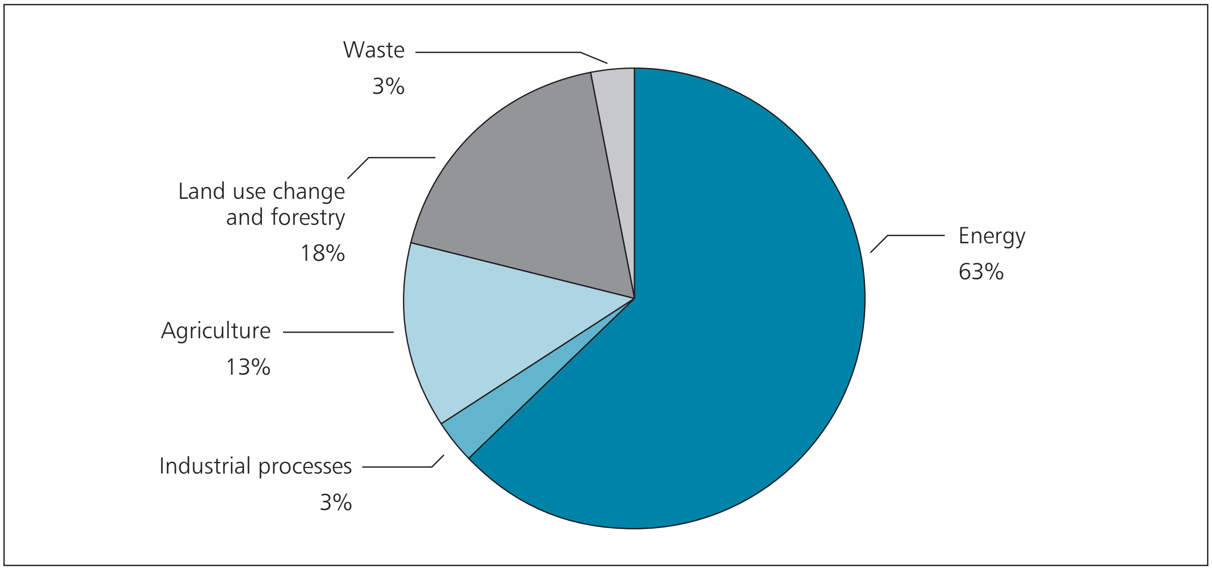
[14] Total LULUCF emissions, which include biomass clearing and burning for agriculture and urban expansion, as well as timber and fuelwood harvesting, were nearly 18% of total GHG emissions in 2000, or 7,618 Mt CO_2 equivalents. Concerning food production specifically, estimates of the amount of total emissions in this sector that are due to land conversion for agricultural extensification are difficult to make. One estimate, however, attributes 9% of total global emissions—that is, half global LULUCF emissions—to expansion into forests for feed-crop and livestock production (Steinfeld et al. 2006).

Figure 5.2: Share of Global Greenhouse Gas Emissions, by Sector, 2000



Source: Drawn from data of WRI 2008.

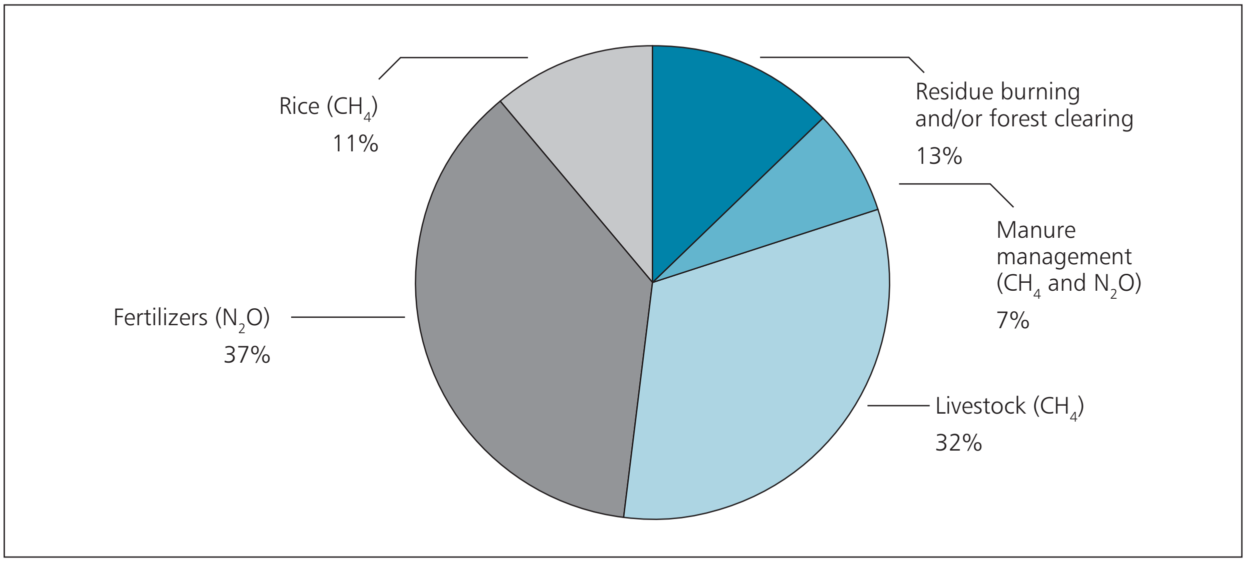
world's total emissions from agricultural production, and the People's Republic of China (PRC) alone accounts for more than 18% of the total (WRI 2008).

Emissions from agriculture come from four principal sectors: agricultural soils, livestock and manure management, rice cultivation, and the burning of agricultural residues and savanna for land clearing. Figure 5.3 presents the share and pollutants from each of these sources. The largest shares of emissions originate from agricultural soils (N_2O), and enteric fermentation (that is, the natural digestive processes of ruminants such as cattle and sheep) associated with livestock and rice production (CH_4). Emissions from agriculture are expected to rise because of increased food demand for growing and more prosperous populations able to afford more varied diets with higher shares of meat and dairy products (see, for example, Delgado et al. 1999). This shift will also lead to increased pressure on forests from agricultural expansion. Both emissions from fertilizers and livestock are expected to continue to increase significantly by 2020 as a result (Figure 5.4).

South and East Asia emit the largest shares of emissions from Asia and the Pacific. Together, they contribute 43% of global N_2O emissions from soils or 1,136 megatons (Mt) CO_2-eq/yr (Table 5.1). East Asia alone emits 68% of global CH_4 emissions from rice production, and South Asia accounts for another 20% of the global total of 561 Mt CO_2-eq/yr.

The release of CH_4 from enteric fermentation from these two subregions emits an additional 569 Mt CO_2-eq/yr, or 47% of the global total in this category. Fertilizer and manure applied on soils

Figure 5.3: Sources of Emissions from the Agriculture Sector, 2000



Note: CH_4 indicates methane, and N_2O is nitrous oxide.

Source: Drawn from data presented in USEPA (2006).

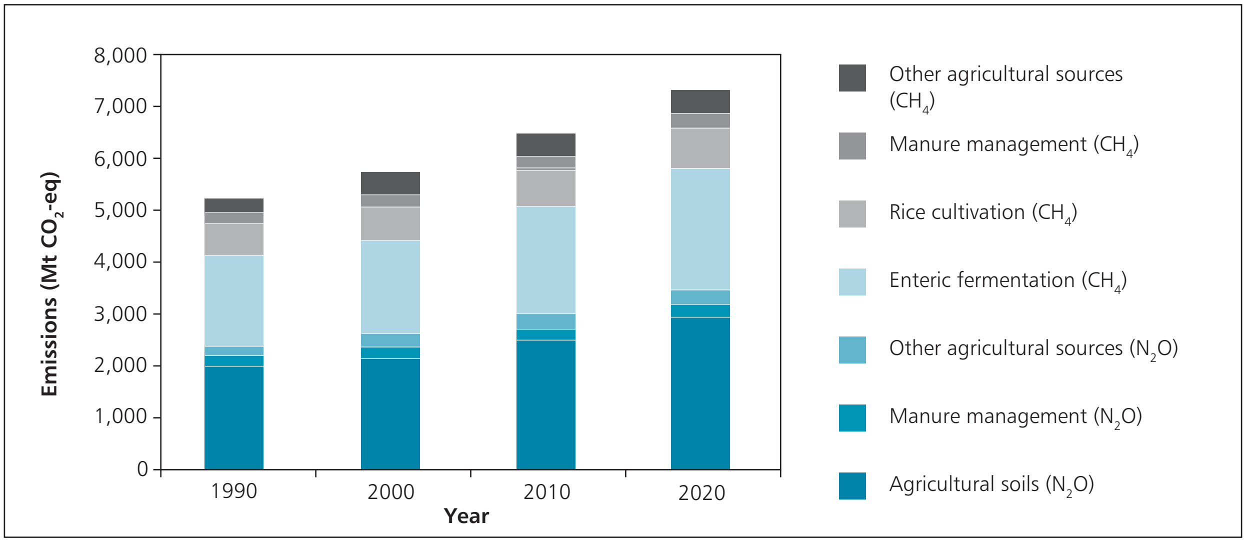
were the main sources of N_2O, whereas the large livestock population contributed to the high enteric fermentation that releases CH_4 gases (USEPA 2006). Emission trends in these two areas will continue up to 2020, when N_2O from soils is expected to nearly double to approximately 2,000 Mt CO_2-eq/yr, CH_4 emissions are expected to increase to 1,250 Mt CO_2-eq/yr, and CH_4 emissions from livestock will rise by a third to approximately 800 Mt CO_2- eq/ yr (Figure 5.5). Overall in 2020, the developing countries of South and East Asia are expected to emit 2,800 Mt CO_2-eq/yr across all agricultural sources.

Agricultural Soils

N_2O is the largest source of GHG emissions from agriculture, accounting for 38% of agricultural GHGs globally. N_2O is produced naturally in soils through the processes of nitrification and denitrification. Activities may add nitrogen to soils either directly or indirectly. Direct additions occur through the use of nitrogen fertilizer, application of managed livestock manure and sewage sludge, production of nitrogen-fixing crops and forages, retention of crop residues, and cultivation of soils with high organic-matter content. Indirect emissions occur through volatilization and subsequent atmospheric deposition of applied nitrogen, as well as through surface runoff and leaching of applied nitrogen into groundwater and surface water (USEPA 2006).

Direct application of nitrogen-based fertilizers, both synthetic and organic, is a major source of growth in N_2O emissions. Under a business-as-usual scenario, these emissions are expected to increase

Figure 5.4: Emissions from Historical and Projected Data in the Agriculture Sector, by Source, 1990–2020



Note: CH$_4$ indicates methane; N$_2$O, nitrous oxide; and Mt CO$_2$-eq, megatons of carbon dioxide equivalent. Other agricultural sources include open burning of biomass during agricultural activities and from land use change. Projections beyond year 2000 have been held constant for other agricultural sources due to lack of information.

Source: Drawn from data projected in USEPA (2006).

by 47% from 1990 to 2020. In 1990, the OECD and the PRC accounted for approximately 50% of all N$_2$O emissions from agricultural soils. Projections to 2020, however, show that emissions will remain relatively static in the OECD, with major increases coming from the PRC (50% increase). On the other hand, current agricultural production in Central Asia is only about 60%–80% of its 1990 level but is expected to increase by 15%–20% above 2001 levels by 2010 owing to the increasing wealth of the countries in the region (Smith et al. 2007a). Central Asia focuses on agricultural expansion that includes an increase of 10%–14% in arable land for the whole of the Russian Federation, as well as use of intensive management technologies in farm areas. Such trends suggest that an extensive application of production technologies will be required to achieve the 2- to 2.5-fold increase in grain and fodder yields with a consequent reduction of arable land and intensified nitrogen fertilizer usage (Smith et al. 2007a).

Livestock and Manure Management

Enteric fermentation is the second largest source of total emissions from agriculture, at 34% of the total. Other domesticated animals, such as swine, poultry, and horses, also emit CH$_4$ as

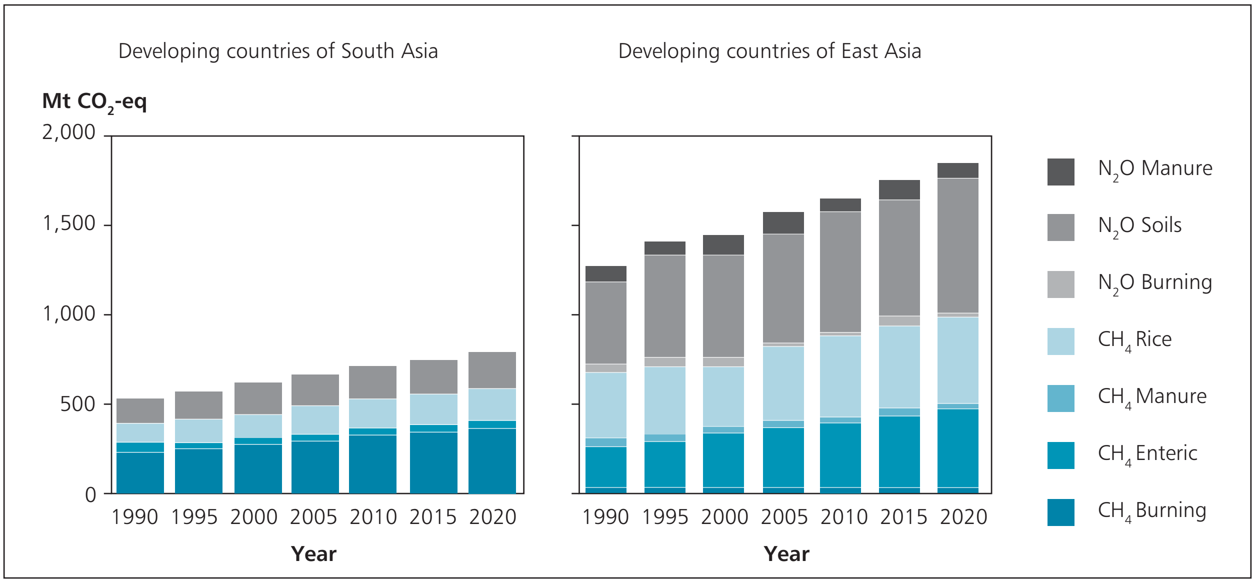
Table 5.1: Greenhouse Gas Emissions by Main Sources in the Agriculture Sector, by Subregion, 2005

Subregion and emissions	N_2O from soils	CH_4 from enteric fermentation	CH_4 from rice cultivation	CH_4 and N_2O from manure	CH_4 and N_2O from burning	Total
South Asia						
Mt CO_2-eq/yr	536	275	129	40	24	1,005
Share of regional total (%)	53	27	13	4	4	100
Share of world total (%)	20	15	20	9	3	17
East Asia						
Mt CO_2-eq/yr	600	294	432	127	53	1,505
Share of regional total (%)	40	20	29	8	4	100
Share of world total (%)	23	16	68	29	14	25
Subtotal for global—developing regions						
Mt CO_2-eq/yr	1,946	1,300	617	211	363	4,438
Share of regional total (%)	44	29	14	5	8	100
Share of world total (%)	74	70	97	48	92	74
Subtotal for global—developed regions						
Mt CO_2-eq/yr	700	554	20	225	32	1,531
Share of regional total (%)	46	36	1	15	2	100
Share of world total (%)	26	30	3	52	8	26
Total						
Mt CO_2-eq/yr	2,646	1854	637	436	395	5,969
Share of regional total (%)	44	31	11	7	7	100
Share of world total (%)	100	100	100	100	100	100

Note: CH_4 indicates methane; N_2O, nitrous oxide; and Mt CO_2-eq/yr, megatons of carbon dioxide equivalent per year.

Source: USEPA (2006).

Figure 5.5: Methane and Nitrous Oxide Emissions from Historical and Projected Data in the Agriculture Sector, 1990–2020



Note: CH_4 indicates methane; N_2O, nitrous oxide; and Mt CO_2-eq, megatons of carbon dioxide equivalent.

Source: Drawn from data presented in USEPA (2006) from Smith et al. (2007a).

a by-product of enteric fermentation. Manure management includes the handling, storage, and treatment of manure and accounts for 7% of agricultural emissions. CH_4 is produced from the anaerobic breakdown of manure, whereas N_2O results from handling the manure aerobically (that is, nitrification) and then anaerobically (that is, denitrification), and is often enhanced when available nitrogen exceeds plant requirements (Oenema et al. 2005; Smith and Conen 2004).

Demand for beef and dairy products is expected to rise globally, with sharp increases in consumption and production in the developing world. By 2020, more than 60% of meat and milk consumption will take place in the developing world, and the total global production of beef, pork, other meat, poultry, and milk will at least double from 1993 levels (Delgado et al. 1999). As a result, CH_4 emissions from enteric fermentation are projected to increase by 32% by 2020, with the PRC, India, and Pakistan as the top sources (Figure 5.5). In addition, CH_4 and N_2O emissions from manure management are expected to increase by an estimated 21%, with large shares from the PRC.

Rice Cultivation

Flooded rice fields are the third largest source of agricultural emissions in South and East Asia

(Table 5.1), and the fourth largest source of global agricultural emissions (11%). Rice production systems that employ extended periods of flooding emit CH_4 through the anaerobic decomposition of organic matter in an oxygen-deficit environment (Mosier et al. 1998). The PRC and Southeast Asian countries produce the lion's share of CH_4 emissions from rice, accounting for more than 90% of the total in 1990. Because of population growth in these countries, emissions are expected to increase by 36% in Southeast Asia and 10% in the PRC by 2020 (USEPA 2006).

Other Agricultural Sources

Biomass[15] burning constitutes the largest share of emissions in this category, while small amounts of methane emissions from agricultural soils represents the remainder (USEPA 2006). Sources of N_2O are savanna burning, agriculture residue burning, and open burning from land use clearing. Globally, biomass burning was the source of 13% of agricultural emissions, with Latin America and Africa responsible for over 75% of the total (USEPA 2006). South East Asia and the PRC emitted 36.6 and 5.3 $MtCO_2$-eq in 2000, respectively, which is small relative to other global regions (USEPA 2006). Due to a lack of information for basing estimates, the USEPA (2006) does not make projections on increases in emissions from burning. Others estimate that in a typical year in the Asia and Pacific region, forest burning comprises 45% of the total biomass burned; crop residues burning in the field comprises 34%, and 20% comes from the burning of grassland and savanna (Streets et al. 2003). Of these sources, the PRC contributes 25% of the total; India, 18%; Indonesia, 13%; and Myanmar, 8% (Streets et al. 2003).

Mitigation Strategies in the Agriculture Sector

As outlined above, the biological processes associated with agriculture are natural sources of GHGs; yet, farmers have the potential to reduce the quantity of emissions through the efficient management of carbon and nitrogen flows. Mitigation as a strategy in response to global climate change is defined as measures that reduce the amount of emissions (that is, abatement) or enhance the absorption of GHGs (that is, sequestration). The total global potential for mitigation depends on many factors, including emission levels, the availability of technologies, energy prices, enforcement, and incentives. In many situations, agricultural efficiency can be improved at a low cost; however, when low-cost incentives are unavailable, policy development is important. The types of incentives that policy development can provide are discussed in this chapter's section on Integrating Mitigation and Adaptation in Sustainable Development Pathways.

Mitigation strategies in agriculture can be categorized in three ways: carbon sequestration into soils, on-farm emission reductions, and emission displacements from the transport sector through biofuel production (Smith et al. 2007a). These three options for mitigation in agriculture are discussed further in the following pages.

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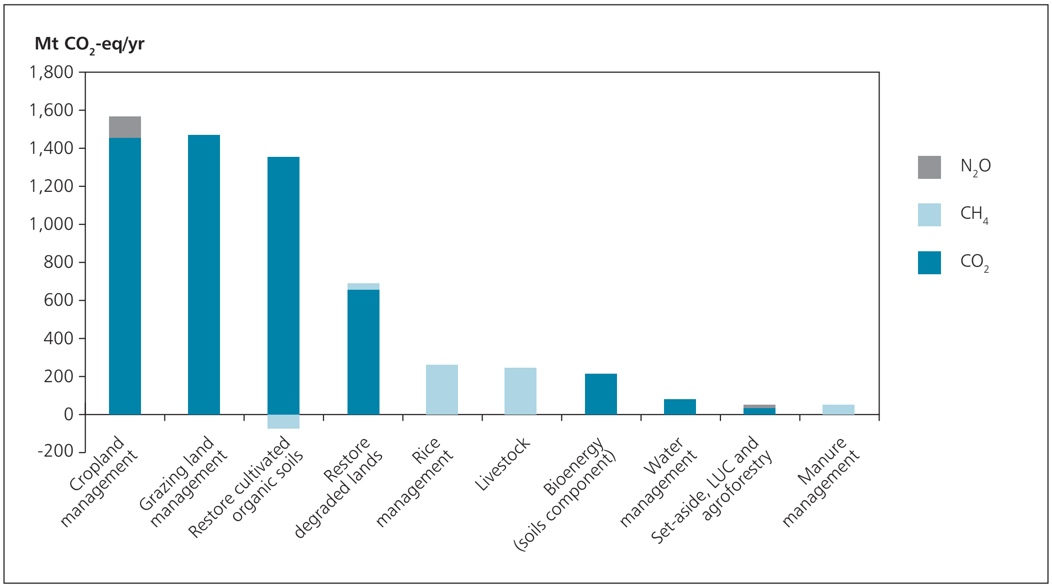
[15] The word "biomass" is used here in its general context, i.e., the total mass of all living material in a specific area, rather than in the environmental-energy context, i.e., biological materials used as fuel or source of energy.

Carbon Sequestration

Sequestration activities enhance and preserve carbon sinks and include any practices that store carbon through cropland management "best practices," such as no-till agriculture, or that slow the amount of stored carbon released into the atmosphere through burning, tillage, and soil erosion. Sequestered carbon is stored in soils, resulting in increases in soil organic carbon (SOC). However, SOC will approach a new equilibrium over a 30–50 year period into the future, and is therefore limited by saturation. In addition, there is potential for the re-release of SOC into the atmosphere through fire or tillage, which raises concerns about the "permanence" of SOC storage. On the other hand, emissions abatement through improved farm management practices could be sustained indefinitely. Despite these limitations, soil carbon sequestration is estimated to account for 89% of the technical mitigation potential in agriculture, compared with 11% for emissions abatement (Smith et al. 2007a). Figure 5.6 shows the dominance of soil carbon sequestration (CO_2 sequestration) in technical mitigation potential.

Figure 5.6: Projected Global Technical Mitigation Potential for Each Agricultural Management Practice in 2030, by Greenhouse Gas



Note: LUC means land use change; Mt CO_2-eq/yr indicates megatons of carbon dioxide equivalent per year; N_2O indicates nitrous oxide; CH_4, methane; and CO_2, carbon dioxide. Cropland management includes improved agronomic practices that lead to increased soil carbon storage, nutrient management, tillage and residue management, improved water management, agroforestry, and allowing land cover change ("set-aside").

Source: Smith et al. (2007a).

Many best management practices in agriculture raise SOC. Such practices include reducing the amount of bare fallow, restoring degraded soils, improving pastures and grazing land, adopting irrigation, rotating crops and forage, and adopting no-till practices (Smith et al. 2007a). The total technical potential of global cropland soils to sequester carbon through a combination of these techniques has been estimated at 0.75 to 1 Gt per year (Lal and Bruce 1999). Specifically, South Asia could increase SOC by 25 to 50 Mt through the restoration of cultivated land and adoption of integrated nutrient management [16] (Lal 2004).

One technique that the literature highlights as having a high mitigation potential is no-till agriculture (Box 4.1). Estimates show that tillage reductions on global cropland could contribute significantly to emission reductions—up to 25 Gt over the next 50 years (Pacala and Socolow 2004). Some researchers have noted that tillage reductions may not be feasible on all soil types (Chan, Heenan, and So 2003). Baker et al. (2007), however, argue that improper sampling techniques together with modern gas-based measurements cast doubt on previous findings of positive carbon offsets through tillage reductions.

Another way to increase SOC is grazing land management, which increases the cover of high-productivity grasses and overall grazing intensity. Degraded or overgrazed land can be restored to produce more biomass by selectively planting grasses, adding phosphate fertilizers, and alternating grazing with rest periods for the land (Robert 2001). Increasing biomass productivity on grazing lands enhances soil cover, increases moisture availability, and increases the overall amounts of stable organic matter in the soil. In Asia, large technical potential exists in India, which has one of the world's largest grazing land areas.

The application of biochar is now being considered an option for raising SOC. Biochar is a by-product of the pyrolysis of biomass, or agricultural residues, and can be applied to soils. Agricultural residues that can be burned in pyrolysis have the co-benefit of producing fuel energy, with biochar as the end product. Biochar is claimed to be better at storing SOC than leaving biomass on fields, as it can go beyond the saturation point in its activated form (Lehmann, Gaunt, and Rondon 2006). In addition, biochar can be used as a soil amendment to help retain nutrients and fertilizers, reducing emissions of GHGs such as N_2O (Lehmann et al. 2003; Steiner et al. 2008). Currently, there are no large-scale biochar production schemes in Asia and the Pacific; however, biochar is growing in importance in upcoming mitigation strategies, in both the energy and agriculture sectors, and will need to be given consideration in future policy development.

Bioenergy

The production of liquid fuels from dedicated energy crops, such as grains and oilseeds, is being evaluated for use as transport fuel in response to concerns over the environmental sustainability of continued fossil fuel dependence. The potential of biofuels to reduce carbon emissions, however, is

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[16] Lal (2004) considers integrated nutrient management practices, such as "use of manure, compost, green manuring and other biosolids including city sludge, mulch farming, conservation tillage, and diverse crop rotations based on legumes and cover crops in the rotation cycle." In addition, the use of chemical fertilizer also increased the formation of soil organic carbon (SOC) in combination with integrated nutrient-management practices (Lal 2004).

highly dependent on the nature of the production process through which they are cultivated and manufactured. There tends to be a high degree of variance in the literature over the net carbon balance of various biofuels because of differences in the technological assumptions used when evaluating the processes embedded in any life-cycle assessment. Early life-cycle assessments of biofuels found a net carbon benefit, which has contributed to consumer acceptance (for example, Wang, Saricks, and Santini 1999). Yet a number of studies are challenging the net carbon benefit in comparison with traditional fossil fuels (Pimentel and Patzek 2005), especially when biofuel production requires land conversion from cover with a high carbon sequestration value, such as forests (Searchinger et al. 2008).

The extent to which biofuels can offset carbon emission hinges on the type of land cover that their cultivation would replace. The conversion of land from higher carbon value, such as forestland to cropland, would release carbon dioxide into the atmosphere. Even when considering the additional savings from fossil fuel substitutions, only high-yielding biofuel feedstock crops grown on existing cropland or degraded lands offer carbon benefits (Gibbs et al. 2008). Yet, the cultivation of fuel crops on existing cropland may push food production into the agricultural frontier, especially in production systems with low productivity growth, ultimately resulting in land use change in the long-run. In addition, the cultivation of crops on marginal lands will likely require input-intensive management, such as fertilizer applications and irrigation, in order to remain competitive. Ultimately, the extent that biofuels are adopted and sustainably produced will depend upon a complex mix of market cues, such as production costs, relative price of energy, and government incentives that will affect each farmer's final choice of land use. The trade-offs that farmers will face upon considering the adoption of a mitigation strategy, such as biofuel production, will be discussed further in the next section.

The second generation of biofuels is expected to lessen the pressure on land conversion since the new crops can be grown on marginal lands. The most promising varieties of second-generation biofuel crops include short rotation woody crops— such as eucalyptus, poplars, and willows—and perennial grasses—such as miscanthus and switchgrass. In general, these lingocellulosic forms of biomass are considered to provide environmental and energy gains over first-generation crop-based fuels (FAO 2008f). Some varieties, for instance, can be grown on degraded soils not suitable for agricultural production (Tilman, Hill, and Lehman 2006). In addition, it is possible to harvest more biomass per hectare (ha) over crop-based biofuels because the entire plant can be converted (Rajagopal and Zilberman 2007).

By considering the impact that continued crop cover [17] would have for agricultural soil emissions, bioenergy production is estimated to have a technical potential of approximately 200 Mt CO_2-eq/yr by 2030 (Smith et al. 2007a) (Figure 5.6). But the potential for GHG savings is much higher when the offsetting potential from displacement of fossil fuels is considered. It is estimated that 5%–30% of cumulative carbon emissions would be abated if

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[17] The technical mitigation potential of biofuels is derived from the cessation of soil disturbance only, as through no-till agriculture (see Smith et al. 2007a, Table 8.4).

bioenergy supplied 10%–25% of world global energy in 2030 (Ferrentino 2007). But rapid expansion in bioenergy of this magnitude would have significant trade-offs with food security, as has already been seen in the past few years (Box 5.2), and could have significant negative impacts on land use change and biodiversity, as mentioned above. Each of these trade-offs merits careful assessment in Asia and the Pacific, further discussion of which is provided below.

Food Security Trade-offs

Global growth in crop-based biofuel production has affected the supply of grains available on international markets. During 2002–2007, the production of maize-based ethanol in the United States was responsible for 30% of the increase in global wheat and feed-grain use, and, by 2007, nearly a quarter of all maize produced in the United States (US) was diverted to ethanol markets (Trostle 2008). These supply shifts have affected world grain prices. Since 2002, there has been a sustained increase in food commodity prices, with a 60% increase since 2006 (Trostle 2008). While many factors are converging to drive this trend, including historically low grain stockpiles and historically high oil prices, demand for biofuel feedstocks has had a substantial impact in recent price spikes. According to one study, the additional demand for biofuels is responsible for 30% of the price increase on weighed grain from 2000 to 2007 (Rosegrant 2008). Looking at the longer term impacts of expanded biofuel production, OECD (2006) calculates a 20% increase in the price of vegetable oil by 2014 as a result of the combined effects of the US, the European Union, and Canada’s biofuel blending mandates. In addition, the International Food Policy Research Institute’s International Model for Policy Analysis of Agricultural Commodities and Trade (IFPRI IMPACT) projections show that the prices of all feedstock commodities—cassava, maize, oil seeds, sugar, and wheat—will increase under biofuel expansion through 2050. For example, the price increases of oil seeds in 2050 will be 20%–40% higher compared with the baseline, depending on the rate of biofuel expansion.

These global price changes will cascade through regional markets in Asia and the Pacific. Due to price increases in key commodities through 2050, calorie availability is projected to decline by between 2%–4% in East Asia and the Pacific, and between 2%–5% in South Asia, depending on the rate of biofuel expansion (IFPRI IMPACT projections). As a result, by 2050, the prevalence of malnutrition will have expanded by 750,000 to 1.5 million preschool-aged children in East Asia and the Pacific and by 1–2 million preschool-aged children in South Asia compared with baseline levels (IFPRI IMPACT projections). While these projections assume baseline productivity growth, they are important for illustrating the trade-offs with food security that crop-based biofuels will likely present—even in the absence of climate change.

Second-generation biofuels grown on marginal lands may also have indirect effects on land prices that can translate into higher food prices. Under one scenario where cellulosic biomass conversion to electricity is considered, crop, food, and livestock price indexes increase by 5%–10% over the baseline for aggregate regions (Gurgel, Reilly, and Paltsev 2007). While these price increases are low in comparison with those under crop-based biofuels, there may be significant variation in price effects because these are average increases and there are regional variations. The price effects of second-generation biofuels remain an important area for further research.

Potential in Asia and the Pacific

While the production of biofuels is overwhelmingly dominated by Brazil, Europe, and the US, Asia and the Pacific is beginning to expand its production capacity. Indonesia, Malaysia, and the Philippines have national blending targets for biofuels, while India and Thailand are making significant investments in conversion technologies and in expanding the production of key feedstocks. From a global perspective, however, the overall impact of these mandates on commodity markets will be small in comparison to those set by major consuming countries such as the US and European Union, where demand for transport fuel is far greater. From a regional perspective, however, crop-based biofuel production will present a number of trade-offs that merit close consideration, such as those with biodiversity, food prices, and land use.

Oil palm in Southeast Asia is a high-yielding feedstock crop in biodiesel production. Its production on degraded lands in this subregion is estimated to provide net carbon savings when considering their fossil fuel replacement (Gibbs et al. 2008). Yet, oil palm is widely cultivated and is a current cause of deforestation in the subregion. Indonesia has doubled the area under cultivation from 2.2 million hectares (ha) in 2001, to over 4.6 million ha in 2007 (FAO 2009a). Together with Malaysia, these countries cultivate 85% of total global oil palm in terms of area. Under voluntary carbon markets, oil palm cultivation on deforested land is up to 10 times more profitable to landowners than preserving it for carbon credits (Butler, Koh, and Ghazoul 2009). As a result, policy responses that include carbon markets and payments for environment services, such as avoided deforestation and cultivation on marginal lands to restore SOC and provide bioenergy, will be critical to the subregion.

On-Farm Mitigation

Improved management practices that reduce on-farm emissions include livestock and manure management, fertilizer management, and improved rice cultivation.

Enteric Fermentation

Methods to reduce CH_4 emissions from enteric fermentation include improving digestive efficiency with better feeding practices and dietary additives. The efficacy of these methods depends on the quality of the feed, the livestock breed and age, and whether the livestock is grazing or stall-fed. Developing countries are assumed to provide lower quality feed to livestock, which raises the emissions rate per animal over developed-country herds. The technical potential to mitigate livestock emissions in 2030 is 300 Mt CO_2-eq/yr (Figure 5.6). Furthermore, Smith et al. (2007a) quantify the technical potential for reducing CH_4 production through improved feed practices, specific agents and dietary additives, and longer term structural and management changes and animal breeding. Improved feeding practices for dairy cows and buffalo in East Asia are calculated to have the greatest technical mitigation potential of all the practices and regions considered (Smith et al. 2007a).

Manure Management

In manure management, cooling and using solid covers for storage tanks and lagoons, separating solids from slurry, and capturing the CH_4 emitted are effective techniques. In developing countries, however, applying this type of manure management may be difficult because animal excretion happens in the field. Composting manure and altering feeding practices may help reduce emissions to a certain extent. The technical potential of improved manure management by 2030 is 75 Mt CO_2-eq/yr (Figure 5.6).

Fertilizer Management

Improving the efficiency of fertilizer application or switching to organic production can decrease the nutrient load and N_2O emissions. Overall benefits will need to be weighed, however, against

Box 5.2: Opportunities for Pro-Poor Biofuel Production

Opportunities for increasing the welfare benefits to the poor may arise through the use of small-scale biofuel production models that convert feedstocks locally (Ewing and Msangi 2009). Examples of small-scale production models found in the literature demonstrate a wide range of welfare gains, including new sources of energy and electricity, and the development of enterprises related to coproducts, such as soap and organic fertilizer. Energy crops can be converted into fuels to satisfy a number of rural applications, including electrification, small machinery power, irrigation pumping, and food processing. In addition, bioenergy development for clean-burning cooking fuel, such as ethanol-based gelfuels, can provide significant time savings for women and children by reducing the need to search for and collect fuelwood. Furthermore, the use of clean-burning ethanol has positive health impacts, reducing the level of indoor air pollution and related illness.

Small-scale production models can also minimize food security impacts by focusing on non-edible energy crops that can be grown on marginal lands. Biofuel production on marginal lands may be particularly well suited to poor farmers who do not have access to high-quality lands (Binns 2007). One crop well suited to areas with low rainfall and low soil quality is *jatropha*. This crop is currently being piloted in a number of small-scale biodiesel development projects in Sub-Saharan Africa, India, and the Philippines. Sweet sorghum is also ideal for drier areas and has properties similar to sugarcane in ethanol production. In addition, declining demand for sweet sorghum as a food source, as well as its coproduction value as a livestock feedcake, lessen its threat to food security (ICRISAT 2007). A promising variety similar to jatropha is *pongamia (pongamia pinnata)*. Although there are fewer case studies on pongamia production, this tree has been found to produce more than twice as much oil per hectare in comparison with jatropha (Rajagopal and Zilberman 2007).

Despite these benefits, there are barriers to small-scale bioenergy development in rural areas. A considerable level of effort would be needed in the conscious design of production systems to enable smallholders to directly benefit from the opportunities that biofuels may offer the agriculture sector. At the local level, lack of technical know-how related to feedstock and conversion, low capital availability for start-up costs, lack of private sector capacity and support, poor market development, and insecure land tenure are often cited as limitations to small-scale agricultural development. In addition, a common critique of jatropha-focused biofuel production is its rather low yield if it is grown on marginal lands without irrigation, which makes it less cost-competitive than fossil-based fuels. Most industrial processes require economies of scale and high levels of extraction efficiency to remain economically competitive, which raises the question of whether small-scale jatropha can survive in the long term.

Despite these challenges, a number of small-scale biofuel production projects across Africa and Asia are providing examples and generating knowledge of the possibilities and constraints surrounding sector development. In India, a large-scale public–private partnership has been launched to promote the profitable participation of small-scale famers in the cultivation of sweet sorghum feedstocks for ethanol production. A private business partner—Rusni Distilleries—is providing sweet sorghum seed to farmers and feedstock supply contracts to local processing facilities in order to create a village-based supply-chain model (Binns 2007). The operation of the refinery for sweet sorghum is creating 40,000 person-days of labor (ICRISAT 2007). Also in rural India, a pongamia oil project led by women and used to run small generators for household electricity is being replicated by the state government in nearly 100 villages (ICRISAT 2007).

Source: Adapted from Ewing and Msangi (2009).

potential impacts on yield. Although some studies (such as Delate et al. 2003; Pimentel et al. 2005) have shown that organic agriculture offers yields competitive with conventional fertilizer applications, fertilizer reductions of 90% in rainfed maize fields were shown to reduce yields by 10.5% over the baseline in the PRC (USEPA 2006). In addition, the lack of access to soil nutrients to improve the quality of degraded soils in many parts of the developing world is a hindrance to achieving food security (Gruhn, Goletti, and Yudelman 2000). Overall, cropland management could reduce emissions in 2030 up to 150 Mt CO_2-eq/yr (Figure 5.6).

Rice Cultivation

Improving water management in high-emitting, irrigated rice systems through mid-season drainage or alternate wetting and drying has shown substantial reductions in CH_4 emissions in Asia. These effects may be partially offset, however, by an increase in the amount of N_2O emitted (Wassman, Butterbach-Bahl, and Doberman 2006). The technical potential of improved rice management is 300 Mt CO_2-eq/yr (Figure 5.6).

Summary of Technical Mitigation Potential

Considering all mitigation strategies in the agriculture sector combined, the global technical mitigation potential is 5,500–6,000 Mt CO_2-eq/yr by 2030 (Smith et al. 2007a) (Figure 5.6). Of this estimate, carbon sequestration accounts for nearly 90% of the potential, and CH_4 mitigation and soil N_2O emission reductions account for 9% and 2%, respectively. Across the subregions of Asia, approximately 1,100–3,000 Mt CO_2-eq/yr can be mitigated by 2030 for all GHGs (Smith et al. 2007a, estimated from Figure 5.1). At the upper end, Asia could contribute 50% of the total technical mitigation potential by 2030.

Economic Potential of Mitigation Options

Calculations of economic potential come from two main sources: Smith et al. (2007b) and USEPA (2006). The results from USEPA (2006) are preferred for non-CO_2 emissions abatement because they have a finer level of regional disaggregation, which enables explicit examination of the economic potential of developing countries. Smith et al. (2007a) conducted a comparison of Smith et al. (2007b) and USEPA (2006) and find consistent results across emission sources. Smith et al. (2007a, b), however, provide a more comprehensive assessment of the potential for soil carbon sequestration.

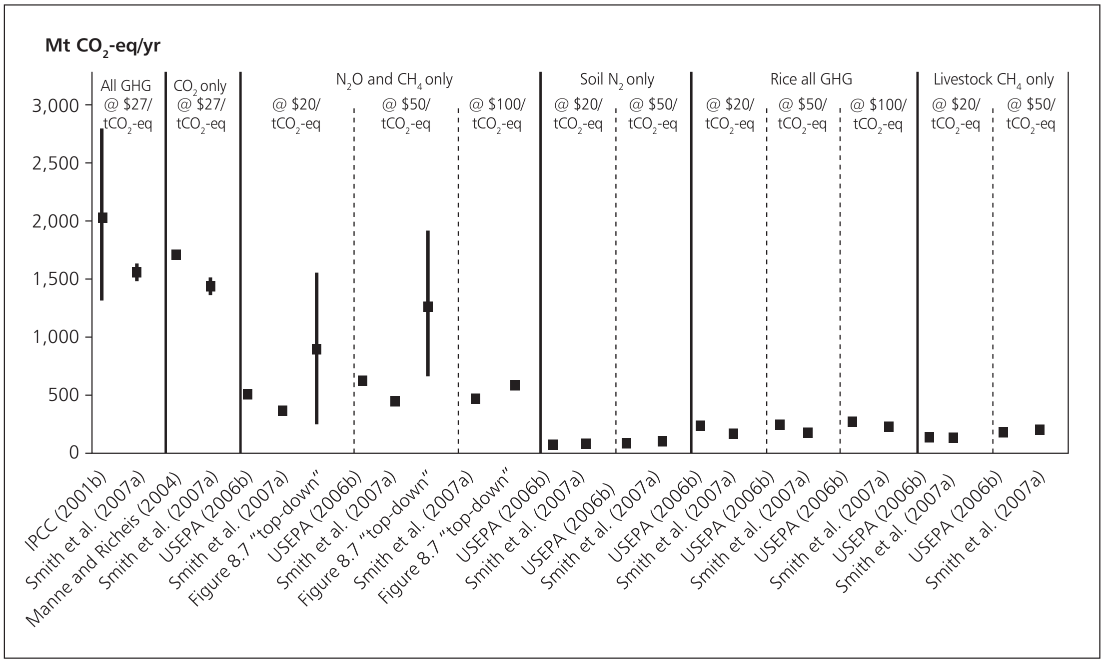
The USEPA (2006) estimates three categories of emissions mitigation and sequestration: rice cultivation; livestock and manure management; and cropland management (including N_2O from fertilizer reductions, soil carbon sequestration through no tillage—but not through other management and policy changes—and split fertilization, each under both rainfed and irrigated conditions for rice, soybeans, and wheat). Marginal abatement curves are constructed for 2010, 2020, and 2030 to determine the relationship between carbon price and quantitative emission reductions.

Smith et al. (2007a) estimated global economic potential for agricultural mitigation using top-down and bottom-up modeling. Bottom-up mitigation responses described typical constraints to input management (such as fertilizer quantity or type of livestock feed) as well as cost estimates (partial equilibrium, where input and output market prices are fixed such as acreage or production). On the other hand, the top-down mitigation responses add more generic input-management responses as well as changes in output (such as shifts from cropland to forest) and market prices (such as decreases in land prices with rising production costs due to a carbon tax). Figure 5.7 presents the global estimates of economic potential for agricultural mitigation from various studies at different assumed carbon prices in 2030.

Bioenergy

Neither Smith et al. (2007a) nor USEPA (2006) calculate the marginal abatement costs of bioenergy cultivation related to agricultural soils. Estimates do, however, exist for their potential displacement of fossil fuels. Specifically for the transport sector, liquid biofuels are predicted to reach 3% of demand under the baseline scenario, increasing up to 13%–25% of demand under alternative scenarios in 2030 (IEA 2006). This outcome could reduce emissions by 1.8–2.3 Gt CO_2, corresponding to between 5.6% and 6.4% of total emissions reductions across all sectors at carbon prices greater than $25 per ton of CO_2 (\$25/tCO_2) (Ferrentino 2007).

Figure 5.7: Global Estimates of Economic Mitigation Potential in Agriculture at Different Carbon Prices in 2030



Note: USEPA (2006) figures are for 2020 rather than 2030. Values for top-down models are taken from ranges given in Figure 8.7 of Smith et al. (2007a). Mt CO_2-eq/yr indicates megatons of carbon dioxide equivalent per year. GHGs indicates greenhouse gases, N_2O is nitrous oxide, and CH_4 is methane.

Source: Smith et al. (2007a).

On-Farm Mitigation

Cropland Management (N_2O and CO_2)

Compared with the baseline, approximately 15% of global cropland emissions can be abated at no cost, and approximately 22% of emissions can be mitigated for less than \$30/tCO_2-eq. Beyond this point, abatement costs rise exponentially. These results are similar for all years considered. Regional calculations show that the largest zero- and low-cost potential (up to \$30/tCO_2-eq) is in the Russian Federation (31.7% reductions over the baseline in 2020), and that there is modest potential in South and Southeast Asia (11% over the baseline). The reasons that fertilizer reductions do not have a strong mitigation potential for developing countries may include existing low levels of fertilizer usage or the effect of sub-optimal nutrient application on yields in some developing countries, particularly on the African continent. On the other hand, across the PRC and India, converting from conventional tillage to no till resulted in yield increases for each crop considered. This practice thus has large potential as a negative cost option or "no-regret" scenario. Yet, farmers in these subregions are not adopting no-tillage practices, showing that the analysis fails to capture cost barriers, which may include profit variability or complex management requirements (USEPA 2006).

Smith et al. (2007a) consider a broader range of cropland management practices for soil carbon sequestration, such as reducing bare fallow and residue management. Under this broader spectrum, the economic potential for soil carbon sequestration increases by up to 800 Mt CO_2-eq in 2030 at carbon prices of up to \$20/tCO_2-eq (Figure 5.8). Given that 70% of total emissions abatement could come from developing countries, soil carbon sequestration will be an important management practice. Yet the economic potential of soil carbon sequestration practices in Asia and the Pacific has not been estimated on a wide scale.

Rice Cultivation

Only 3% of emissions from rice cultivation could be abated in 2000 at zero cost compared with 11% in 2010, and only 22% of global emissions could be abated at \$30/tCO_2-eq in 2010. The PRC and India each could reduce CH_4 emissions from rice fields by 26% at low cost (less than \$15/tCO_2-eq) by 2020. This result is not surprising, given that the PRC and South and Southeast Asian countries produced more than 90% of CH_4 emissions from rice in 1990.

Enteric Fermentation and Manure Management

Improved livestock and manure management together could reduce emissions by 3% at no cost, and between 6%–9% at carbon prices of \$30/tCO_2-eq. Annex 1 countries[18] designated by the United Nations Framework Convention on Climate Change (UNFCCC), and OECD have the highest least-cost economic potential. Yet the countries with the highest herd numbers, such as India, have relatively low economic potential, reducing emissions through livestock management only up to 2.5% at carbon prices of up to \$30/tCO_2-eq.

Summary of Economic Mitigation Potential

Overall, opportunities for emission mitigation in the agriculture sector at no or low cost are modest. USEPA (2006) estimates *without carbon sequestration*, show that 9%, 12%, and 15% of

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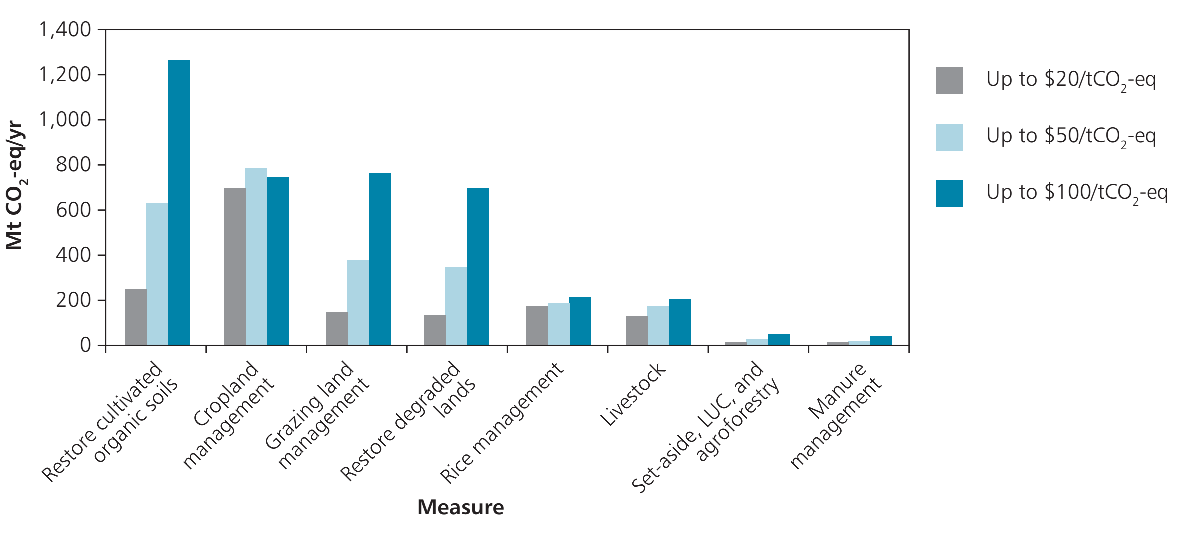
[18] Annex 1 of the UNFCCC document lists mainly western countries and does not include ADB developing member countries.

Figure 5.8: Economic Potential to Mitigate Agricultural Greenhouse Gases by 2030 at a Range of Carbon Dioxide Equivalent Prices



Note: Mt CO_2-eq/yr indicates megatons of carbon dioxide equivalent per year, LUC indicates land use change.

Source: Smith et al. (2007b).

emissions could be reduced from the baseline at carbon prices of up to $30/t$CO_2$-eq by 2030 in India, the PRC, and South and Southeast Asia, respectively. The PRC and India each could reduce CH_4 emissions from rice fields by 26% at low cost (less than $15/t$CO_2$-eq) by 2020. The consideration of expanded practices of soil carbon sequestration by Smith et al. (2007b) indicates that no-tillage and other sequestration methods could have significant economic potential in Asia. Across all practices, subregions of Asia could potentially reduce emissions by 276.8 Mt CO_2-eq/yr at a carbon price of $20/t$CO_2$-eq (Smith 2009, Table 5.2). Therefore, expanding mitigation options to include potential from soil carbon sequestration enlarges the economic mitigation potential in Asia. At this price, investments in mitigation would amount to more than $5.5 billion per year. Compared with total global economic mitigation potential estimated by Smith et al. (2007b), Asia could mitigate approximately 18% of emissions at carbon prices of $20/t$CO_2$-eq (calculated from Smith et al. 2007a, Figure 5.8; and Smith 2009).

Institutional Barriers to Mitigation in Agriculture in Asia and the Pacific

To date, little progress has been made in implementing mitigation measures in the agriculture sector on a global scale and particularly at the regional level. GHG mitigation potential

Table 5.2: Costs of Mitigation in Subregions of Asia at Various Carbon Prices

Region and/or Subregion	Potential (Mt CO_2-eq/yr) at up to \$20/tCO_2-eq	Potential (Mt CO_2-eq/yr) at up to \$50/tCO_2-eq	Potential (Mt CO_2-eq/yr) at up to \$100/tCO_2-eq
Western Asia	84.19	117.67	139.40
Southeast Asia	93.36	190.24	344.38
South Asia	16.40	41.25	84.11
East Asia	27.69	36.67	39.24
Central Asia	55.15	126.61	245.44
Total	276.79	512.44	852.57
Total investments at the carbon price	\$5,535 million	\$25,622 million	\$85,257 million

Note: Mt CO_2 - eq/yr^1 indicates megatons of carbon dioxide equivalent per year.

Source: Smith (2009).

would be enhanced with an appropriate international climate policy framework providing policy and economic incentives.

The market for trading carbon emissions offers limited possibilities for agriculture to benefit from land uses that sequester carbon or save non-CO_2 emissions. The Clean Development Mechanism (CDM) under the Kyoto Protocol of the UNFCCC is the most established mechanism for payments to developing countries. The CDM allows polluters in developed countries to purchase carbon-offsetting projects in developing countries once it has been determined that the project would not have been undertaken otherwise. Currently, eligible activities under the CDM are limited to afforestation and reforestation, and the reduction of non-CO_2 gases in agriculture. Carbon sequestration activities, such as conservation tillage and the restoration of degraded soils, are not eligible under the CDM.

Because soil carbon sequestration has the highest technical potential for mitigation in the agriculture sector, room exists to expand agricultural mitigation through the CDM if carbon sequestration projects are included. Yet, there are feasibility issues in selling agricultural soil carbon within a market-based credit-trading program. The transaction costs in soil carbon sequestration include the cost of obtaining site-specific information on the baseline stock of carbon and the potential to sequester carbon. The transaction costs per ton of carbon associated with negotiating contracts will decline as the size of the contract increases, and a market for carbon credits is likely to operate for large, standardized contracts (such as for 100,000 tons or more). For a typical individual farmer who can sequester 0.5 t/ha/yr, these transaction costs would be prohibitive.

In addition to global mechanisms, regional institutions and financing arrangements need to be scaled up and expanded to address key region-specific climate change needs (Sharan 2008). Nascent financing arrangements have emerged to service the ADB's developing member countries, including the Climate Change Fund, the Clean Energy Financing Partnership Facility, Asia and the

Pacific Carbon Fund, the Future Carbon Fund, the Water Financing Partnership Facility (WFPF), and the Poverty and Environment Fund (PEF). A large share of these funds is directed toward energy efficiency, with fewer projects in biofuel, biomass, and biogas promotion and sustainable land use and forestry. Current efforts need to be expanded and scaled up to reach more farmers, and broadened to include emission reductions from soil carbon sequestration and other GHG sources in the agriculture sector.

Integrating Mitigation and Adaptation in Sustainable Development Pathways

At the 2009 Delhi Sustainable Development Summit, Yvo de Boer, the executive secretary of the UNFCCC, urged stakeholders in the development of climate change policy to take every opportunity to ensure that "…*nationally appropriate mitigation action serves broader development goals on the one hand, and that development goals serve climate change abatement on the other.*"

One of the main objectives for climate change mitigation agreements at the 15th Conference of Parties in December 2009 will be to develop "…*nationally appropriate mitigation actions by developing country parties in the context of sustainable development, supported by technology and enabled by financing and capacity-building*" (Road to Copenhagen 2009). These initiatives reveal a growing recognition that climate change mitigation and adaptation need to be synonymous with poverty alleviation and sustainable development. Moreover, the ADB's developing member countries represent more than 2 billion people who depend on agriculture for their livelihoods, so mitigation and adaptation policies need a combined focus on both agriculture and poverty alleviation (Box 5.3).

Current carbon financing aims to offset emissions rather than ensure pro-poor development. As a result, the bulk of projects in the CDM targets large-scale emitters. Yet, expanding frameworks to include the emission reduction potential from agriculture in a post-2012 framework will help to ensure that the overall emission reduction objective of the UNFCCC is achieved. Moreover, developing countries—and specifically those with economies rooted mainly in agriculture or forestry—have stated that their support for a post-2012 agreement will be conditional on the inclusion of mitigation options from agriculture, forestry, and other land uses.

The large scope for synergies between adaptation and mitigation practices demands that strategies be mainstreamed to maximize co-benefits. The FAO recommends certain features for bridging mitigation activities with broader development objectives, including "…*financing arrangements that address specific needs in smallholder agriculture mitigation adoption including the need for investment capital and insurance, and a range of options for mobilizing private and public funds for financing, including the use of compliance market credits, voluntary market credits, publicly funded programs and agricultural product labels*" (FAO 2009a, p. 9).

These recommendations underscore the need to link farmers, and in particular small farmers, to the financing mechanisms, technology, property rights, and capacity strengthening necessary to realize synergies between adaptation and mitigation in the context of sustainable development. The development of nationally appropriate mitigation actions (NAMAs) by developing countries is one suggestion for providing a framework for achieving these linkages which emerged under the Bali Action Plan. While it is not currently mandatory

Box 5.3: Biogas in Asia: An Example of Integrating Mitigation and Adaptation to Improve Livelihoods

Biogas produced through the anaerobic digestion of animal dung has been implemented at the household and village scale for the generation of cooking fuel, electricity, and power. The oldest initiative is in the People's Repubic of China, where 15 million households have access to biogas, with plans to expand biogas plants to 27 million households, or 10% of rural households, by 2010. Government subsidies cover up to two-thirds of the cost, and local government commitments fund the rest. Similar programs have had success in India, Nepal, and Viet Nam. In India, more than 12 million biogas plants have been installed with a high rate of continued functionality. Since 1992, more than 140,000 biogas plants have been installed in Nepal, which has plans to increase availability of high-altitude digesters.

Biogas production has improved livelihoods and decreased the strain on scarce resources by reducing the dependence on firewood collection. Through the displacement of firewood, indoor air quality has improved, positively affecting the health of women and children. In addition, the time savings for women are significant. In Nepal, an average of three hours a day can be saved by reducing the dependency on dispersed forms of biomass. Another livelihood benefit is the production of organic fertilizer—a main by-product of the anaerobic digestion process. The availability of the fertilizer saves farmers money and also reduces nutrient-loading on fields. Finally, the construction and maintenance of biogas plants creates additional employment opportunities. In Nepal, it is estimated that 11,000 such jobs have been created.

The Netherlands Development Organization (SNV) has committed to scaling up and expanding biogas development in Asia, and plans to reach 1.2 million people with 210,000 additional biogas plants. Local financing issues, however, have proved to be significant barriers in Bangladesh and Cambodia. Carbon finance could prove to be one option for securing the necessary funds for continued biogas development. Currently, the Clean Development Mechanism (CDM) has approved projects only for large-scale pig and dairy farms. Small-scale biogas programs are not eligible because of difficulties in measurement, reporting, and verification. If the high transaction costs for small-scale projects can be eliminated, carbon markets could be a significant source of financing.

Source: van Ness (2006).

to elaborate on them under the UNFCCC, NAMAs would outline objectives and actions for technology transfers and development, capacity building, and financing needs, taking into account local development and mitigation objectives, and regional and global actions in agriculture. These plans would provide a basis for conceptualizing linkages between mitigation and sustainable development, and should be considered in the context of adaptation strategies.

Specific steps can be taken toward integrating mitigation and adaptation into sustainable development. First, synergies between adaptation and mitigation should be recognized and exploited so that strategies can be mainstreamed. Second, potential economic losses that might result from pursuing synergies in adaptation and mitigation should be overcome by creating financial markets and other payments for environmental services. Finally, it is important to ensure that carbon markets and other global, regional, and national frameworks provide adequate income flows and encourage the participation of small farmers. Each of these steps is discussed in turn below.

Synergies between Mitigation and Adaptation

The strategies for reducing emissions (mitigation) also have significant synergies with adaptation. Strategies to conserve soil and water resources, such as agroforestry, restoring degraded soils, and efficient water use in rice cultivation, also enhance ecosystem functioning, increase water availability, and provide resilience against droughts, pests, and other climatic threats. In general, the mismanagement of agroecological systems generates emissions, degrades ecosystem functioning, and ultimately threatens food security. Therefore, measures to reduce emissions through integrated crop, grazing land, pest, and water management will build ecosystem resilience, thereby lessening sensitivity to climate change.

Rao (1994) reports that rice, nutrient, water, and tillage management can mitigate GHG emissions from agriculture. Efficient drainage and effective institutional support lower irrigation costs to farmers and thus support the economic aspect of sustainable development. In addition, the appropriate combination of rice cultivation with livestock, in what is known as an "integrated annual crop–animal system," is traditionally found in India, Indonesia, and Viet Nam. This system enhances net income, improves cultivated agro-ecosystems, and enhances well-being (MA 2005).

Rice is the staple food widely grown in Asia, but it is a significant contributor of CH_4 emissions. A study by Wassman, Butterbach-Bahl, and Dobermann (2006) offers four approaches in offsetting CH_4 emissions: (i) improving rice plants through breeding, (ii) improving fertilizer management, (iii) improving water management, and (iv) utilizing crop residues for renewable energy and carbon sequestration. Using high-yielding varieties, shifting to rice–wheat production systems, and alternating dry–wet irrigation are technologies that both mitigate emissions and build resilience by conserving water, reducing land requirements, and reducing fossil–fuel use. In many of the countries of Asia and the Pacific, the dependency on rice for food calories is very high (defined as greater than 800 kilocalories/person/day) (Nguyen 2005). In addition, considering that the majority of the world's rice is produced in India and Southeast Asian countries, many households derive their livelihoods from its cultivation. Given the strong mitigation potential estimated by USEPA (2006), whereby the PRC and India could each reduce CH_4 emissions from rice fields by 26% at low cost (less than \$15/tCO_2-eq) by 2020, the potential exists to integrate the objectives of mitigation, adaptation, and poverty alleviation in rice production.

Improving pasture management by controlling overgrazing has favorable impacts on livestock productivity (higher income with the same number of livestock) and decelerates—if not completely minimizes—desertification (environmental aspect) (Smith et al. 2007a). In the PRC, overgrazing is controlled by disallowing free grazing (Rao 1994). Controlling overgrazing will be a challenge, however, especially in other Central Asian countries with large dryland and desert areas that rely on pasture grazing for food and economic needs (Smith et al. 2007a).

The breeding of improved crop varieties is another approach that has synergies with adaptation and mitigation. Crops can be bred to be more drought, pest, heat, and weed tolerant and to require fewer nutrient inputs. More efficient nitrogen use by crops has several important environmental advantages, in addition to lowering production costs for farmers, in light of high fertilizer prices. Genes have been identified that improve the efficiency with which plants use nitrogen fertilizer, and genetically modified plants with these genes are currently being developed under field conditions. The reduced need for synthetic nitrogen fertilizers will reduce energy costs and help lower GHG production.

Combating Economic Losses in the Pursuit of Mitigation Strategies

Farmer adoption of any mitigation technology depends on their assessment of its effects on their well-being. It is important to distinguish between two types of mitigation strategies. The first is financially attractive but involves upfront investments or significant technical capacity unavailable to farmers. Policies and programs to improve access to credit and providing technology and management training will accelerate adoption of these desirable mitigation strategies, as farmers see it in their long-term interest to do so.

The second type would result in an economic loss, either because of reduced income or increased risk. Adoption by farmers will require some form of payment for these services. For example, Pathak and Wassman (2007) found that a single mid-season drying results in substantial CH_4 emissions from irrigated rice with a small reduction in yields and therefore farm income. Essentially, society will need to pay farmers to provide the mitigation service. This is a specific example of the concept of payment for environmental services (PES). To be most effective, PES programs identify, and pay for, only those services with the greatest mitigation benefit per unit of payment. Choice of payment mechanism can have a substantial effect on adoption of a mitigation technology and costs.

Generating Income from Carbon Markets and Ensuring Smallholder Participation

In general, there is tremendous potential to link famers in developing regions of Asia and the Pacific while generating co-benefits in adaptation and sustainable development. Therefore, it is important to ensure that emerging carbon markets benefit developing countries. Rules under the CDM—or a more flexible successor program to CDM—should encourage the participation of small farmers and protect them against major livelihood risks, while still meeting investor needs and rigorously ensured carbon goals. Important reforms for inclusion of small farmers in carbon trading include:

- *Promoting measures to reduce transaction costs:* Rigorous but simplified procedures should be adapted to developing country carbon-offset projects. Small-scale soil carbon sequestration projects should be eligible for simplified modalities to reduce the costs of these projects. The permanence requirement for carbon sequestration should be revised to allow shorter term contracts or contracts that pay based on the amount of carbon saved per year.

- *Establishing international capacity-building and advisory services:* The successful promotion of soil sequestration for carbon mitigation will require investment in capacity-building and advisory services for potential investors, project designers and managers, national policy makers, and leaders of local organizations and federations (CIFOR 2002).

- *Investing in advanced measurement and monitoring:* Proper measuring can dramatically reduce transaction costs. Measurement and monitoring techniques have been improving rapidly owing to a growing body of field measurements and the use of statistics and computer modeling, remote sensing, global positioning systems, and geographic information systems, so that changes in stocks of carbon can now be estimated more accurately at lower cost.

Summary

Asia is a key emitter of GHGs, through fertilizers and soils (N_2O), as well as livestock and rice production (CH_4). Much of the expected increase in agricultural emissions in Asia will be the result of the food production growth required to feed a larger, wealthier population. Despite this emissions growth, up to 50% of the theoretical global mitigation potential could be realized in Asia by 2030, and this potential is particularly high in Southeast Asia.

Key low- or no-cost GHG mitigation activities in Asia and the Pacific include low or no till and other sequestration methods, as well as reducing CH_4 emissions from rice fields. At a price of \$20/tCO_2-eq, benefit streams from mitigation could amount to \$5.5 billion per year. Compared with the total global economic mitigation potential, Asia could mitigate approximately 18% of emissions at these carbon prices. Specifically, the PRC and India could each reduce CH_4 emissions from rice fields by 26% over baseline levels at low cost (less than \$15/tCO_2-eq) by 2020. Using high-yielding varieties, shifting to rice–wheat production systems, and alternating dry–wet irrigation are technologies that both mitigate emissions and build resilience by conserving water, reducing land requirements, and reducing fossil–fuel use.

The production of biofuels for energy markets will create new market value for cropland, putting additional pressure on increasingly scarce land and water resources. In addition to the need for land-based services such as food and timber production, biodiversity preservation, and carbon sequestration, land-intensive biofuel production will contribute to further land competition. Current policy developments, such as renewable fuel mandates and carbon market legislation, will determine the nature and extent of short- to medium-term pressure on land resources, while constraints on resources will likely shape longer term development. Biofuels—when produced on marginal lands that do not directly or indirectly lead to deforestation—are a mitigation strategy with high technical feasibility in oil palm-producing regions; however, trade-offs with food and land markets would need to be closely monitored. Finally, it should be recognized that biofuels are only one mitigation strategy and their implementation should be weighed against all available low-cost abatement technologies.

Some conditions need to be met for realizing mitigation potential. The agriculture sector in Asia can play a significant role in GHG mitigation, but incentives to date are not conducive to investing in mitigation. At the same time, aligning growing demand for agricultural products with sustainable and emissions-saving development paths will prove challenging. Moreover, the carbon market for the agriculture sector is underdeveloped. To be sure, the verification, monitoring, and transaction costs are high, but the carbon market could be stimulated with different rules of access and operations in carbon trading, together with capacity building and advances in measurement and monitoring. Finally, policies focused on mitigating GHG emissions, if carefully designed, can help create a new development strategy that encourages the growth of more valuable pro-poor investments by increasing the profitability of environmentally sustainable practices.

Significant potential exists for small farmers to sequester soil carbon if appropriate policy reforms are implemented. If the high transaction costs for small-scale projects can be eliminated, carbon markets could be a significant source of financing. Successful implementation of soil carbon trading would generate significant co-benefits for soil fertility and for long-term agricultural productivity. The outcome of international climate change negotiations will have major effects on the role of agriculture in mitigation. Action toward including agriculture in a post-Kyoto regime must be taken now with a focus on integrating smallholder farmers into carbon markets.

CHAPTER VI

Conclusions and Policy Recommendations

Introduction

This report reviewed the state of knowledge of, and undertaken highly innovative modeling analyses on, the predicted impacts of climate change on agriculture in Asia and to some extent the Pacific Islands together with potential strategies for adapting to and mitigating those impacts. This chapter briefly synthesizes the salient findings of Chapters I–V, discussing the severity of the impacts on agriculture and food security; agriculture's contribution to greehouse gas (GHG) emissions, adaptation and mitigation measures; and the various actors that have critical roles in mainstreaming and implementing climate change policies related to agriculture in Asia and the Pacific.

Agriculture's Role in Asia and the Pacific

Agriculture is important for all of the Asian Development Bank's developing member countries. More than 60% of the economically active population and their dependents—2.2 billion people—rely on agriculture for their livelihoods, but the weight of the sector's importance varies significantly by subregion. In Central Asia, agriculture's contribution to gross domestic product (GDP) has declined rapidly, with the exception of Turkmenistan. Similarly, agricultural GDP in East Asia has been declining and accounts for only 12% of GDP in the People's Republic of China (PRC). Nevertheless, nearly 64% of the economically active population in this subregion is employed in agriculture. Food security has been improving rapidly in East Asia overall, but 30% of Mongolia's population remains undernourished. Given significant land scarcity in the subregion, several countries—including the PRC and the Republic of Korea—have started to purchase or lease land for food production in other parts of Asia as well as in Africa, Eastern Europe, and Latin America. Agricultural GDP has also weakened in most countries in Southeast Asia, except in Cambodia and the Lao People's Democratic Republic (Lao PDR), where it still contributes 30% and over 40%, respectively. Undernourishment has been declining significantly in the Southeast Asia subregion to 18%, on average.

Unlike in Central, East, and Southeast Asia, the importance of agriculture to South Asia's GDP remains high, with only a slight decline from 1995 to 2006. As a result, employment in agriculture is also high, with close to 50% or more of the population employed in this sector (with the exception of the Maldives). The proportion of undernourished people averages over 20%, making South Asia the least food secure subregion both in Asia and the Pacific and in the world.

Data for the Pacific Islands on irrigated cropland, undernourishment, and the importance of agriculture in GDP are scarce. Data from Papua New Guinea, however, indicates that the share of agriculture in GDP has been rising, from 32% in 1995 to 42% of GDP in 2005. In addition, the proportion of the population employed in agriculture in the Pacific subregion averages close to 40%.

While agriculture is crucial for the region's food security and is the backbone of employment throughout Asia and the Pacific, farming systems vary significantly, ranging from the relatively dry wheat-producing areas of Central Asia to the very wet rice-producing lands of Southeast Asia. Similarly, support for agriculture and agricultural technologies varies significantly across the countries.

Even without climate change, competition for land and water resources is high in many Asian and Pacific countries. Climate change will intensify the struggle for these natural resources, exacerbating challenges to their management in the region and increasing the risk of conflict. Central and South Asia are particularly prone to conflicts as a result of water and land scarcity.

Thus, while agriculture's contribution to GDP is declining in all subregions in Asia and the Pacific overall, large populations are still based in rural areas and depend on agriculture either directly or indirectly for employment and income. Poverty remains highest in rural areas, and the disparity between rural and urban incomes is widening. While agriculture's role has been declining in the overall economies of Asia, goals of (close to) food self-sufficiency have increased in importance, not least as a result of the recent food and financial crises. These crises have also reduced trust in open trading systems, prompting several Asian countries to revert to trade-distorting policies, including export restrictions. Establishing mechanisms to ensure that food can move in times of such crises, and reach the poorest populations, will be an important step for regional cooperation on agriculture under climate change.

Climate Change Trends

Overall, Asia and the Pacific is expected to become warmer, with a greater degree of temperature variability depending on latitude. In general, areas of higher latitude will experience greater warming than those of lower latitude. As a result of global warming, the Himalayan glaciers are receding faster than any other glaciers in the world. While Pacific Island countries will experience the lowest annual mean changes in rainfall and temperature, rising sea levels are expected to significantly alter livelihoods and livability on some of the smaller islands in particular. Coastal areas in South and Southeast Asia will face the triple threat of changing precipitation, changing temperatures, and rising sea levels. Finally, cooler northern subregions of the Asian landmass are expected to warm, which may bring welcome news to farmers in terms of longer growing seasons.

Climate change is predicted to increase runoff in parts of South and East Asia, increasing the risk of floods during the wet season, while Central Asia will face a decrease in mean runoff. Climate change is also likely to affect groundwater resources by altering recharge capacities in some areas, increasing demand for groundwater as a result of reduced surface water availability, and causing water contamination as sea levels rise. Significant impacts are expected in countries highly dependent on groundwater for food production, including the PRC, India, and Pakistan.

Vulnerability to Climate Change in Asia and the Pacific

Studies show that several countries in Asia and the Pacific have high levels of vulnerability to climate change. The region is already highly prone to natural disasters: statistics for 1975–2006 show Asia as the most disaster-afflicted region in the world, during which period, Asia accounted for about 89% of people affected by disasters worldwide, 57% of total fatalities, and 44% of total economic damage. Temperatures are expected to increase in all countries in Asia and the Pacific under climate change but precipitation changes vary by subregion, with increased annual precipitation volumes expected for most Asian countries with the exception of Central Asia where declines in annual volumes are predicted. Moreover, glacier melt and sea-level rise are of particular concern for the countries of Asia and the Pacific.

Nevertheless, vulnerability to climate change depends not only on exposure to climate events, but also on the physical, environmental, socioeconomic, and political factors that influence the sensitivity of countries to a changing climate and how they will be able to cope. The countries most vulnerable to climate change are Afghanistan, Bangladesh, Cambodia, India, Lao PDR, Myanmar, and Nepal. Countries with significant vulnerability include Bhutan, the PRC, Indonesia, Pakistan, Papua New Guinea, Sri Lanka, Thailand, Timor-Leste, Uzbekistan, and Viet Nam. Data for most Pacific Islands are insufficient to construct the same vulnerability indicator. While high levels of vulnerability indicate an urgent need for investments focusing on adaptation, both the capacity of these countries to absorb additional funding and the governance structures and institutions required to support adaptation, need to be carefully assessed.

Climate Change Impacts on Agriculture

Based on the modeling framework used—combining macroeconomic with crop models—the study finds that Asia and the Pacific experiences, under the climate change scenarios examined here, the largest negative impact on rice and wheat yields across all subregions. Biophysical (crop model) results indicate irrigated rice yield declines in 2050 of 14%–20%, depending on scenario, irrigated wheat yield declines of 32%–44%, irrigated maize yield declines of 2%–5%, and irrigated soybean yield declines of 9%–18%, all compared to a no climate change case. Spreads are somewhat wider for rainfed crops. Rainfed maize yield changes range from -6% to +1%, and rainfed wheat yield changes from -16% to +18%. If carbon fertilization is included, then changes in crop yields are smaller or even turn positive in some cases. However, recent research experiments indicate that carbon fertilization effects have been overestimated and models have yet to be adjusted to account for recent insights.

Analysis that combines biophysical modeling with the IMPACT global agricultural supply, demand, and trade model shows that food prices increase sharply for key crops due to climate change, with adverse consequences for the poor. Rice prices increase 29%–37% by 2050 compared to the no climate change case, wheat prices rise 81%–102%, maize prices rise 58%–97%, and soybean prices increase 14%–49%.

Higher food prices in turn induce autonomous adaptation in the form of demand, supply, and trade responses. As a result, final yield and production price declines are lower than the biophysical shock from climate change, but remain large in much of Asia and the Pacific. Higher food prices also result in a reduction in consumption and increase in malnutrition. For Asia and the Pacific, rice yields decline by 10%–18%, on average, without carbon fertilization, and wheat yields by 35%–48%, while maize yields increase by 4%–13%, and soybean yields increase by 4%–10%. This shows the importance of autonomous adaptation as well as the need for functioning global trading regimes to compensate with net food imports in regions of the world that are particularly hard hit by climate change.

While Asia and the Pacific is particularly hit with lower rice and wheat yields, other regions fare worse regarding maize yields. As a result, prospects for changing trading patterns are mixed for the region. Net imports to Asia increase in one climate change scenario and decline in two scenarios compared to the no climate change case. There is a clear result for India, however, with increases in net cereal imports under all three scenarios.

In addition, a separate sea-level rise impact analysis showed that under a 1-meter sea-level rise, a total of 7.7 million hectares (ha) of cropland in Asia and the Pacific is submerged, while under a potential 3-meter sea-level rise, the area submerged more than doubles to 16.1 million ha. Rice is by far the most affected crop, at 4.9 million ha and 10.5 million ha, respectively in Asia and the Pacific, accounting for 5% and 11% of global rice cultivated area, respectively. Such area losses could create significant additional upward pressures on world rice prices and downward pressure on consumption, especially for the poor. Also significantly affected, but not brought into the calculation here, would be large negative impacts on aquaculture production for Asia and the Pacific countries with secondary impacts on prices for livestock products.

What are the implications for food security in Asia and the Pacific? Across the region, calorie availability under climate change drops sharply, by 13%–15% compared to a no climate change scenario. The subregion hardest hit by a decline in calorie availability is Central Asia, with projected reductions from 15% to18%, given their combination of low levels of calorie intake at the outset and the strong impact from climate change. Childhood malnutrition levels, which are directly linked to calorie availability, are projected to increase dramatically under climate change: between 9 and 11 million children—on top of the 65 million children—are projected to remain malnourished in 2050 even under current climate conditions. Avoiding such an increase is a tall order, but not impossible. The study implemented several alternative investment scenarios to explore which sectoral investments could help lower future increases in childhood malnutrition for Asia and the Pacific. The analysis found that aggressive, but plausible investments in crop yield and livestock numbers growth will lead to large declines in childhood malnutrition, reducing by two-thirds the increase in malnutrition levels resulting from climate change. However, agricultural productivity increases alone will not be sufficient to counteract the adverse impacts from global climate change in Asia and the Pacific. If large investment increases in agriculture are combined with more aggressive investments in complementary sectors, such as education and health, then childhood malnutrition levels can be brought back to levels projected under normal climate, or even somewhat below. Alternatively, accelerated investments in agriculture in the rest of the developing world and in industrialized countries can also boost nutrition outcomes in Asia and the Pacific, but the strongest push by far comes from local productivity increases, given that those most affected by food insecurity are located in rural Asia.

Adaptation Measures

At the center of agricultural adaptation are innovative responses to climate change, which are already in development but have not been implemented on a wide scale. These responses include changes in agricultural practices for crop and livestock systems. Enhancing the ability of farmers to respond to climate variability and climate change will require significant improvements in developing and disseminating agricultural technologies targeted toward the major biotic and abiotic stresses generated by climate change, which are still evolving. Improved crop varieties have the potential to be more drought tolerant, make better use of water and nutrients, and require reduced applications of pesticides. However, new technologies, by themselves, are insufficient to address successfully the challenges that climate change poses for agriculture—including increased risks to production and household income.

To protect against the devastating outcomes of agricultural failure due to weather and climate, reduce risk aversion in farmers' production decisions and thus enhance potential adoption of adaptive farming systems, programs and policies should be implemented to improve risk management and crop insurance, including index-based weather insurance.

A stable and supportive policy environment that makes such programs available and profitable is also a critical factor. Such a policy environment requires strengthening of important ongoing development initiatives to support climate change adaptation, which have been implemented in varying degrees throughout the developing world. These initiatives include secure property rights; improved economic incentives and green markets; improved information collection, use, and dissemination; extension services; and enhanced social protection and fiscal resilience. These adaptation areas need to be supported by ongoing local coping and indigenous knowledge, which farmers have employed for many years and in some cases for centuries. It will also be important to take account of the special needs of women in agriculture.

Finally, effective implementation of an agenda for climate change adaptation will require mainstreaming climate change and adaptation into development planning, reforming climate-related governance and institutions, and undertaking massive new investments.

Given shifts in the volume of rainfall, increased temperatures, and rising sea levels, investments focusing on enhanced water control, management, and efficiency will be crucial in adapting to climate change, particularly in Bangladesh, India, Viet Nam, Nepal, Bhutan, and the Pacific Islands. Knowledge and information sharing among farmers, government implementing agencies, and researchers should be given an enabling environment that supports adaptive management. Crop breeding will be an essential component of adapting to key biotic and abiotic stresses related to climate change, including drought, heat, salinity, pests, and disease. Biotechnology and genetic modification will be an increasingly large component of crop breeding because of the nature of upcoming climate change stresses.

Only one study (by the United Nations Framework Convention on Climate Change [UNFCC]) provides a quantification of future investment and financial flows required to meet climate change adaptation needs in agriculture, forestry, and fisheries (AFF). According to the study, about $14 billion in investment and financial flows are estimated to be needed for agriculture, forestry, and fisheries globally during 2000–2030, including $11 billion for production and processing, most of which is expected to be financed by domestic private sources; and $3 billion needed for research and development (R&D) and extension, which is expected to be met by public sources. If converted to annual estimates, developing country needs for adaptation research are estimated at a relatively low $47 million per year and extension needs at $2 million per year up to 2030. These numbers contradict the results of most National Adaptation Programme of Action (NAPA) that advocate strong investments in agriculture in developing countries. Our analysis shows that even very aggressive investments into the agriculture sector (including public agricultural research, rural roads, and irrigation in Asia and the Pacific—amounting to $3.0–$3.8 billion annually during 2010–2050)—while cutting by two-thirds the projected increase in child malnutrition due to climate change—are insufficient to counteract the adverse impacts of climate change (based on mean changes in temperature and rainfall). Given the significant trade linkages between Asia and the Pacific and the rest of the world, large-scale increases in agricultural investment in the rest of the developing, and also the developed, world will provide an additional boost to adaptation in Asia and the Pacific. A further third of malnutrition levels can be eliminated, if modest investments in key complementary sectors affecting childhood malnutrition are added—estimated at $1.2 billion per year—particularly investments in female secondary education and safe domestic water supplies. While it is encouraging to see that investments of this magnitude can significantly help reverse the adverse impacts of climate change, the cost of reversing future damage from extreme weather events and rising sea levels are not part of this calculation.

Synergies between Adaptation and Mitigation

Agricultural activities release significant amounts of GHGs into the atmosphere. Agriculture's share of emissions was 13% in 2000, but if land use change is considered, agriculture contributes upwards of 30% of total emissions. Emissions from this sector are primarily CH_4 and N_2O, making the agriculture sector the largest producer of non-CO_2 emissions (60% of the world total in 2000). In that year, Asian countries accounted for 37% of total world emissions from agricultural production, with the PRC alone accounting for more than 18%. The contribution of Asia and the Pacific to the world total is increasing.

Emissions from agriculture are expected to continue to rise because of increased demand for agricultural production from growing populations, improved nutrition, and changes in diet preferences favoring meat and dairy products. Yet, farmers have the potential to reduce the quantity of emissions through the efficient management of carbon and nitrogen flows. Mitigation strategies in agriculture can be categorized in three ways: carbon sequestration into soils, on-farm emission reductions, and emission displacements from the transport sectors through biofuel production.

Important low- or no-cost GHG mitigation activities in Asia and the Pacific include low- or no-till and other sequestration methods, as well as CH_4 emission reduction from rice fields. At a price of \$20/tCO_2-eq, benefit streams from mitigation could amount to \$5.5 billion per year. Compared with the total global economic mitigation potential, Asia could mitigate approximately 18% of emissions at these carbon prices.

Biofuels—when produced on marginal lands that do not directly or indirectly lead to deforestation—are a mitigation strategy with high technical feasibility in oil palm producing areas; however, trade-offs with food and land markets would need to be closely monitored. Finally, it should be recognized that biofuels are only one mitigation strategy, and their implementation should be weighed against all available low-cost abatement technologies.

Some conditions need to be met for realizing mitigation potential. The agriculture sector in Asia can play a significant role in GHG mitigation, but incentives to date have not been conducive to investing in mitigation. Significant potential exists for small farmers to sequester soil carbon if appropriate policy reforms are implemented. If the high transaction costs for small-scale projects can be eliminated, carbon markets could be a significant source of financing. Successful implementation of soil carbon trading would generate significant co-benefits for soil fertility and for long-term agricultural productivity. The outcome of international climate change negotiations will have major effects on the role of agriculture in mitigation. If agriculture is to be included in a post-Kyoto regime, action must be taken now, with a focus on integrating smallholder farmers into carbon markets.

Conclusions and Priority Actions

The results of this study reveal six key messages for Asia and the Pacific:

1. **Climate change will have negative impacts on agricultural production and food security throughout Asia and the Pacific.** Adverse impacts of climate change on agriculture are of particular concern for the region given the dominant role of agriculture in employment, economic development, and global food security.
2. **Agricultural adaptation funding is required for all countries in the region. On the margin, assistance should be targeted toward those countries most vulnerable to climate change.** The most vulnerable countries are Afghanistan, Bangladesh, Cambodia, India, Lao PDR, Myanmar, and Nepal. Actual investment programs for these countries need to take into account suitability of governance structures and absorptive capacity. Required public agricultural research, irrigation, and rural road expenditures are estimated to be \$3.0–\$3.8 billion annually during 2010–2050, *above and beyond* projected baseline investments. In addition, these agricultural investments require complementary

investments into education and health, estimated at $1.2 billion annually up to 2050 for countries in Asia and the Pacific.

3. **Several important adaptation and mitigation measures should be implemented despite remaining uncertainty regarding climate change impacts.** These include increased investments in agricultural research and rural infrastructure (including irrigation and rural roads as noted in point 2 above), and investment in market and climate information as well as disaster preparedness information systems. Key policy measures to be implemented include those that improve the efficient use of land, water, and ecosystems; those that reduce inefficient subsidies; those that support the development of carbon markets and other ecosystem services; and those that promote open and transparent trade. Remaining uncertainties as to where climate changes will have impacts should be reduced through more spatial analysis and improved information generated by local agencies, users, and scientists.
4. **The global agricultural trading regime should be opened so that the risks associated with climate change can be shared and thus, resilience increased.** This requires that the Doha Round of Agricultural Trade Negotiations be completed.
5. **Regional cooperation among governments in Asia and the Pacific needs to be improved to ensure effective implementation of national adaptation and mitigation strategies and implementation of current and future funding mechanisms to address climate change.** Regional cooperation initiatives in Asia, such as Central Asian Countries Initiative for Land Management (CACILM) and the Greater Mekong Subregion (GMS), are important building blocks for climate change adaptation. Moreover, formal regional organizations in Asia and the Pacific, including the Association of South East Asian Nations (ASEAN) and the South Asian Association for Regional Cooperation (SAARC), should play more prominent roles in technology and knowledge transfer across the region.
6. **Agricultural adaptation and mitigation strategies must be incorporated into the ongoing international climate change negotiations to ensure the creation of appropriate incentive mechanisms.** These include innovative institutions, technologies, and management systems, as well as the necessary financing mechanisms.

These messages are discussed in more detail in the sections that follow.

Negative Impacts on Agricultural Production and Food Security

Climate change hinders development in all sectors, not only in Asia, but globally. It is negatively affecting agriculture, particularly by intensifying the struggle for land and water resources. Understanding the adverse impacts on agriculture in Asia and the Pacific is important because agriculture plays a crucial role in ensuring inclusive and sustainable development and because agricultural growth contributes to the attainment of the Millennium Development Goals, particularly those on hunger, poverty, environmental sustainability, water access, and to some extent, health.

Agriculture is the principal source of livelihood for more than 60% of the population of the region and the sector most vulnerable to climate change. Therefore, the effects on food production systems will directly affect the primary income source of billions of people in the region, and perturbations in the food supply will have overall implications for the wider population of net food purchasers. Finally, Asia and the Pacific accounts for half the world's supply of and demand for cereals. Any significant changes in the food systems of this region will have implications for food supply and food prices globally.

Climate change will have significant negative impacts on agricultural production in Asia and the Pacific with all crops affected negatively under the three scenarios examined here. Negative crop impacts are strongest for rice and wheat. Climate change impacts on agriculture will render Asia and the Pacific less food and nutrition secure. Given that climate change is a global phenomenon, trade is an important measure that will provide some relief, but will be insufficient to fill production gaps from adverse future climate change. Home-grown productivity improvements will be the key path to maintaining food production growth and food security under climate change. Such productivity improvements require advances in agricultural research, development, and extension, including advances in crop and livestock breeding, enhanced farm management practices, soil quality improvements, and investments in rural infrastructure, including rural roads and irrigation.

Significant declines in agricultural production will adversely affect agricultural GDP in many Asian countries, and grave climatic conditions will cause heavy economic losses in Pacific Island countries. The decline in production due to climate change is projected to lead to substantial increases in food prices, at levels close to those seen during the 2008 food price crisis. While these predictions have been shown across a number of models, specific effects will differ by subregion. The effects of multiple stresses, such as extreme weather events, pests, and diseases, have not been adequately considered and require additional analysis.

Thus, given agriculture's pivotal role in employment, economic development, and global food security, adverse impacts on agriculture are of particular concern for the countries of Asia and the Pacific.

Assistance Should be Targeted Toward Those Most Vulnerable to Climate Change

In addition to broad-based adaptation investments, within Asia and the Pacific, targeted assistance should be directed toward those countries that are most vulnerable to climate change—that is, those with large exposure to climate change impacts, high sensitivity to the impacts from climate change, and low adaptive capacity. These countries include Afghanistan, Bangladesh, Cambodia, India, Lao PDR, Myanmar, and Nepal—with poor outcomes under all three categories of vulnerability—revealing South and Southeast Asia as the subregions of Asia and the Pacific most vulnerable to climate change.

Countries in South Asia, Southeast Asia, and the Pacific Islands are highly vulnerable to rising sea levels, which will increase the risk of floods. Glaciers in the Himalayas and Central Asia are already melting as a result of global warming. In areas highly dependent on livestock production, such as Mongolia and Inner Mongolia, the PRC, overgrazing increases vulnerability to climate change.

Vulnerability assessments are important to ensure that scarce public and private resources are allocated to those most in need of adapting to climate change. Although various vulnerability assessments generally come to similar conclusions, differences in results do exist because of the use of different data, different factors representing vulnerability, and differing methodologies. Given the low levels of adaptive capacity in the highly vulnerable countries, it will be important to take governance structures and country absorptive capacities into account during the development of adaptation strategies.

As was shown by Bangladesh's improved resilience to tropical cyclones between 1991 and 1997, adaptation is possible even for the most destitute and vulnerable countries.

Key Adaptation and Mitigation Measures Need to be Undertaken Now

Sound development policies are necessary but not sufficient to effect the necessary agricultural adaptations to climate change. A pro-growth, pro-poor development agenda that supports agricultural sustainability is vital, including more targeted assistance to improve resilience. Adaptation will, however, also require targeted investments in agriculture.

First, because climate change has a negative impact on agricultural production in most developing countries, achieving any food security target will require greater investments in agricultural productivity. Key areas for increased investment include agricultural research, irrigation, rural roads, information technologies, market support, and extension services.

Second, the allocation of investment within and across sectors will need modification to achieve effective adaptation. Investments in agricultural research will need to undergo a relative shift toward traits relevant to climate change adaptation, such as drought and heat tolerance, insect and pest tolerance, and nitrogen use efficiency—all of which can reduce carbon emissions while promoting agricultural productivity. Biotechnology and genetic modification will play an increasingly large role in crop breeding because of the need for wider genetic variation to adapt to climate change stresses. In irrigation and water resources, investments may be needed to expand large-scale storage to deal with the increased variability of rainfall and runoff. On the other hand, in subregions where changes in precipitation are highly uncertain, investments would better be distributed in a variety of small catchments. Climate change and variability in water supply, together with potential long-term changes in the cost of energy, could also dramatically change the cost–benefit calculus for big dams for storage, irrigation, and hydropower, making these investments more attractive despite the environmental and human relocation issues that such dams raise. The appropriate level and location of future irrigation investments could also change dramatically.

Third, adaptation will require a shift away from business-as-usual development policy because greater variability in weather and production outcomes will require greater attention to risk-sharing and risk-reducing investments. Such investments include financial market innovations, climate-based crop insurance, and broad-based social safety nets to both protect against the negative impacts of increased risk and induce farmers to make decisions that are not unduly risk-averse. International agricultural trade is an important mechanism for sharing climate change risk, so open trading regimes should be supported. Appropriate agricultural advisory services, hydrometeorological infrastructure, functioning financial markets, and effective institutions are necessary to minimize the risks to farmers as they make decisions about agricultural production. Also directly related to managing risk is the need to upgrade the efficiency and sophistication of infrastructure and other investments, including modernizing instead of rehabilitating irrigation, and investing in paved, not dirt, roads. More sophisticated agricultural practices, such as integrated pest management, are also needed, requiring improved human capacity in agricultural management. Strengthening the role of women in household and agricultural production, as well as their rights to and control of assets, would further improve the effectiveness of risk management.

Fourth, investments will need to be targeted at subregions where the benefits are magnified because of climate change, and they should be reduced in areas where climate change impacts are so severe that production is no longer feasible. Sea-level rise will increase salt concentrations in coastal farming areas, which may require retooling of production systems, for example. Instead of producing crops, farmers may be better off pursuing alternative livelihoods, such as raising livestock, as practiced in the southwestern coastal areas of Bangladesh during flood season.

Fifth, climate change will exacerbate the negative implications of bad policies, thereby further increasing food, energy, and water prices. Subsidies for water, energy, and fertilizers should therefore be reduced, with the savings invested in adaptation activities that boost farm incomes and productivity. These subsidies have not only distorted production decisions, but also encouraged carbon emissions beyond economically appropriate levels. As the real prices of natural resources rise, market-based approaches to managing environmental services in response to climate change (such as through water pricing, payments for environmental services, and carbon trading) will become increasingly important. Improved definition and protection of land and water property rights will be necessary to effectively implement market-based approaches to climate change policy.

Sixth, the valuation of carbon through carbon trade and other forms of agricultural ecosystem services will increase the value of sustainable farming practices, thereby improving the likelihood that farmers will adopt such practices as minimum tillage; integrated soil fertility management; and integrated pest, disease, and weed management.

Implementation of these adaptation and mitigation measures can only be realized through increased agricultural investments. A strong need exists to revisit national investment priorities and opportunities among the countries of Asia and the Pacific. Developing countries have chronically underinvested in science, technology, and innovation; and growth in public investments in research stagnated in developing countries after the 1980s. Investments in biotechnology and biosafety, especially by the public sector, may be insufficient to address pressing needs in both areas. In spite of the limitations, the public sector in many developing countries has invested in agricultural biotechnology research, yet few of its technologies have reached the commercialization stage. Many developing countries, particularly those in Southeast Asia, need to develop the minimal infrastructure and scientific capacity to master and implement risk assessments and biosafety regulations.

Investments in biotechnology, including genetically modified (GM) crops, could provide a transformational approach to addressing the trade-offs between energy efficiency and agricultural productivity. Biotechnology could profoundly affect future demand for freshwater and investment requirements in irrigation and other water sectors. GM crops have the potential to address major water-related stresses under both rainfed and irrigated farming and possibly to offer solutions to important water-quality problems. Breeding crop varieties with high water-use efficiency—a good indicator of the crop's ability to withstand environmental stresses, particularly drought and salinity—is thus, one policy option. Biotechnology's role as a possible substitute for large-scale water investments must be considered in future planning for irrigation, water supply, and sanitation investments.

Increased and diversified investments are needed in plant breeding, livestock improvement, and other interventions at the biological and molecular levels to enhance agricultural productivity in ways that ultimately contribute to poverty reduction, agricultural development, and economy-wide growth throughout the region. Such a program requires heavy investment in advanced scientific expertise and equipment, as well as a political and social commitment to long-term funding of agricultural science and technology at levels significantly greater than current funding. Furthermore, it requires new investments to create organizations that are more dynamic, responsive, and competitive than the public organizations that currently make up the bulk of national agricultural research and extension systems in Asia.

Major investments in water infrastructure are also needed. Dams have proven to be an effective means of protecting agricultural systems and human settlements from water variability, and a higher demand for dams is expected to result from increasing water variability and energy demand. Big dams are known, however, to cause considerable environmental and social impacts. Furthermore, investment is needed in engineering techniques to reduce environmental impacts, management techniques to optimize their use, planning tools to reduce social impacts, and tools to improve design and operational techniques. Investments should also be made to scale up underground storage techniques. Finally, more investments should be made in research on the viability of inter-basin transfer schemes, which can be politically challenging and risky in light of future uncertainty about water availability.

Policies that favor private investment in crop improvements targeted to climate change in the developed and developing world are critical. These policies include (i) decreasing the bureaucratic hurdles to business formation, (ii) developing infrastructure that enables the production and distribution of improved seeds and other agricultural inputs, (iii) developing appropriate regulatory and biosafety protocols for the introduction of transgenic cultivars, and (iv) reforming intellectual property rights that could encourage private investment in crop improvement.

Meeting the challenges of climate change adaptation in agriculture also requires long-term investment by farmers. Long-term investment (in areas such as integrated soil fertility management, tree planting, and water harvesting), in turn, requires secure property rights to provide people with the incentive and authority to make such investments. By changing the profitability of land, such as through the potential for income from carbon markets and biofuels, climate change may worsen the position of those farmers with insecure property rights, leading to expulsion from their land as landlords seek to increase their share of the new income streams. Improvement in land rights is, therefore, an essential component in effective and equitable adaptation.

International agricultural trade is an important mechanism for sharing climate change risk. A more open global trading regime would increase resilience to the impacts of climate change.

Climate change can become the stimulus for implementing difficult but necessary changes. Managing climate change as an international public good creates opportunities for new markets and pricing policies that can help meet longer-term sustainability goals through the valuation of resources. Rising prices of carbon, food, fuel, and environmental resources due to climate change could stimulate significant policy and investment opportunities. Instead of seeing climate change as a tax on growth, countries can benefit by implementing low-cost, resource-conserving technologies in the agriculture sector. They can exploit synergies between building ecosystem resilience and agricultural productivity through a focus on agricultural productivity enhancement, and new agricultural financing mechanisms such as carbon markets.

Agriculture can help mitigate GHG emissions in Asia and the Pacific with appropriate incentive mechanisms and innovative institutions, technologies, and management systems. Incorporation of agricultural adaptation and mitigation in the ongoing international climate change negotiations must happen now in order to open opportunities to finance sustainable growth under climate change. Mitigation strategies that support adaptation should be favored.

A broad set of technical skills will be needed to plan for and respond to a wide range of unpredictable contingencies, and the backbone of these efforts will be improved knowledge, coordination, collaboration, information exchange, and institutional responsiveness. Building resilience—especially among the poor—will require enhancing the adaptive capacity of individuals and institutions to deal with uncertainties in their local settings through the testing and scaling up of effective pilot projects.

While many adaptation and mitigation investments can be implemented now, others require additional information to reduce uncertainty about where climate change will manifest impacts. Disagreements among modeling studies with regard to the future impacts of climate change on agricultural capacity and crop yields are, in part, a result of different assumptions. Another major limitation is the lack of an integrated assessment incorporating all key climate variables. Many climate variables have feedback effects among themselves, which are left out of already complex modeling exercises. Furthermore, almost all climate change modeling efforts leave out several key factors. Extreme weather events and other stressors—such as increased climate variability, rising sea levels, and land degradation—are often partially or entirely ignored. In agriculture, pest and disease aspects and their feedback effects are seldom taken into account. A further limitation is that the quality and extent of research varies by country. For example, much information is available on the PRC, but little, if any is available, on Central Asia and the Pacific Island states.

International Trade is an Important Mechanism for Sharing Climate Change Risk

A more open global trading regime would increase resilience to the impacts of climate change. Rule-based, fair, and free international trade is particularly critical in times of crisis, as the export ban problems following the food price crisis of 2007–2008 underline. A sound global trading system is especially crucial in the context of climate change. As shown in Chapter II, the impacts of climate change on agricultural growth and production will likely make many Asian developing countries increasingly reliant on food imports. To increase confidence in international agricultural trade, the World Trade Organization Doha Round should be completed. Organisation for Economic Co-operation and Development countries should reduce or eliminate trade restrictions that limit a developing country's export access to markets, and buffering mechanisms should be established to better address volatility in world markets. Alternative or complementary approaches to market stabilization for cereals include a joint pooling of fixed portions of national stocks into an international grain reserve and/or a financial facility, provided by the International Monetary Fund, for imports by countries during food emergencies.

Regional Cooperation among Governments in Asia and the Pacific Needs to be Improved

Cooperation among governments in Asia and the Pacific is necessary to ensure effective implementation of adaptation and mitigation strategies in their respective countries, as well as to explore the financial means for addressing climate change. Funding modalities related to climate change, such as the Clean Development Mechanism and other carbon funds, payments for environmental services, or other mechanisms to mitigate GHGs, must be implemented by Asian development planners and policy makers, and such funds must be accessible to vulnerable people. Climate action plans need to be integrated into Poverty Reduction Strategy Papers or other national development plans. Without this integration, climate adaptation plans may simply add another layer of planning rather than aid the mainstreaming process. Actors at all levels are called to action in the effort to adapt to climate change.

Adaptation to climate change, typically treated as a stand-alone activity, should be integrated into development projects, plans, policies, and strategies. Development policy issues must inform the work of the climate change community, and development and climate change perspectives should be integrated into approaches that recognize how persistent poverty and environmental needs exacerbate the adverse consequences of climate change. Climate change will alter the set of appropriate investments and policies over time, both in type and in spatial location. Effective adaptation, therefore, requires not only that policy makers judiciously select measures within their policy context and strategic development framework, but also that they explicitly target the impacts of climate change, particularly on the poor.

Development policies and plans at all levels need to consider the impacts of climate change on the agriculture sector. National and regional policy makers must integrate the effects of climate change and the outcomes of assessments and scenarios into their national agricultural plans and policies. Moreover, mainstreaming should aim to limit development policies and plans that inadvertently encourage, rather than minimize, vulnerability to the impacts of climate change.

Achieving these goals will require, first, the engagement of a core ministry—such as the Ministry of Finance or the Ministry of Planning, alongside the Ministry of Agriculture—to ensure strong government support. Second, the core capacities of developing country governments will need to be further developed. Such capacity building is required in a number of areas including climate forecasting and scenario planning, and general development topics such as governance, accountability, and empowerment of local communities. Third, adaptive and flexible management will be essential to address the broadening nature and increasing severity of potential climate impacts in a given area and the unavoidable uncertainties associated with predicting these impacts.

New mechanisms to support adaptation, including the Least Developed Country Fund, the Special Climate Change Fund, and the Adaptation Fund, provide the opportunity to mainstream adaptation into local and regional development activities.

Short-term regional adaptation initiatives could include transboundary or regional adaptation evaluation exercises and investment assessments. Medium-term regional adaptation initiatives could include the development of agricultural climate information systems, regional disaster and emergency relief funds, and larger scale infrastructure development. Regional initiatives should be supported by climate change interest groups staffed by experts from the region's ministries of agriculture and finance.

In addition, the private sector—particularly the insurance and reinsurance industries—needs to engage more in adaptation activities in developing countries, building on the risk-transfer products they have already begun to develop, such as microinsurance, weather and crop insurance, and disaster-related bonds.

Agriculture Needs to Form Part of International Climate Change Negotiations

Agriculture can help mitigate GHG emissions in Asia and the Pacific with appropriate incentive mechanisms and innovative institutions, technologies, and management systems. Incorporation of agricultural adaptation and mitigation in the ongoing international climate change negotiations must happen now in order to open opportunities for financing of sustainable growth under climate change. Mitigation strategies that support adaptation should be favored.

Because agriculture is still the main source of livelihood for more than half of the people in the region, benefit streams for Asia from mitigation strategies have the potential to contribute to poverty reduction, food security, and the resilience of agroecological systems. Small farmers have significant potential to sequester soil carbon if appropriate policy reforms are implemented. Successful implementation of soil carbon trading would generate significant co-benefits for soil fertility and long-term agricultural productivity. If the high transaction costs for small-scale projects can be eliminated, carbon markets could be a significant source of financing. The benefit stream from mitigation of 276.79 Mt CO_2-eq a year at a carbon price of $20/t CO_2-eq in agriculture could amount to $5.5 billion annually for Asia, accounting for 18% of total global mitigation potential.

The use of high-yielding crop varieties, a shift to rice–wheat production systems, and alternating dry–wet irrigation are technologies that combine mitigation and adaptation objectives by reducing emissions, conserving water, and reducing land requirements and fossil fuel use. Other mitigation strategies that have substantial synergistic effects with adaptation and food security for rural communities in Asia and the Pacific include the restoration of degraded soils and efficient water use in crop cultivation. All of these strategies help conserve soil and water resources while enhancing ecosystem functioning, including water use efficiency and crop resilience to pests, diseases, and extreme weather events. GHG emissions from agriculture can be further mitigated through nutrient, water, and tillage management; through improved crop varieties (particularly rice, the main staple in Asia); and through the use of crop residues for renewable energy and carbon sequestration.

Improved pasture management to control livestock overgrazing will help decelerate desertification.

Although there are viable mitigation technologies in the agriculture sector, key constraints need to be overcome. First, the rules of access—which still do not credit developing countries for reducing emissions by avoiding deforestation or improving soil carbon sequestration—must change. Second, the operational rules—with their high transaction costs for developing countries, and small farmers and foresters, in particular—must be streamlined.

Policies focused on mitigating GHG emissions, if carefully designed, can help create a new development strategy that encourages the creation of more valuable pro-poor investments by increasing the profitability of environmentally sustainable practices. To achieve this goal, it will be necessary to streamline the measurement and enforcement of offsets, financial flows, and carbon credits for investors. It is important to enhance global financial facilities and governance to simplify rules and increase funding flows for climate change mitigation in developing countries.

Appendixes

Appendix 1: Additional Tables

Table A1.1: Results from Previous Vulnerability Assessments

Scenario	Vulnerability	2050	2100	Source and Methodology
Static index of current national adaptive capacities	Extreme	Bangladesh	All countries investigated	Vulnerability as a function of exposure, sensitivity, and adaptive capacity. Assumption: climate sensitivity is 5.5°C. Scenario: A2. Source: Yohe et al. (2006). Observations: (i) Countries not in the sample: Afghanistan, Central Asia, Lao PDR, Mongolia, Myanmar, most of Pacific Island countries. (ii) Papua New Guinea
	Significant	PRC, Nepal, Pakistan	–	
	Moderate	India, PNG, Southeast Asia, Sri Lanka	–	
	Little or none	–	–	
National adaptive capacities improving over time	Extreme	–	Bangladesh, Cambodia, PRC, India, Nepal, Pakistan, PNG, Philippines, Viet Nam	
	Significant	–	Other Southeast Asia, Sri Lanka	
	Moderate	Bangladesh, PRC, India, Nepal, Pakistan, PNG	–	
	Little or none	Southeast Asia, Sri Lanka	–	
Mitigation scenario (greenhouse gas concentration constrained to 550 parts per million or ppm) combined with a scenario of static adaptive capacity	Extreme	–	Bangladesh, Cambodia, PRC, India, Nepal, Pakistan	
	Significant	Bangladesh, Nepal,	Other Southeast Asia, PNG, Sri Lanka	
	Moderate	Cambodia, PRC, India, Pakistan, PNG	–	
	Little or none	Other Southeast Asia, Sri Lanka	–	

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Table A1.1 continued

Scenario	Vulnerability	2050	2100	Source and Methodology
Mitigation scenario combined with an enhanced adaptive capacities scenario	Extreme	–	PRC, Pakistan, Nepal	
	Significant	–	Bangladesh, India, PNG, Philippines, Viet Nam	
	Moderate	Bangladesh, PRC, India, Nepal, Pakistan	Other Southeast Asia, Sri Lanka	
	Little or none	PNG, Southeast Asia, Sri Lanka	–	

Scenario	Vulnerability –Resilience Indicators	2095	1990	Source and Methodology
Current	Resilient countries		Cambodia, Indonesia, Republic of Korea	Thirty-eight countries around the world were investigated, of which eight were in Asia and the Pacific. Vulnerability to climate change is assessed by combining indicators that measure sensitivity to climate change (settlement, food security, human health, ecosystems, and water indicator) and coping-adaptive capacity (economic capacity, human resources, and environmental capacity). A vulnerability–resilience indicator is calculated by estimating the difference between aggregated sensitivity and adaptation capacity. Exposure was not assessed in this study. Source: Moss et al. (2001).
	Vulnerable countries		Bangladesh, PRC, India, Thailand, Uzbekistan	
A1v2 (rapid growth)	Resilient countries	Bangladesh, Cambodia, PRC, India, Indonesia, Republic of Korea, Thailand, Uzbekistan		
	Vulnerable countries	–		
B2h (local sustainability)	Resilient countries	Cambodia, PRC, Indonesia, Republic of Korea, Thailand, Uzbekistan		
	Vulnerable countries	Bangladesh, India		
A2A1 (delayed development)	Resilient countries	Cambodia, Indonesia, Republic of Korea, Thailand		
	Vulnerable countries	Bangladesh, PRC, India, Uzbekistan		

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Table A1.1 continued

Time and/or Scenario	Vulnerability (to mortality from climate-related disasters)	Countries Affected	Source and Methodology
Current	Most vulnerable countries	Afghanistan, Pakistan, Turkmenistan	This study assesses vulnerability to climate-related mortality at the national level. Climate outcomes are represented by mortality from climate-related disasters using the emergency events data set; statistical relationships between mortality and a shortlist of potential proxies for vulnerability are used to identify key vulnerability indicators. Eleven key indicators related to health status, governance, and education were found to exhibit a strong relationship with decadally aggregated mortality associated with climate-related disasters. Validation of indicators, relationships between vulnerability and adaptive capacity, and the sensitivity of subsequent vulnerability assessments to different sets of weightings are explored using expert judgment data, collected through a focus group exercise. Source: Brooks, Adger, and Kelly (2005).
	Moderately to highly vulnerable	Azerbaijan, Bangladesh, Bhutan, Cambodia, Lao PDR, Nepal, Tonga	

Time and/or Scenario	Human Vulnerability to Climate Extremes	Countries Affected	Source and Methodology
Next 20–30 years (GIS)	High human vulnerability	Afghanistan, Cambodia, northern and western PRC, India, Indonesia, Lao PDR, Mongolia, Myanmar, Pakistan	The authors use Geographical Information Systems (GIS) to map specific hazards associated with climate change—specifically floods, cyclones, and droughts—and place them in relation to factors influencing vulnerability. This study identifies the most likely humanitarian implications of climate change for the next 20–30 year period. In this study, human vulnerability refers to the likelihood that individuals, communities, or societies will be harmed by a hazard. We divide the factors shaping human vulnerability into five groups: natural, human, social, financial, and physical. Each group contains one or more individual indicators, which were combined to construct vulnerability indices for each. The groups were then combined to give a single, overall human vulnerability index. This was combined with information on the distribution of hazards to identify climate change-risk hotspots.
	Flood risk hotspots	South and Southeast Asia	
	Cyclone risk hotspots	Bangladesh, several parts of India, Viet Nam, and several other Southeast Asian countries	
	Drought risk hotspots	Afghanistan, parts of India, Indonesia, Myanmar, Pakistan, and Viet Nam	
	Extreme climate risk hotspots + high population density	South and Southeast Asia	
	Drought risk hotspots + risk of conflict	South Asia	Source: Ehrhart et al. (2008).

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Table A1.1 continued

Time and/or Scenario	Vulnerability to Climate Hazards	Countries Affected	Source and Methodology
Current (only in Southeast Asia)	Overall vulnerability	Almost all the regions of Cambodia; western and eastern Java in Indonesia; North and East Lao PDR; all parts of the Philippines; the west and south of Sumatra; the Bangkok region of Thailand; and the Mekong River Delta region of Viet Nam	Vulnerability to climate change in Southeast Asia is measured by taking into account indicators of exposure (multiple hazard risk exposure), sensitivity (human and ecological), and adaptive capacity. Authors assessed exposure using information from historical records of climate-related hazards (tropical cyclones, floods, landslides, droughts, and sea-level rise). Population density was used as a proxy for human sensitivity to climate-hazard exposure. Biodiversity information (percentage of protected areas) was used as a proxy for ecological sensitivity. An index of adaptive capacity was created as a function of socioeconomic factors, technology, and infrastructure. Source: Yusuf and Francisco (2009).
	Drought hotspots	Western and eastern area of Java Island, Indonesia; Sabah state in Malaysia; the Philippines; southern regions of Thailand; northwestern Viet Nam, eastern coastal areas of Viet Nam	
	Floods hotspots	Western and eastern area of Java Island, Indonesia; the Philippines; Bangkok and its surrounding area in Thailand; southern regions of Thailand	
	Sea-level rise hotspots	Western and eastern area of Java Island, Indonesia; Bangkok and its surrounding area in Thailand; Mekong region of Viet Nam	
	Cyclone hotspots	The Philippines, eastern coastal areas of Viet Nam	
	Landslide hotspots	Western and eastern area of Java Island, Indonesia; the Philippines	

GIS = Geographical Information Systems, Lao PDR = Lao People's Democratic Republic, PNG = Papua New Guinea, PRC = People's Republic of China.

Note: Yohe et al. (2006) estimate vulnerability considering several assumptions: a static index of current national adaptive capacities, with national adaptive capacities improving over time, under a mitigation scenario (greenhouse gases concentration constrained to 550 ppm) combined with a scenario of static adaptive capacity, and under a mitigation scenario combined with an enhanced adaptive capacities scenario.

Moss, Brenkert, and Malone (2001) assess vulnerability to climate change by combining indicators that measure sensitivity to climate change (settlement, food security, human health, ecosystems, and water indicator) and coping-adaptive capacity (economic capacity, human resources, and environmental capacity) for 1990 and 2095. A vulnerability-resilience indicator is calculated by estimating the difference between aggregated sensitivity and adaptation capacity. By 1990, 16 out of 38 countries were considered vulnerable to climate change including Bangladesh, the PRC, India, Thailand, and Uzbekistan. By 2095, only one country remains vulnerable in the rapid growth scenario -A1v2 (Yemen), three countries in the local sustainability scenario - B2h (Bangladesh, India, and Yemen) and nine countries in the delayed development scenario - A2A1 (South Africa, Bangladesh, the PRC, Egypt, India, Senegal, Tunisia, Yemen, Ukraine, Uzbekistan).

Brooks, Adger, and Kelly (2005) find that 11 key indicators related to health status, governance and education exhibit a strong relationship with decadally aggregated mortality associated with climate-related disasters. Through a focus group exercise, expert judgment data was used for validation of indicators, relationships between vulnerability and adaptive capacity, and the sensitivity of subsequent vulnerability assessments to different sets of weightings. Following this methodology, most vulnerable countries were found to be mainly in Sub-Saharan Africa. However, within Asia and the Pacific, Afghanistan, Pakistan, and Turkmenistan were also in the most vulnerable group.

Table A1.2: Parameters for Agricultural Employment as Share of Total Employment
(reflecting sensitivity to climate change)

Country	Agricultural Employment as % of Total Employment
High sensitivity	
Bhutan	93.6
Nepal	93.0
Timor-Leste	81.1
Lao PDR	75.8
Papua New Guinea	72.0
Solomon Islands	71.7
Myanmar	68.9
Cambodia	68.6
Viet Nam	65.7
Afghanistan	65.7
China, People's Republic of	64.4
India	57.8
Thailand	53.3
Bangladesh	51.8
Indonesia	45.7
Pakistan	45.0
Sri Lanka	44.3
Medium sensitivity	
Fiji Islands	38.1
Philippines	37.1
Vanuatu	34.4
Nauru	33.3
Turkmenistan	31.9
Samoa	31.8
Tonga	31.6
Tajikistan	31.2
Cook Islands	28.6
Azerbaijan	25.1

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Table A1.2 continued

Country	Agricultural Employment as % of Total Employment
Uzbekistan	25.0
Marshall Islands	25.0
Tuvalu	25.0
Micronesia, Federated States of	24.4
Kiribati	23.9
Kyrgyz Republic	23.4
Palau	22.2
Mongolia	21.5
Maldives	19.3
Georgia	17.8
Kazakhstan	16.1
Malaysia	15.9
Low sensitivity	
Armenia	10.9
Korea, Republic of	7.7
Singapore	0.1

Source: FAOSTAT (FAO 2004).

Table A1.3: Poverty Incidence Reflecting Relative Adaptive Capacity in the Asia and Pacific Subregions

Country	Poverty Incidence (PPP, 2005)[a]
Low Adaptive Capacity	
Nepal	54.70
Bangladesh	50.47
Timor-Leste	43.56
India	41.64
Cambodia	40.19
Uzbekistan	38.81
Afghanistan	[b]

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Table A1.3 continued

Country	**Poverty Incidence (PPP, 2005)**[a]
Myanmar	[b]
Lao People's Democratic Republic	35.68
Medium Adaptive Capacity	
Papua New Guinea	29.70
Bhutan	26.79
Viet Nam	22.81
Philippines	22.62
Pakistan	22.59
Mongolia	22.38
Kyrgyz Republic	21.81
Tajikistan	21.49
Indonesia	21.44
China, People's Republic of	15.92
Georgia	13.44
Turkmenistan	11.72
Sri Lanka	10.33
High Adaptive Capacity	
Armenia	4.74
Kazakhstan	1.15
Malaysia	0.54
Thailand	0.40
Azerbaijan	0.03

[a] Based on $1.25 a day, which represents the international poverty line for extreme poverty. Poverty estimates are based on Purchasing Power Parity (PPP) for 2005. No data could be found for most island countries.

[b] Anecdotal data sources for Afghanistan and Myanmar indicate poverty levels above 30%.

Source: Bauer et al. (2008).

Table A1.4: Local Coping Strategies as Adaptation Tools to Mitigate the Impacts of Climate Change in Agriculture

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
A. CENTRAL ASIA									
Tajikistan	Central	Extreme cold Shift of season	Loss of crops. Decreased food security.	Improved cropping systems or alternative cultivation methods	Using cold frames to allow earlier seeding of plants	Higher income from farming	None	Wood, glass, and screws; seedbeds and watering Total cost = $90 per cold frame	Increased growing season in Central Tajikistan through cold frames. CARE Tajikistan. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=177>
	Central (mountainous areas)	Shift of season Extreme cold	Loss of crops. Loss of livelihoods.	Improved food processing and storage	Increasing knowledge of food preservation and canning techniques to respond to winter food insecurity	Increased inter-community trade in fruits and vegetables	None	Food preservation and canning equipment like glass jars or plastic bottles	Food preservation and canning in mountain communities of Central Tajikistan. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=178>
		Erratic rainfall	Landslides. Land degradation. Soil erosion.	Afforestation and/or reforestation	Combining the planting of trees and an innovative watering system	Cultivation of leguminous as intermediate crops, mulching, and use of compost as fertilizers	None	Fencing materials (cement poles or armature, wire netting), seedlings, plastic bottles for drop irrigation; labor Total = $1,700 per hectare	Reforestation/afforestation to prevent soil erosion and landslides in Tajikistan. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=179>
	Central	Floods Extreme cold	Damage to forests. Land degradation. Soil erosion.		Developing joint adaptation projects across communities. Dissemination of knowledge, education. Disaster risk management.	Higher risk awareness	None	Maps, papers, shovels, poles Total cost = $1,200	Community risk assessment and mapping in Central Tajikistan. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=181>

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Table A1.4 continued

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
B. EASTERN ASIA									
People's Republic of China (PRC)	Western and Northern PRC of Yellow River (loess highlands)	Floods	Soil erosion	Check dams; control soil erosion	Controlling soil erosion through a series of dams or dam-fields	Higher crop yields	Unable to treat the whole watershed for soil erosion particularly those occurring at the sides and top of the hills. Dam-fields suffer from salinization due to the high concentration of mineral salts in the water; upon evaporation, these salts were deposited on soil surface, which are harmful to the crops; no specific measure designed to check salinization in dam-fields.	Locally available materials like stones, clay, pebbles. Tools and understanding of soil and water flows.	Dam-fields in Northwest China. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=40>
	Western Sichuan, Tibetan Plateau	Extreme cold	Low survival and/or productivity of livestock	Appropriate livestock breeding	Livestock selection, for example, breeding jiulong (valley-type) and maiwa (plateau-type) yaks	Enhances yaks and knowledge on breeding	None	Yaks and knowledge on breeding	Ning Wu. 1998. Indigenous knowledge of yak breeding and cross-breeding among nomads in western Sichuan, China. *IK Monitor* 6 (1).
C. SOUTH ASIA									
Bangladesh	Jamalpur District	Floods	Loss of livelihoods	Livelihood diversification through integrated agriculture–aquaculture system	Establishing a community rice–fish farm	Increased community cooperation. Improved use of resources. Increased fish availability in the area. Increased income.	None	Training on organizational management. Fingerlings. Rice varieties for planting. Rice bran to feed fish. Bamboo, nets, tree branches, bushes. Shovels and other hand tools for digging. Making bunds and fish enclosures.	Dey, M. and M. Prein. 2005. Increased Income from Seasonally Flooded Rice Fields through Community-Based Fish Culture in Bangladesh and Viet Nam. *Plant Prod Sci* 8 (3). pp. 349–353. FAO. 2001. Integrated agriculture–aquaculture. A primer. *FAO Fisheries Technical Paper 407* K.M. Reshad Alam, M.C. Nandeesha, and Debasish Saha. Community Rice–Fish Farming in Bangladesh. Prein, M. and M.M. Dey. Rice and Fish Culture in Seasonally Flooded Ecosystems

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Table A1.4 *continued*

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
		Floods	Loss of crops. Loss of livelihoods.	Appropriate crop selection. Alternative cultivation methods or hydroponics.	Adjusting transplanted Aman rice cultivation to more frequent floods	Higher crop yields	None	Follow the flood schedule, establish early or late varieties of transplanted Aman (wet season rice) to avoid loss of crops due to variations in flood recurrence, take advantage of the early production of rice by growing additional crops.	Early or Late Transplanted Aman Rice Production in Bangladesh. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=194> Livelihood Adaptation to Climate Variability and Change in Drought-Prone Areas in Bangladesh – DP9/1-BGD/01/004/01/99, Asian Preparedness Centre, FAO of the UN, Establishment of field demonstrations for Kharif II season/June–October 2007.
Bangladesh		Floods	Waterlogging	Appropriate crop selection	Growing salient-resistant crops like Mele *(Cyperus tagetiformus)*	Growing salient-resilient reeds to earn additional income. Potential for micro-enterprise (sold raw or as woven mats).	Species selection critical in Mele cultivation to ensure favorable results.	Mele seeds. Waterlogged area. Labor.	Cultivation of Mele Reed in Bangladesh. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=82> ITDG-B. 2003. An Attempt on Application of Alternative Strategies for Community Based Flood Preparedness in South-Asia, Bangladesh.
	Southwestern but applicable to other flooded areas of the country	Floods	Waterlogging	Alternative cultivation methods like hydroponics	Growing of crops or vegetables in floating gardens	Subsistence food during flooding. Potential source of additional income.	None	Seeds and seedlings. Water hyacinth. Paddy straw. Labor.	Hydroponics in Bangladesh. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=80>

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Table A1.4 *continued*

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
	Southwestern coastal area	Floods	Low survival and/or productivity of poultry	Poultry breeding	Raising duck during monsoon. Diet diversification.	Food during monsoon. Cash generation for household needs.	None	Ducklings. Small shelter. Moderate technical knowledge. Access to waterbodies, vaccines. Small quantity of supplementary feed (locally available fish).	Mallik, F. 2005. Adaptation in Action. Community-Level Adaptation Techniques in the Context of the Southwestern Region of Bangladesh. ITDG-B 2003. An Attempt on Application of Alternative Strategies for Community-Based Flood Preparedness in South-Asia, Bangladesh.
Bangladesh		Floods – two types: Barsha – moderate flood; useful as it brings silt to the agricultural land; Bonna – high-intensity flood that affects livelihoods and assets	Loss of crops. Destruction of human settlements.	Appropriate crop selection. Disaster risk management.	Cultivation of fast growing crops. Repairing of houses and boats.	Maintained crop yield	None	Seed and seedlings. Boats. Materials for house repair or construction. Government and NGOs offer agricultural and extension support through soft loan, seed and fertilizer subsidies, etc.	Post-Flood Rehabilitation in Bangladesh. Case Study. <htpp://maindb.unfccc.int/public/adaptation> Ahsan Uddin Ahmed. 2003. Observed Adaptation During Moderate and High-Intensity Floods in Bangladesh.
		Rising sea levels	Loss of crops	Appropriate crop selection	Cultivating maize and fodder grass during dry season	Increased paddy yield. Livestock raising as alternative livelihood.	None	Seeds and seedlings. Livestock. Labor.	Hossen and Roy. 2005. Local Contributions to Operationalising the UNFCCC, CBD and UNCCD. Reducing Vulnerability to Climate Change in the Southwest Coastal Region of Bangladesh.

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Table A1.4 *continued*

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
	Northwestern district Barind tract called Varenda Tract; includes Dinajpur, Rangpur, Pabna, Rajshahi, Bogra, and Joypurhat districts of Rajshahi Division	Drought and/or aridity	Loss of crops. Water shortage.	Appropriate crop selection. Alternative cultivation methods.	Planting drought-resistant fruit trees to secure income. Mango gardening in Northwestern district. Jujube gardening in Barind tract.	Households with alternative source of livelihood. Increased farmer income. Ensures food security. Diet diversification.	3–4 year old mango trees produce a high shadow cover that threatens rice if used for intercropping, since the latter does not grow under the shadow. Under changing climatic conditions, increasing temperatures may induce synchronized maturity, which could lead to price drops.	Seedlings of fruit trees	Selvaraju, R., A.R. Subbiah, S. Baas, I, Juergens. 2006. Livelihood Adaptation to Climate Variability and Change in Drought-Prone Areas in Bangladesh – Case Study, implemented under the Project Improved Adaptive Capacity to Climate Change for Sustainable Livelihoods in the Agriculture Sector – DP9/1-BGD/01/004/01/99, Asian Preparedness Centre, FAO of the UN, Rome.
Bangladesh	Northwestern Barind tract	Drought and/or aridity	Water shortage	Improved cropping system through alternative cultivation method	Adjusting transplanted aman seeding practices to more frequent droughts. Adopt alternative seedbed methods for timely transplanting of seedlings; these methods may be mat-type seedlings in tray, dry seedbeds; dapog nurseries	Higher crop yields	None	Materials for seedbed. Rice seedlings.	Jensen, J.R., S.M.A. Mannan, S.M.N. Uddin. 1993. Irrigation requirement of transplanted monsoon rice in Bangladesh. *Agricultural Water Management.* 23: pp. 199–212.
		Drought and/or aridity	Water shortage	Rainwater harvesting	Using gutters and pipes to collect rooftop water	Improved health and sanitation. Boost local enterprise.	None	Gutters. Pipes. Storage tank.	UNEP DTIE. 2000. Rooftop Rainwater Harvesting for Domestic Water Supply. In Sourcebook of Alternative Technologies for Freshwater Augmentation in Some Countries in Asia, UNEP DTIE. <http://www.unep.or.jp/ietc/publications/techpublications/techpub-8e/rooftop.asp>

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Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
		Drought and/ or aridity	Land degradation	Alternative cultivation methods	Using organic matter to enhance soil	Higher crop yield	None	Homestead waste. Water hyacinth. Debris. Dung. Farm yard.	Two Chamber Farm Yard Manure/Water Hyacinth Compost Preparation in Bangladesh. UNFCCC case study. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=191> Amoding, A., N.R. Muzira, M.A Bekunda, and P.L. Woomer. 1999. Bioproductivity and decomposition of water hyacinth in Uganda. *African Crop Science Journal* 7: pp. 433–439.
		Drought and/ or aridity	Land degradation. Soil erosion.	Soil conservation. Livelihood diversification.	Home gardening as a means to climate-proofing farming	Increased farmer's income	None	Vegetable seeds. Seeds and/or seedlings of drought-tolerant tree and vegetable species. Backyard as garden.	Homestead Gardens in Bangladesh. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=192> Homestead food production—An effective integrated approach to improve food security among the vulnerable char dwellers in northern Bangladesh. *Homestead Food Production Bulletin* No. 4. Dhaka: Helen Keller International, Bangladesh.
Bhutan	Wangling, Jangbi, Phumzur villages in Trongsa District	Erratic rainfall	Loss of crops	Diet diversification	Harvesting wild vegetables, fruits, and tubers from the forest by the Monpas, a Bhutanese ethnic group	Ensured food security. Indigenous knowledge passed from generation to generation preserves this practice.	None	Knowledge about flora and fauna. Labor and skills for collecting wild edibles.	Harvesting Wild Foods in Bhutan. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=7> Centre for Bhutan Studies <http://www.bhutanstudies.org.bt/main/index.php0>

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Table A1.4 *continued*

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
	West central	Drought and/or aridity	Water shortage	Rainwater harvesting	Collecting, storing, and distributing water through a tank system	Vegetable production	None	Materials to construct water tanks, bamboo or polythene pipe for water distribution. Some maintenance is required periodically to ensure collection and equal distribution of water to the beneficiaries.	Water Storage Tanks in Bhutan. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=26>
		Drought and/or aridity	Loss of crops. Water shortage.	Sustainable water management	Using bamboo stems for drip irrigation during the dry season	Increase in crop yield	None	Bamboo and local labor for setting up the drip-irrigation system and filling the bamboo with water regularly during the dry period; bamboo needs to be replaced after 5 years or more	Drip Irrigation in Bhutan. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=21> Down to Earth 2003 <http://www.cseindia.org/dte-supplement/water-index.htm>
		Drought and/or aridity	Loss of crops	Alternative cultivation methods	Managing common pool resources	Preservation of traditional agriculture system practiced by small farmers	None	Labor. Seeds. Livestock. Access to forest resources.	Integrated Farming Systems in Bhutan. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=161> Sonam Tobgay. 2005. Small Farmers and the Food System in Bhutan, Agricultural Marketing Services, Ministry of Agriculture, Royal Government of Bhutan.

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Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
Himalayas		Drought and/or aridity	Water shortage. Soil erosion.	Rainwater harvesting Soil conservation	Controlling soil erosion and managing rainwater. Terracing. Field leveling. Ploughing. Sheet erosion control. Wind erosion control. Biofencing.	Higher crop yields		Stones, gravel and boulders. Grasses, bamboo, shrubs, and seabuckthorn (*Hippophae rhamnoides*). Shovels, tamping tools. Plough. Labor.	Verma, L.R. 1998. Soil and water management techniques. In Indigenous technology knowledge for watershed management in upper north-west Himalayas of India. *PWMTA Field Document No.* 15, Kathmandu.<http://www.fao.org/docrep/X5672E/x5672e03.htm>
India	Uttar Pradesh	Floods	Loss of crops	Appropriate crop selection	Breeding rice varieties in flood-prone areas	Higher crop yields. Ensured food security.		Agricultural expertise on flood-prone rice and collection methods. Rice seeds. Partnerships between scientists and farmers.	Maurya, D.M. 1997. Participatory Breeding, On-farm Seed Management and Genetic Resource Conservation Methodology <http://archive.idrc.ca/library/document/104582/maurya.html> Dwivedi, J.L. 1997. Conserving genetic resources and using diversity in flood-prone ecosystems in eastern India. <http://www.idrc.ca/en/ev-85297-201-1-DO_TOPIC.html>
	Himachal Pradesh	Erratic rainfall	Water shortage	Sustainable water management	Utilizing and distributing glacier runoff	Improved agricultural output and food security. Improved health.	If a similar system is intended to be set up, one has to pay due attention to water rights	Rocks Wood Tools Cement Pipes	Verma, L.R. 1998. Soil and water management techniques. In Indigenous technology knowledge for watershed management in upper north-west Himalayas of India, *PWMTA Field Document No. 15*, Kathmandu. <http://www.fao.org/docrep/X5672E/x5672e03.htm> Waterharvesting.org Kul Irrigation of the Trans-Himalaya. <http://www.rainwaterharvesting.org/methods/traditional/kuls.htm>

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Table A1.4 *continued*

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
	Several northeastern states	Erratic rainfall	Loss of crops	Appropriate crop selection	Domesticating indigenous varieties of cereals and fruit trees	Promotes local enterprises for women	None	Seeds and seedlings. Labor.	UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy. pl?id_project=79>
India	Himalayas	Erratic rainfall	Loss of crops	Alternative cultivation methods	Growing apricots, walnuts, grapes, and vegetables in the cold deserts. Farmer's practices to cultivate fruits and vegetables to ensure stable supply of vitamins. Root spreading of cabbage through use of tokhre (small wooden structure) for surface feeding of nutrient or moisture uptake. Mahotra, dhing, guchhi (mushroom) harvested in grasslands or forests for food and additional income. Localized greenhouse grape cultivation in Nubra valley. Apricot grafting. Fruiting walnuts.	Higher crop yield	None	Indigenous knowledge for recognizing mushroom species. Bricks. Knives or other cutting tools. Walnut and apricot trees.	Verma, L.R. 1998. Indigenous technology knowledge for watershed management in upper north–west Himalayas of India. *PWMTA Field Document No.* 15, Kathmandu: FAO. <http://www.fao.org/docrep/X5672E/x5672e00.htm>
		Erratic rainfall	Loss of crops	Appropriate crop selection in cold deserts	Rotational cropping. Seed selection.	Improved soil properties. Higher crop yields.	None	Seeds for appropriate species for intercropping. Wooden tools for spreading soil.	Verma, L.R. 1998. Indigenous technology knowledge for watershed management in upper north–west Himalayas of India. *PWMTA Field Document No.* 15, Kathmandu. FAO. <http://www.fao.org/docrep/X5672E/x5672e00.htm>

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Table A1.4 *continued*

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
India	Western Himalayas	Erratic rainfall	Loss of crops	Disaster risk management. Appropriate cropping practices.	Using meteorological indicators and animal behavior to predict rain such as visible spectrum around the sun and moon. Clouds and wind direction. Activities of various birds, animals, and insects. Crop performance. Condensation.	Possibility for reduced livelihood losses	As climate change occurs, these traditional forecasting indicators may change. Locals have to continue their observations and adjust their predictions accordingly to ensure that correct coping mechanisms will be applied	Indigenous forecasting knowledge	Indigenous Forecasting in Western Himalayas. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=46> Verma, L.R. 1998. Indigenous technology knowledge for watershed management in upper north–west Himalayas of India *PWMTA Field Document No.* 15. Kathmandu: FAO. <http://www.fao.org/docrep/X5672E/x5672e00.htm>
	Himalayas	Erratic rainfall	Water shortage	Rainwater harvesting	Using roofs, ponds, and tanks to harvest rain, dew, and fog water	Higher crop yields		Tools. Materials to build an irrigation system. Cement or pang grass to line storage areas.	Verma, L.R. 1998. Indigenous technology knowledge for watershed management in upper north-west Himalayas of India. *PWMTA Field Document No. 15*. Kathmandu: FAO. <http://www.fao.org/docrep/X5672E/x5672e00.htm>
	Himalayas	Erratic rainfall	Loss of crops	Appropriate crop selection	Rotational cropping. Seed selection.	Improved soil properties. Higher crop yields.		Seeds of appropriate species for intercropping. Wooden tools for spreading soil.	Verma, L.R. 1998. Indigenous technology knowledge for watershed management in upper north-west Himalayas of India. *PWMTA Field Document No. 15*, Kathmandu: FAO. <http://www.fao.org/docrep/X5672E/x5672e00.htm>

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Table A1.4 *continued*

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
India	Goa	Sea-level rise	Waterlogging	Integrated agriculture–aquaculture system	Balancing agriculture and fisheries through sluice gates. Application of khazan – traditionally community-managed integrated agriculture–aquaculture ecosystems.	Promotes symbiotic relationship between the rich and poor class through employment generation and labor sharing.	None	Agricultural land. Labor. Wood for shutters of sluice gates. Canoes and nets for fishing.	TERI–INTEREST Three case studies using different ecosystems: Traditional Aquaculture – Goa, Agriculture – Karnataka, Bamboo forests – Haryana. The Energy and Resources Institute. <http://www.teriin.org/teri-wr/projects/interestaqua.pdf>
		Drought and/ or aridity	Water shortage	Rainwater harvesting	Building anicuts (small and medium-sized dams) to serve as water reservoirs such as: supplementary irrigation during erratic monsoons. Groundwater recharge during very low water levels.	Increased crop yield. Sustainable supply of drinking water for cattle and people. Better hygiene – bathing of men and women.	None	Stone. Mud. Concrete or local materials to construct dam labor.	Narain, P., M. A. Khan, and G. Singh. 2005. Potential for water conservation and harvesting against drought in Rajasthan, India. *Working Paper 104* (Drought Series: Paper 7). Colombo, Sri Lanka: International Water Management Institute. Anicuts in India. UNFCCC case study. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=12>
	Himalayas	Erratic rain. Drought and/ or aridity	Land degradation	Nutrient management	Manure and ash application to increase soil fertility. Organic manure. Crop residue harvesting. Kitchen ash.	Improved soil properties. Higher crop yields.	None	Farm yard manure. Compost. Tools.	Verma, L.R. 1998. Indigenous technology knowledge for watershed management in upper north-west Himalayas of India. *PWMTA Field Document No. 15*, Kathmandu: FAO. <http://www.fao.org/docrep/X5672E/x5672e00.htm>

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Table A1.4 continued

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
India	Central Himalayas (northwest most border areas), Garhwal Region	Drought and/or aridity	Loss of crops	Diet diversification	Use of wild foods and medicinal plants by Bhotiya tribes (Tolchha, Marchha, Jadhs)	Improved health and nutrition	None	Local knowledge about plant resources	Maikhuri, R.K., Sunil Nautiyal, K.S. Rao, and R.L. Semwal. 2000. Indigenous knowledge of medicinal plants and wild edibles among three tribal subcommunities of the Central Himalayas, India. *IK Monitor* 8 (2). <http://web.archive.org/web/20041215132544/www.nuffic.nl/ciran/ikdm/8-2/maikhuri.html>
	Thar Desert	Drought and/or aridity	Water shortage	Rainwater harvesting	Building underground tanks (called *kunds*) for collecting and storing water	Improvements in health, i.e., reduced water-borne diseases, which are common in desert areas.	None	Lime plaster. Building materials. Gravel, pond silt, or charcoal ash. Wire mesh. Tools.	Rainwater harvesting. <http://www.rainwaterharvesting.org/methods/traditional/kunds.htm> Kunds in Thar Desert, India. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=57>
	Northeast	Drought and/or aridity	Loss of crops. Water shortage.	Sustainable water management	Using bamboo to transport stream and spring water to irrigate plantations by the Meghalaya tribal farmers	Higher crop yields	None	Bamboo for pipes and stakes. Tools. Local network for maintenance of the bamboo irrigation system.	Drip Irrigation in Northeast India. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=58>
	Andaman and Nicobar Islands	Drought and/or aridity	Loss of crops	Alternative cultivation method	Intercropping with banana and using plant residues	Higher crop yields	None	Seedlings. Plant residues.	Dr. A.K. Bandyopadhyay, Director (CARI) and Dr. G.S. Saha, Scientist (CIFA). Coping with heat and water shortages on the Andaman and Nicobar Islands, India. *Indigenous Knowledge and Development Monitor*. 7 (2). pp. 26–27. July 1999.

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Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
India	Andaman and Nicobar Island	Drought and/or aridity	Loss of crops	Appropriate crop selection	Selecting and storing rice, pulse and vegetable seeds	Selected seeds provide higher yields	None	Seeds and containers to store dried seeds. Leaves of Neem or Salamu plant to protect from insects. Cow dung.	A.K. Bandyopadhyay and G.S. Saha. 1998. Indigenous methods of seed selection and preservation on the Andaman Islands in India. *IK Monitor* 6 (1). <http://web.archive.org/web/20041215132629/www.nuffic.nl/ciran/ikdm/6-1/bandy.html>
	Gujarat	Drought and/or aridity	Water shortage	Rainwater harvesting	De-silting, cleaning, and deepening of ponds to collect rainwater	Increased crop yield. Reduced labor migration.	None	Plastic lining for ponds. Labor to dig and deepen wells and ponds.	Ponds in Gujarat, India. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=16>
	Maharashtra	Drought and/or aridity	Water shortage Soil erosion	Rainwater harvesting	Building ground barriers and shallow excavations through various barriers such as contour bunds, nalla bunds, check dams, gabions. Shallow excavations such as contour trenches, farm ponds, reservoirs in bedrock. Roof tops. Water recycling by using domestic waste water to irrigate kitchen gardens.	Improved food security and livelihoods. Increased understanding and educational opportunities for the community on water resource management.	None	Training on water harvesting and resource management. Expertise on hydrology and hydrogeology. Tools.	UNESCO, Conjunctive use of water resources in Deccan Trap. In UNESCO Best Practices on IK. <http://www.unesco.org/most/bpik13-2.htm> Sivanappan, R.K. 1997. Technologies for water harvesting and soil moisture conservation in small watersheds for small-scale irrigation. FAO.
India	Orissa	Drought and/or aridity	Loss of crops	Appropriate crop selection	Storing and exchanging rice varieties and medicinal plants	Higher crop yields. Ensured food security. Increase in knowledge of indigenous varieties. Higher biodiversity.	Communities and projects must ensure that vegetables, trees, and other plants promoted are suitable in the areas.	Seedlings. Knowledge on how and when to plant and preserve them. Farmers network. Storage facilities.	Seed Banks in Gujarat, India. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=59>

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Table A1.4 continued

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
		Drought and/ aridity	Water shortage	Rainwater harvesting	Water management practices including conservation, recycling, instilling, and maintaining tube wells	Better health and hygiene. Promotes cohesiveness within the communities. Acts as social safety nets in times of disaster.	None	Human resources. Materials for construction of tube wells.	Sanjoy Bandyopadhyay. 2003. Coping strategy and vulnerability reduction to climate extremes. Presentation at the expert workshop on local coping strategies and technologies for adaptation, Delhi, India. <http://unfccc.int/files/meetings/workshops/other_meetings/application/pdf/sanjoy.pdf>
	Rajasthan	Drought and/ or aridity	Water shortage	Rainwater harvesting	Harvesting water and recharging groundwater through earthen check dams (johads)	Higher crop yields. Increased forest coverage. Associated availability of fuelwood and tree leaves for fodder.	None	Concrete. Soil. Shovels. Buckets. Labor.	Johads in Rajasthran. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=41>
		Drought and/ or aridity	Water shortage	Rainwater harvesting	Building contour bunds (contour ridges) to collect water runoff	Reclamation of degraded land	None	Stone. Mud. Concrete or other local materials to construct bunds. Labor.	Bunds in Rajasthan, India. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=9>
		Drought and/ or aridity	Loss of crops	Appropriate crop selection	Cultivating Bajra millet in arid regions (millet can be cultivated in sandy and under rainfed conditions)	Food security	None	Seeds and seedlings. Labor.	Bajra Millet in Rajasthan, India. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=13>
India	Rajasthan	Drought and/ or aridity	Loss of crops	Appropriate crop selection. Income diversification.	Growing "Sona Mukhi" (*Cassia angustifolia*) as medicinal cash crop	Cash income	None	Sona-mukhi seedlings. Labor. Access to markets.	Brook Bhagat. 2002. Spitting in the wind—Combating Desertification in the Great Indian Desert. <http://ecoworld.com/Home/Articles2.cfm?TID=323>

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Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
		Drought and/or aridity	Land degradation	Nutrient management	Using worms to process organic waste	Increase in crop yield. Reclamation of degraded land.	None	Organic waste. Earthworm. Labor.	Dr. Henamgee Jambhekar, Vermiculture in India. <http://fadr.msu.ru/rodale/agsieve/txt/vol7/art3.html>
	Tamil Nadu	Drought and/or aridity	Water shortage	Sustainable water management	Improving wells and irrigation	Improved agricultural outputs. Improved livelihoods.	None	Tools. Pipes. Lime mortar. Technical expertise for siting, construction, and maintenance measures.	Manoharan, M. and S. Kombairaju. 1995. ITK suits transported sandy soils. *IK Monitor* 3 (1). <http://web.archive.org/web/20041217210736/www.nuffic.nl/ciran/ikdm/3-1/articles/manoharan.html>
		Drought and/or aridity	Soil erosion	Soil conservation	Applying soil amendments to improve soil properties	Improved agricultural outputs. Improved livelihoods.	Possible salinization	Tank silt. Machinery and tools. Pipes. Lime mortar. Technical expertise for siting, construction and maintenance measures.	Manoharan, M. and S. Kombairaju. 1995. ITK suits transported sandy soils. *IK Monitor* 3 (1). <http://web.archive.org/web/20041217210736/www.nuffic.nl/ciran/ikdm/3-1/articles/manoharan.html> John Butterworth, Barbara Adolph, and Suresh Reddy. 2003. How farmers manage soil fertility: A guide to support innovation and livelihoods. Chapter 4 Soil amendments. Hyderabad: Andhra Pradesh Rural Livelihoods Project. Chatham: Natural Resources Institute.
		Drought and/or aridity	Water shortage. Soil erosion.	Soil conservation	Coping with wind erosion through application of farm yard manure. Use of coconut. Planting drumstick species (Jafna or Yalpanam Murungai).	Higher yields. Additional income.	None	Farm yard manure. Coconut seedlings less than six months old. Banana plants. 10% dust of benzene hexachloride. Diammonian phosphate complex. Potash mixture. Stem cuttings of 2.5–3 feet of drumstick. Pruning shears or knives.	Manoharan, M. and S. Kombairaju. 1995. ITK suits transported sandy soils. *IK Monitor* 3 (1). <http://web.archive.org/web/20041217210736/www.nuffic.nl/ciran/ikdm/3-1/articles/manoharan.html>

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Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
India	Tamil Nadu	Drought and/or aridity	Loss of crops	Post-harvest management	Threshing, winnowing, cleaning, and drying for dryland crops.	Improved nutrition. Recognition of women farmers for their knowledge and practice.	Important to consider local humidity and pests for replication of this post-harvest technology	Labor. Tools and skills required are simple.	Parvathi, S., K. Chandrakandan, and C. Karthikeyan. 2000. Women and dryland post-harvesting practices in Tamil Nadu, India. *IK Monitor* 8 (1). <http://web.archive.org/web/20041204232430/www.nuffic.nl/ciran/ikdm/8-1/parvathi.html>
	Uttar Pradesh	Drought and/or aridity	Land degradation	Nutrient management	Increasing soil fertility through gypsum, manure, and compost applications	Reclamation of degraded soil. Increase in crop yield.	None	Labor. Seeds and seedlings. Livestock for manure. Organic pesticides such as Neem.	Department of Agriculture and Cooperation. 2005. Uttar Pradesh Sodic Land Reclamation Project with World Bank Assistance (Phase II), Indian Ministry of Agriculture. <http://agricoop.nic.in/PolicyIncentives/nrmd.htm>
Nepal		Extreme cold	Loss of crops	Post-harvest management	Processing green, leafy vegetables	Promotes local enterprise for mountain women	None	Green, leafy vegetables. Wooden stick to beat the vegetables. Containers to store vegetables.	Narayan P. Manandhar. 1998. The preparation of gundruk in Nepal. A sustainable rural industry? *IK Monitor* 6 (3). <http://web.archive.org/web/20041215133649/www.nuffic.nl/ciran/ikdm/6-3/manandh.html>
Pakistan	Sindh	Drought and/or aridity	Water shortage	Sustainable water management	Building laths at different levels to irrigate fields	Increase in crop yield	Possible land degradation as some areas are no longer flooded	Community water management system. Machinery to build canals and move earth.	Spate Irrigation in Sidh, Pakistan. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=69>

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Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
Sri Lanka		Drought and/ or aridity	Water shortage	Rainwater harvesting (cascading tanks)	Using stored water efficiently	Increased crop yield	Overexploitation of tanks and poor management disturb water use within watersheds	Bricks and cement. Tools. Labor.	Tikiri Nimal Herath. 2001. Farmer's knowledge of water management methods in the dry zone of Sri Lanka. *IK Monitor* 9 (3). <http://web.archive.org/web/20040719195342/www.nuffic.nl/pdf/ciran/ikdm0111.pdf>
		Drought and/ or aridity	Water shortage	Rainwater harvesting	Managing water by women	Improved health through clean water supplies. Improved food security. Diversified diets.	None	Tanks. Pots. *Styrclinos potatorum* seeds. Training or public awareness on water conservation and/or efficiency.	R.K. Ulluwishewa. 1994. Women's indigenous knowledge of water management in Sri Lanka. *IK Monitor* 2 (3). <http://web.archive.org/web/20041218040330/www.nuffic.nl/ciran/ikdm/2-3/articles/ulluwishewa.html>
	Anuradhapura District	Drought and/ or aridity	Water shortage	Sustainable water management	Distributing the work of maintaining and repairing small-scale irrigation systems (a practice known as *pangu*)	Improved crop yield	None	Tools and labor. Community organization.	Pangu Practice in Sri Lanka. www.unesco.org/most /bpik22.htm>
		Drought and/ or aridity	Loss of crops	Alternative cultivation methods	Zero-tillage paddy cultivation (Nawa Kekulama)	Increased crop yield	None	Labor for the paddy cultivation	G.K.Upawansa. 1997. New Kekulam rice cultivation: A practical and scientific ecological approach. *LEISA Magazine*, 13, Rebuilding Lost Soil Fertility.
		Drought and/ or aridity	Loss of crops	Land redistribution	Temporary redistribution of private fields (bethma practice) covering plots of land among shareholders (being paddy landowners) in the command area of a tank (water reservoir) during drought.	Higher crop yields	None	Some leadership to prevent and/or solve conflicts and to ensure that the bethma practice functions well.	UNESCO, The bethma practice: Promoting the temporary redistribution of lands during drought periods. UNESCO Best practices on IK. www.unesco.org/most/bpik21.htm
Sri Lanka		Drought and/ or aridity	Loss of crops	Pest control	Controlling weed growth through dry straw in paddy fields	Increased crop yields	None	Paddy seeds. Banana plant. Labor.	Control of Weed Growth in Sri Lanka. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/public/adaptation/adaptation_casestudy.pl?id_project=30>

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Table A1.4 continued

Subregion and Country	Local Area	Natural Disaster	Impacts	Adaptation Action	Local Coping Strategies	Non-Climate Benefits	Potential Maladaptation	Resources Required	Source
D. SOUTHEAST ASIA									
Indonesia	West Java	Drough and/ or aridity. Floods.	Loss of crops	Alternative cultivation methods	Growing fish on huma (dry swidden fields) and sawah (wet fields)	Generation of cash income	None	Labor. Paddy fields. Paddy seeds or seedlings. Fish or fingerlings.	FAO. 2001. Integrated agriculture-aquaculture. A primer. *FAO Fisheries Technical Paper* 407. www.fao.org/docrep/005 /y1187e/y1187e00.htm
Timor		Erratic rainfall. Storms.	Loss of crops	Appropriate crop selection	Strategies for seed selecting and planting to cope with disasters	Reduced agricultural losses. Improved food security. Increased biodiversity.	None	Seeds variety. Understanding of breeding and weather forecasting.	Johan Kieft. 2001. Indigenous variety development in food crops strategies on Timor. *IK Monitor* 9 (2). <http://web.archive.org/ web/20041221071223/www .nuffic.nl/ciran/ikdm/9-2/kieft. html>
E. GREATER MEKONG SUBREGION									
Lao PDR	Attapeu Province	Floods	Loss of crops	Alternative cultivation methods. Diet diversification.	Diversifying rice-based diets during flood season	Improved health from diversified diets	Prolonged food shortages threaten wetland and forest resources	Fishing equipment and expertise	Meusch, E., J. Yhoung-Aree, R. Friend, and S.J. Funge-Smith. 2003. The role and nutritional value of aquatic resources in the livelihoods of rural people – A participatory assessment in Attapeu Province, Lao PDR. FAO Regional Office Asia and the Pacific, Bangkok, Thailand, Publication No. 2003/11.
Mekong Delta		Floods. Sea-level rise. Storms.	Loss of crops. Loss of land. Damage to human settlements.	Disaster risk management	Building forecasting capacity and adaptation strategy				Building Forecasting Capacity and Adaptation Strategy in the Mekong Delta. UNFCCC database on local coping strategies. <http://maindb.unfccc.int/ public/adaptation/ adaptation_casestudy. pl?id_project=197>

CARE = Cooperative for Assistance and Relief Everywhere; CARI = Central Agricultural Research Institute; CBD = Convention on Biological Diversity; CIFA = Central Institute of Freshwater Aquaculture; FAO = Food and Agriculture Organization; IK = Indigenous Knowledge; ITDG-B = Intermediate Technology Development Group-Bangladesh; ITK = Indigenous Technical Knowledge; IWMI = International Water Management Institute; Lao PDR = Lao People's Democratic Republic; NGO = nongovernment organization; PWMTA = Participatory Watershed Management Training in Asia; TERI-INTEREST = The Energy and Resources Institute-Interactions between Environment, Society and Technology; UN = United Nations; UNCCD = United Nations Convention to Combat Desertification; UNEP = United Nations Environment Programme; UNESCO = United Nations Educational, Scientific and Cultural Organization; UNFCCC = United Nations Framework Convention on Climate Change.

Appendix 2: List of ADB's Developing Member Countries, by Subregion

Region	Countries
A. Central Asia	Armenia
	Azerbaijan
	Georgia
	Kazakhstan
	Kyrgyz Republic
	Tajikistan
	Turkmenistan
	Uzbekistan
B. East Asia	China, People's Republic of
	Hong Kong, China*
	Korea, Republic of*
	Mongolia
	Taipei,China*
C. South Asia	Afghanistan
	Bangladesh
	Bhutan
	India
	Maldives
	Nepal
	Pakistan
	Sri Lanka
D. Southeast Asia	Cambodia
	Indonesia
	Lao People's Democratic Republic
	Malaysia
	Myanmar
	Philippines
	Singapore*
	Thailand
	Viet Nam

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Appendix 2 continued

Region	Countries
E. The Pacific	Cook Islands
	Fiji Islands
	Kiribati
	Marshall Islands
	Micronesia, Federated States of
	Nauru
	Palau
	Papua New Guinea
	Samoa
	Solomon Islands
	Timor-Leste
	Tonga
	Tuvalu
	Vanuatu
Total DMCs	44

DMCs = developing member countries.

* Non-borrowing regional members.

Source of South Asia region composition: ADB. 2001. *Reorganization of the Asian Development Bank*. Manila. Note, however, that ADB regional groupings were realigned in 2006, resulting in the transfer of Afghanistan and Pakistan to the Central and West Asia Regional Department. Please see: ADB. 2006. *Realignment of Regional Departments.* Manila.

Appendix 3: List of Regional or Subregional Groupings Involving Countries in Asia and the Pacific

Subregions	Member Countries
1. Greater Mekong Subregion (GMS)	1. Cambodia 2. China, People's Republic of (only Yunnan and Guangxi Zhuang Autonomous Region) 3. Lao People's Democratic Republic 4. Myanmar 5. Thailand 6. Viet Nam
2. Central Asia Regional Economic Cooperation (CAREC)	1. Afghanistan 2. Azerbaijan 3. China, People's Republic of 4. Kazakhstan 5. Kyrgyz Republic 6. Mongolia 7. Tajikistan 8. Uzbekistan
3. South Asia Subregional Economic Cooperation (SASEC)	1. Bangladesh 2. Bhutan 3. India 4. Nepal
4. Indonesia-Malaysia-Thailand Growth Triangle (IMT-GT)	1. Indonesia 2. Malaysia 3. Thailand
5. Brunei Darussalam-Indonesia-Malaysia-Philippines East ASEAN Growth Area (BIMP-EAGA)	1. Brunei Darussalam 2. Indonesia 3. Malaysia 4. Philippines
6. South Asian Association for Regional Cooperation (SAARC)	1. Bangladesh 2. Bhutan 3. India 4. Maldives 5. Nepal 6. Pakistan 7. Sri Lanka

continued on next page

Appendix 3 continued

Subregions	Member Countries
7. Subregional Economic Cooperation in South and Central Asia (SECSCA)	1. Afghanistan 2. Pakistan 3. Tajikistan 4. Turkmenistan 5. Uzbekistan
8. Shanghai Cooperation Organization (SCO)	1. China, People's Republic of 2. Kazakhstan 3. Kyrgyz Republic 4. Tajikistan 5. Uzbekistan
9. South Asia Growth Quadrangle (SAGQ)	1. Bangladesh 2. Bhutan 3. India 4. Nepal
10. Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC)	1. Bangladesh 2. Bhutan 3. India 4. Myanmar 5. Nepal 6. Sri Lanka 7. Thailand
11. Pacific Plan	1. Australia 2. Cook islands 3. Fiji Islands 4. Kiribati 5. Marshall Islands 6. Micronesia, Federated States of 7. Nauru 8. New Zealand 9. Nieu 10. Palau 11. Papua New Guinea 12. Samoa 13. Solomon Islands 14. Tonga 15. Tuvalu 16. Vanuatu

continued on next page

Appendix 3 continued

Subregions	Member Countries
12. Asia Cooperation Dialogue (ACD)	1. Bangladesh 2. Bhutan 3. Brunei Darussalam 4. Cambodia 5. China, People's Republic of 6. India 7. Indonesia 8. Japan 9. Kazakhstan 10. Korea, Republic of 11. Lao People's Democratic Republic 12. Malaysia 13. Mongolia 14. Myanmar 15. Pakistan 16. Philippines 17. Singapore 18. Sri Lanka 19. Tajikistan 20. Thailand 21. Uzbekistan 22. Viet nam
13. Ayeyawady-Chao Phraya-Mekong Economic Cooperation Strategy (ACMECS)	1. Cambodia 2. Lao People's Democratic Republic 3. Myanmar 4. Thailand 5. Viet Nam
14. Asia-Pacific Economic Cooperation (APEC)	1. Australia 2. Brunei Darussalam 3. China, People's Republic of 4. Hongkong, China 5. Indonesia 6. Japan 7. Korea, Republic of 8. Malaysia 9. New Zealand 10. Papua New Guinea 11. Philippines 12. Singapore 13. Taipei,China

continued on next page

Appendix 3 continued

Subregions	Member Countries
	14. Thailand 15. Viet Nam
15. Association of Southeast Asian Nations (ASEAN)	1. Brunei Darussalam 2. Cambodia 3. Indonesia 4. Lao People's Democratic Republic 5. Malaysia 6. Myanmar 7. Philippines 8. Singapore 9. Thailand 10. Viet Nam
16. ASEAN plus People's Republic of China, Japan, and Republic of Korea (ASEAN + 3)	1. Brunei Darussalam 2. Cambodia 3. China, People's Republic of 4. Indonesia 5. Japan 6. Korea, Republic of 7. Lao People's Democratic Republic 8. Malaysia 9. Myanmar 10. Philippines 11. Singapore 12. Thailand 13. Viet Nam
17. Asia–Europe Meeting (ASEM)	1. Brunei Darussalam 2. Cambodia 3. China, People's Republic of 4. India 5. Indonesia 6. Japan 7. Korea, Republic of 8. Lao People's Democratic Republic 9. Malaysia 10. Mongolia 11. Myanmar 12. Pakistan 13. Philippines 14. Singapore 15. Thailand 16. Viet Nam

Appendix 4: Survey of Climate Change Impact Models

Models assessing the impacts of climate change on agriculture have been placed under three categories: agronomic-economic simulations, agroecological zone analysis, and Ricardian cross-sectional analyses (Mendelsohn and Dinar 1999). The agronomic-economic simulations use crop models that contain data from carefully controlled experiments, which vary climate and carbon dioxide levels to simulate different climate change scenarios. Economic impacts are then estimated by inputting yield results from the experiments into economic models. Agroecological zone analyses assign crops to specific agroecological zones, and then determine expected yields as well as the impacts that climate change will have on those yields. Ricardian models measure the economic performance of farms in different climatic regions to determine the effect of changes in climate on this performance. In addition to the basic differences arising from the structure of these models, additional variance in results can be observed due to the extent of farmer adaptation and the carbon dioxide (CO_2) fertilization effect on crop yields included in each.

Agronomic-Economic Simulations

Agronomic-economic modeling consists of a crop model that uses output results of experiments that are controlled for climate and CO_2 concentrations. Crop model results are then inputted into an economic model to determine crop prices, outputs and net revenues. Mendelsohn and Dinar (1999) point out that most of these models generally focus on a small selection of crops (generally grains) since expansive experimentation is required for each of the crops to be included in the model.

Parry et al. (1999), Parry et al. (2004), and Lin et al. (2005) use crop models to assess the impact of global warming on yields. Parry et al. (1999) and Parry et al. (2004) use the International Benchmark Sites Network for Agrotechnology Transfer-International Consortium for Agricultural Systems Applications or IBSNAT-ICASA model family to estimate yield responses to temperature and CO_2 level, including Crop Environment Resource Synthesis or CERES-Wheat, CERES-Rice, CERES-Maize, and SOYGRO (for soybean). In Parry et al. (1999), simulations were specified and validated at 124 sites in 18 countries under a number of climate change scenarios. Those simulations were then aggregated into agroclimatic regions to statistically derive regional yield response functions for use in an integrated assessment model. These functions took the form of multiple linear and quadratic regression models to reflect the combined changes in temperature, precipitation, and CO_2 concentration (Zhu 2007).

The same approach was followed by Parry et al. (2004) in evaluating a broader range of climate change scenarios. According to the authors, projected changes in yield were calculated using transfer functions derived from crop model simulations with observed climate data and projected climate change scenarios. The impacts of climate change were estimated for scenarios developed from the Hadley Centre Coupled Model, version 3 (HadCM3) global climate model under the Intergovernmental Panel for Climate Change-Special Report on Emissions Scenarios or IPCC SRES A1F1, A2, B1, and B2 scenarios. The authors used production functions that incorporate: (i) crop responses to changes in temperature and precipitation with the current management; (ii) crop responses to temperature and precipitation with farm-level and regional adjustments; and (iii) crop responses to carbon dioxide. Yield responses to combined changes in temperature and precipitation were taken from over 50 previously published and unpublished regional climate impact studies. Farm-level adaptation strategies included changes in planting date and application of additional fertilization and irrigation in the current irrigated areas. Finally, the basic linked system was used to evaluate consequent changes in global cereal production, cereal prices, and the number of people at risk from hunger. The impacts of climate change on arable land were not considered although the upper limit of available arable land (based on historical climate conditions) for expansion of crop production was considered based on the FAO database (Zhu 2007).

According to Zhu (2007), the advantages of crop simulation models over statistical models are that they can simultaneously consider multiple factors that affect crop growth and that the models are based on the physiological process of crop growth. Process-based crop models are more robust for extrapolation than purely statistically-based models. When statistical models are applied to a different environment, the parameters need to be re-estimated (calibrated), and usually more concerns about the model structure or the functional forms of model equations emerge. However, crop models also need to be calibrated against experimental data, which might be a problem when applied to significantly different environmental conditions, particularly in global assessments (Zhu 2007). A criticism of the agronomic studies is that they fail to account for adaptations that farmers continuously undertake and, therefore, possibly overestimate the negative impacts of climate change (Kurukulasuriya and Ajwad 2007).

Agroecological Zone Analysis

Agroecological zone (AEZ) models assign particular crops to certain agroecological zones, and then estimate yields for the different zones. The model reacts to changes in climate by altering both the agroecological zones and the crops being produced in the zones. In this way, the models can estimate the impact of climate change on crop yields. As in the agronomic-economic models, these results can then be applied to economic models to determine any supply or market impacts (Mendelsohn and Dinar 1999). According to Fischer et al. (2002), the AEZ methodology provides a standardized framework for the characterization of climate, soil, and terrain conditions relevant to agricultural production. Crop modeling and environmental matching procedures are used to identify crop-specific limitations of prevailing climate, soil, and terrain resources, under assumed levels of inputs and management conditions (Fischer et al. 2002). As a result, maximum potential and agronomically attainable (potential) crop yields for basic land resources units are provided.

The Global Agroecological Zones project and associated climate change studies undertaken by the Food and Agricultural Organization of the United Nations (FAO) and the International Institute for Applied System Analysis (IIASA) provide a comprehensive assessment of climate change impacts on crop areas on a global scale (see Fischer et al. 2001, 2002; Zhu 2007). An agroecological zone study indicated that the magnitude of temperature increase and change in rainfall amount would affect the projected area suitable for cereal production (Fischer et al. 2001). At a global level, the amount of cultivable land was found to increase with a 2°C increase in temperature and no change in rainfall amounts. A 3°C increase and no change in rainfall amounts, however, led to a decline in the size of cultivable rainfed land compared to the 2°C increase scenario. Additional results showed that with adaptation of crop calendars, switching crop types, and yield increases due to the CO_2 fertilization effect incorporated into the model, climate change was found to benefit developed countries more than developing countries when allowing for one rainfed crop per year, multi-crop rainfed production or irrigated production.

Ricardian Models

Ricardian models use a cross-sectional approach to analyze the impacts of climate change and other factors on land values and farm revenues (Mendelsohn, Nordhaus, and Shaw 1994). This type of model differs from the two discussed previously in that it incorporates farmers' ability to adjust the inputs or technology used to adapt to a warmer climate into the model. Hence, results from Ricardian models have generally shown a more positive outlook for future agricultural production than the agronomic-economic and agroecological models. The inability to control the experiments across farms is one disadvantage of this type of model compared to the other model types (Mendelsohn and Dinar 1999). Some other criticisms that have been raised against the Ricardian method is that it might overestimate benefits and that it uses constant output and other input prices (Kurukulasuriya and Ajwad 2007).

Seo, Mendelsohn, and Munasinghe (2005) and Kurukulasuriya and Ajwad (2007) use the Ricardian method to estimate the impacts of climate change on agricultural net revenue in Sri Lanka in different climate zones. The model captures adaptation implicitly by comparing net outcomes for farmers facing different zones. It is assumed that farmers maximize net revenues per hectare. Therefore, given household preferences and endowments, farmers will choose the best adaptation strategy available. The Ricardian model regresses net revenue on climate and other explanatory variables. This analysis—cross-sectional observation across different climates—can then reveal climate sensitivity of farms. In both studies, several General Circulation Model (GCM) scenarios were used to project impacts of climate change on agricultural income.

Cline (2007) assesses impacts of climate change on agriculture at national or subnational levels based on two model frameworks: Ricardian models and crop models. Cline's study was based on the idea of model averaging and ensemble forecasting. In this methodology, instead of selecting a "best" model, the modeler can combine the predictions of different candidate models to obtain a more robust prediction. This practice has become popular in recent years and is considered a promising method for dealing with the uncertainty in the specifications of model structure. The author arrived at preferred estimates by synthesizing the two sets of estimates and using them as a basis for new estimates. The first—the Ricardian cross-section models—relates agricultural capacity statistically to temperature and precipitation on the basis of statistical estimates from farm survey or county-level data across climatic zones (Cline 2007). Studies are available for the United States, Canada, many countries in Africa, countries in Latin America, and India.[19] The author applied these country-specific models to estimate impacts in countries accounting for 35% of global agricultural output and about half of the number of countries. In countries where such studies are not available, the author applied the Mendelsohn–Schlesinger Ricardian model for the United States for climate estimates. In these cases, however, the weighting given to Ricardian estimates is reduced and weighting of crop models is increased.
The second model framework is based on crop

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[19] Mendelsohn and Schlesinger, 1999 (United States); Reinsborough, 2003 (Canada); Kurukulasuriya, 2006 (Africa); World Bank farm surveys (Latin America); and Mendelsohn, Dinar, and Sanghi, 2001 (India).

models and consists of region-specific calculations synthesized from estimates by agricultural scientists in 18 countries as applied to alternative GCM projections of climate scenarios. Crop model estimates are from Rosenzweig and Iglesias (2006) (Cline 2007).

Climate Change Impacts on Agriculture in Asia and the Pacific According to Global Assessments

If the CO_2 beneficial effects are fully realized, agriculture in East Asia is likely to benefit from climate change while South Asia agriculture might still be harmed.

Climate change will adversely impact agriculture in all regions in Asia if the beneficial effects of CO_2 on plants are not considered (Parry et al. 2004; Cline 2007). By the 2080s, and if those effects are fully realized, crops in South Asia are still likely to be harmed (Parry et al. 2004; Cline 2007). For East Asia, at the regional level, there seems to be some consensus that CO_2 effects will outweigh the adverse effects of global warming by the 2080s (Parry et al. 2004; Cline 2007; Fischer, Shah, and van Velthuizen 2002).

Global assessment studies disagree about the future impacts of climate change on agriculture in Southeast Asia, Central Asia, and in the Pacific Island countries. Therefore, more research should be done on the matter.

For Southeast Asia, Central Asia, and also the Pacific Island countries—there is either substantial disagreement among scenarios on likely outcomes or there is not enough research on the matter (Cline 2007; Parry et al. 2004; Fischer, Shah, and van Velthuizen 2002).

A recent study projects losses in agricultural production capacity for all Southeast Asia countries by 2080, even if CO_2 fertilization is considered (no data are available for Lao People's Democratic Republic and Singapore) (Cline 2007). Another study, however, predicts small positive and negative variations in crop yields depending on scenario and country (Parry et al. 2004).

According to some studies, countries in Central Asia are likely to increase their agricultural production capacity (Cline 2007; Fischer et al. 2002). According to another study, however, Central Asia is expected to lose between 5%–10% in crop yield potential, even considering CO_2 fertilization effects (Parry et al. 2004). Therefore, it is reasonable to say that it is uncertain whether growing conditions will deteriorate or improve in Central Asia as a result of climate change (Pandya-Lorch and Rosegrant 2000), and more research will be needed on this topic.

More research should also be done to assess the impact of climate change on agriculture in the Pacific region.

Studies show that rice and wheat in Southeast Asia and wheat in South Asia—important crops for food-insecure populations in those regions—will be adversely impacted by climate change

Projections from modeling studies show that crops important for food-insecure populations in South and Southeast Asia will be negatively impacted by climate change (Fischer et al. 2005; Lobell et al. 2008). Simulations project that the regions of South and Southeast Asia will face the largest decreases in wheat production in the world (20%–75% and 10%–95% declines, respectively), and Southeast Asia will have substantial decreases in attainable rice production (Fischer, Shah, and Van Velthuizen 2002; Fischer et al. 2005; Lobell et al. 2008).

Without sufficient adaptation measures, several South Asian crops important to large food-insecure populations will be affected by climate change. A study that uses 20 GCMs to analyze climate risk in 12 food-insecure regions shows that 95% of climate models agree that by 2030, wheat crops in South Asia will be harmed by climate change. At least half of the models also project production loss in rapeseed crops greater than 5% (Lobell et al. 2008).

For Southeast Asia, there seems to be consensus that important crops for food security in the region will be negatively affected by climate change, despite disagreements among modeling studies about impacts on agriculture as a whole (Fischer, Shah, and Van Velthuizen 2002; Lobell et al. 2008). One study shows that 95% of models (out of a total of 20 GCMs) project losses in rice yields in Southeast Asia as a result of climate change (Lobell et al. 2008). This finding is a reason for concern, as the region is one of the most dependent on rice for daily calories in the world (Nguyen 2005).

Asia and the Pacific is the most disaster-afflicted region in the world. If climate extremes are taken into account, climate change impacts on the agriculture sector are likely to be much more severe, including in East Asia, a region highly prone to droughts and floods.

In Asia, a higher incidence of climate extreme events is a particular reason for concern because statistics for 1975–2006 show Asia as the most disaster-afflicted region in the world; Asia accounted for about 89% of people affected by disasters worldwide, 57% of total fatalities, and 44% of total economic damage. In that period, 75% of all natural disasters in Asia were hydro-meteorological disasters (Sanker, Nakano, and Shiomi 2007). Pacific Island countries have also faced substantial economic losses as a result of natural disasters in recent decades. In the 1990s, the cost of extreme events in the region was estimated to exceed $1 billion.

In one example of how climate extremes affect the agriculture sector, between 1978 and 2003, the average annual drought-affected area in the People's Republic of China (PRC) was estimated to be 14 million hectares (ha), with an estimated direct economic cost of 0.5%–3.3% of agriculture sector GDP (Pandey et al. 2007). During drought years in the period 1970–2002, the ratio of loss to average value of total production was 3% in southern PRC, 10% in northeast Thailand, and 36% in eastern India (in the PRC and Thailand, values were estimated only for rice; in India, values accounted for rice and non-rice crops) (Pandey et al. 2007). In absolute terms, production loss in India was estimated at $856 million.

The dramatic consequences of floods can be seen in countries such as Bangladesh, where annual floods inundate about 20% of the country's area and up to 70% during extreme flood events. The increase in the frequency of natural disasters in Bangladesh has led not only to loss of land directly to the sea, but also to deposits of large amounts of sand and salt on agricultural land as a result of river and coastal flooding. These deposits have led to the abandonment of land in some regions (Ansorg and Donelly 2008).

Therefore, a higher incidence of floods and droughts in Asia and the Pacific will likely have catastrophic consequences for the agriculture sector as well as other sectors.

Low-lying areas in South Asia, Southeast Asia, and the Pacific Islands are highly vulnerable to sea-level rise. Coastal populations in the PRC will also be affected.

The low-lying river deltas of Bangladesh, the PRC, India, Viet Nam, and the small island states in the Pacific face the biggest risk of coastal inundation, soil erosion, displacement of communities, loss of agricultural land, intrusion of saline waters into surface and groundwater, and other consequences of sea-level rise (Arnell et al. 2002; Preston et al. 2006; Cruz et al. 2007).

Therefore, countries in South Asia, Southeast Asia, and the Pacific Islands are highly vulnerable to sea-level rise. Under a conservative sea-level rise scenario of 40 centimeters between today and the end of the 21st century, the number of people facing floods in coastal areas will rise annually from 13 million to 94 million, with 60% of this increase occurring in South Asia (coasts of Bangladesh, India, Myanmar, Pakistan, and Sri Lanka) and 20% in Southeast Asia (coasts of Indonesia, the Philippines, Thailand, and Viet Nam) (Cruz et al. 2007).

Appendix 5: IFPRI's Climate Change Modeling Framework

Approach

The International Food Policy Research Institute (IFPRI) implemented this research through an intensive desk study—compiling and critically synthesizing and analyzing existing analyses, secondary data, case studies, and information on climate change, agriculture, and other relevant literature from a large variety of sources. Quantitative analyses supplemented the desk study by applying a modeling system linking several models that provide scenarios of the important impacts of climate change on agriculture up to 2050 with a methodology for assessing adaptation costs. The modeling results are compared with the results from the comprehensive synthesis of the existing climate change impact models.

Modeling Overview

General equilibrium models generally divide the world into 15 to 30 regions with very limited disaggregation at the country or within country scale. Partial equilibrium models generally have a greater level of detail on specific sectors—here agriculture—but rely on economic relationships, neglecting some or all local biophysical settings. However, in the real world, field-level production decisions made by farmers are influenced by variables that include relatively unchanging geophysical variables such as elevation, slope, and soil characteristics; climate variables of precipitation, temperature, and available solar radiation; and economic variables such as prices, property rights, and social infrastructure.

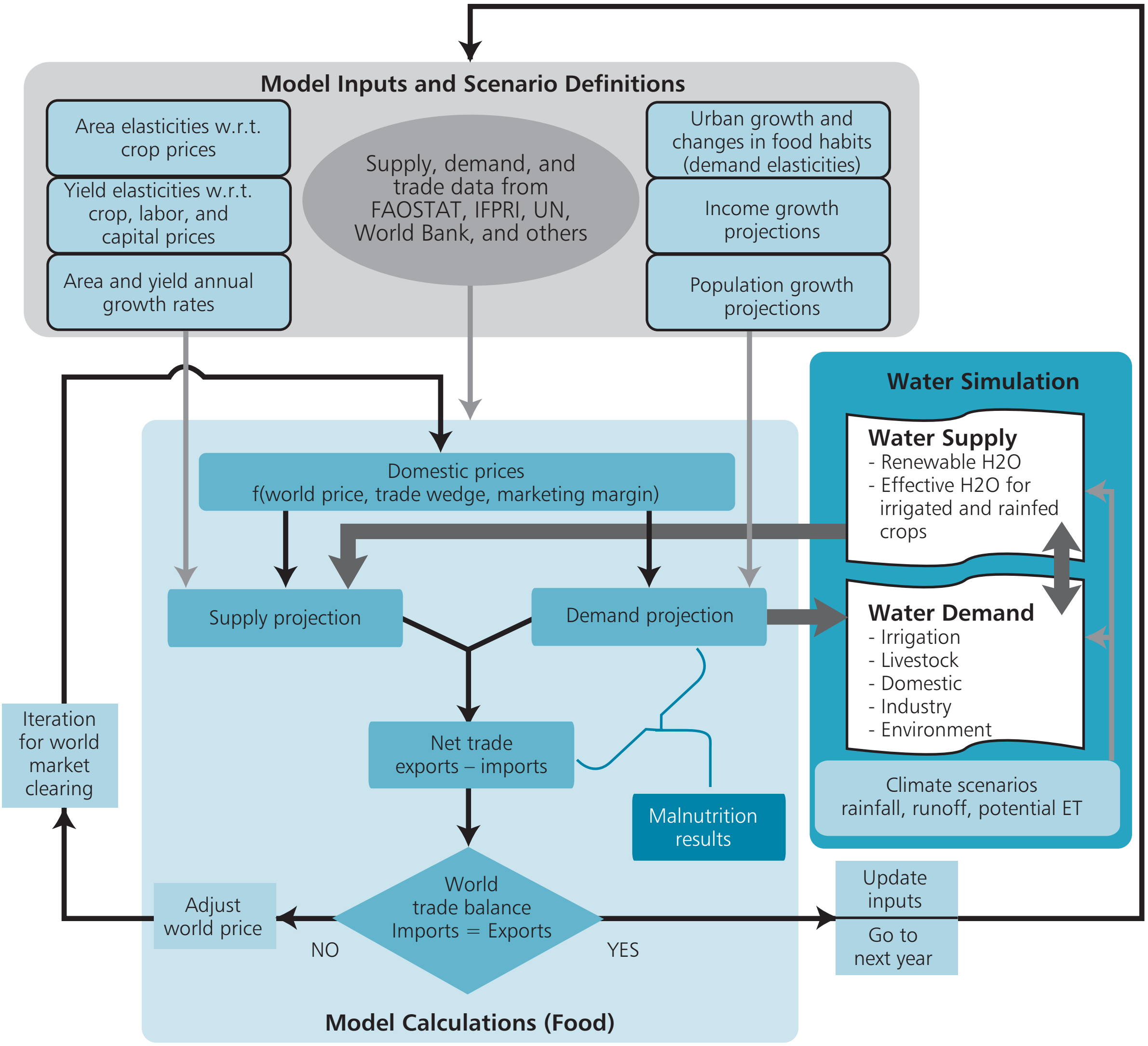
The modeling framework used here reconciles the often limited resolution of macro-level economic models that operate through equilibrium-driven relationships at a national or even more aggregate regional level, with detailed models of dynamic biophysical processes. In particular, we link crop growth model results with a neural-network to allocate results across landscapes. These results are then fed into a partial agricultural equilibrium model. Linking these types of models is needed to assess the impacts of climate change and the potential for climate change mitigation and adaptation policies and programs.

Figure A.1 illustrates the linkage between the macro-level agricultural policy and trade framework of the partial agriculture equilibrium model with the biophysical and agronomic potential model. We see that the main climate change effects occur on the production side while most of the key welfare implications are derived from the demand side results.

The challenge of modeling climate change impacts arises from the wide-ranging nature of characteristics and processes that underlie the working of markets, ecosystems, and human behavior. Our analytical framework integrates modeling components that range from the macro to the micro, and from processes that are driven by economics to those that are essentially biological in nature. Considering this entire range provides a more holistic assessment of the consequences of climate change and the benefits that can be generated by well-designed climate change mitigation and adaptation policies and programs. Simulation techniques that integrate physical and economic models are used to investigate the effects on rural producers under a range of climate and socioeconomic futures.

The climate change modeling system combines a biophysical model (the DSSAT crop modeling suite)

Figure A5.1: The IMPACT 2009 Modeling Framework

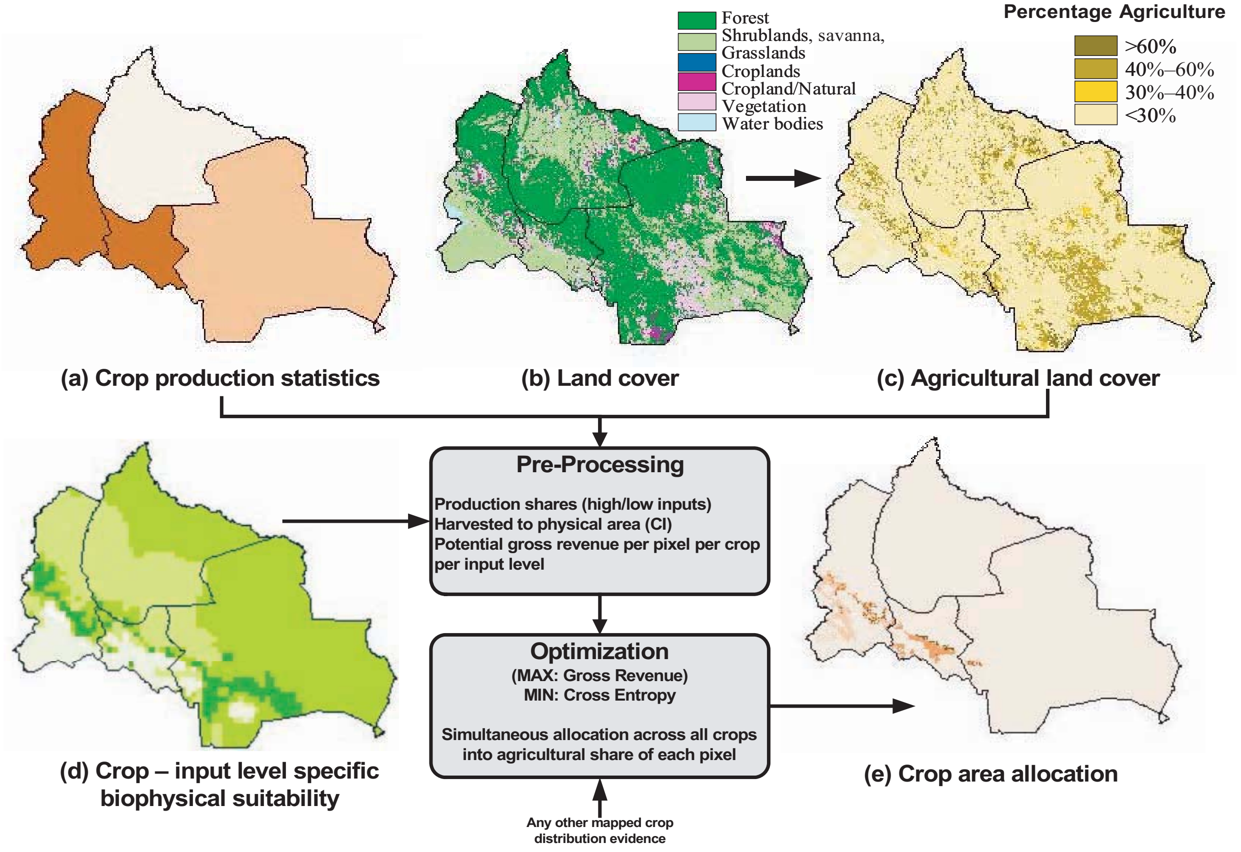


ET = evapotranspiration, H_2O = water, IFRI = International Food Policy Research Institute, UN = United Nations, w.r.t. = with respect to

Source: Authors.

of responses of selected crops to climate, soil, and nutrients with the ISPAM data set of crop location and management techniques (You and Wood 2006) (Figure A.2) and IFPRI's global agricultural supply and demand projections model, IMPACT.[20] IMPACT's detailed partial-equilibrium representation of agricultural production and consumption is enhanced by a detailed biophysical representation of the response of key crops to climate and nutrient changes. This modeling framework is used to undertake economic and policy scenario analysis

Figure A5.2: The ISPAM Data Set Development Process



Source: Authors.

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[20] IMPACT—International Model for Policy Analysis of Agricultural Commodities and Trade. See Rosegrant et al. (2008a) for details at www.ifpri.org/themes/impact/impactwater.pdf

of the impacts that new crop technologies and improved management can have on agricultural economies, as well as the impact of crop prices, fertilizer prices, investments in irrigation, and fertilizer on agricultural productivity. Summary descriptions of the models utilized in the linked system are provided below.

Adaptation Needs and Potential

Climate change will bring location-specific changes in precipitation and variability as well as temperature levels and their variability. Ongoing research at IFPRI and other institutions has identified the agro-climatic suitability for each of the world's crops globally, given today's climate.

This research uses the range of climate conditions expected in 2050 to assess how suitability would change. The location-specific change in suitability for existing crops provides a clear indication of where adaptation efforts would need to be focused. These results are relevant to a variety of audiences—from the Asian Development Bank's (ADB) decision makers and macroeconomic and trade policy makers, for whom the need to rely increasingly on staple imports would be of high interest; to infrastructure planners, for whom the location of newly important agricultural areas should influence road, rail, and irrigation investments; to agricultural research managers, for whom the extent of new suitability environments should be an important factor in research investments.

Modeling Climate Change Impacts on Agriculture

The modeling environment consists of three distinct software models and related databases; the DSSAT crop model, a neural net representation of crop model climate interactions, and IFPRI's IMPACT2009 model.

Crop modeling

The DSSAT crop simulation model is an extremely detailed process model of the daily development of a crop from planting to harvest-ready state. It requires daily weather data, including maximum and minimum temperature, solar radiation and precipitation, a description of the soil physical and chemical characteristics of the field, and crop management, including crop, variety, planting date, plant spacing, and inputs such as fertilizer and irrigation.

For maize, wheat, rice, groundnuts, and soybeans, we use the DSSAT crop model, version 4.0 (Jones et al. 2003). In mapping these results to other crops in IMPACT, the primary assumption is that plants with similar photosynthetic metabolic pathways will react similarly to any given climate change effect in a particular geographic region. IMPACT crops use either the C3 or C4 pathways. Sugarcane follows directly the pathway of maize. Other C4 crops modeled (millet, sorghum) are more drought-resistant compared to maize. Thus, they are mapped to follow all positive but only half of negative yield impacts from maize, in the respective geographic regions. The remainder of the crops all follow the C3 pathway. The climate effects for the C3 crops not directly modeled in DSSAT follow the average for wheat, rice, soy, and groundnut from the same geographic region, with two exceptions. The IMPACT commodities of "other grains," which are more drought-resistant compared to wheat, rice, or soy use half of the negative and all positive yield changes from wheat. Finally, dryland legumes of chickpea and pidgeonpea are directly mapped to the DSSAT results for groundnuts, again only using half of the negative and all of the positive yield impacts, given their relatively higher drought resistance.

Climate data

DSSAT requires detailed daily climate data, not all of which are readily available, so various approximation techniques were developed. To simulate today's climate, we use the Worldclim current conditions data set (www.worldclim.org) which is representative of 1950–2000 and reports monthly average minimum and maximum temperatures and monthly average precipitation. Site-specific daily weather data are generated stochastically using the SIMMETEO software.[21]

Precipitation rates and solar radiation data were obtained from NASA's LDAS website (http://ldas.gsfc.nasa.gov/). We used the results from the Variable Infiltration Capacity land surface model. For shortwave radiation (the sunlight plants make use of), monthly averages at 10 arc-minute resolution were obtained for 1979–2000. Overall averages for each month were computed between all the years (*e.g.*, the January average was computed as [January 1979 + January 1980 + … + January 2000] / 22).

Rainfall rates were obtained at three-hourly intervals for the years 1981, 1985, 1991, and 1995. A day was determined to have experienced a precipitation event if the average rainfall rate for the day exceeded a small threshold. The number of days experiencing a rainfall event within each month was then counted up and averaged over the 4 years.

The monthly values were regressed nonlinearly using the Worldclim monthly temperature and climate data, elevation from the GLOBE dataset (www.ngdc.noaa.gov/mgg/topo/globe.html) and latitude. These regressions were used to estimate monthly solar radiation data and the number of rainy days for both today and the future. These projections were then used by SIMMETEO to generate the daily values used in DSSAT.

For future climate, we use three GCMs—the AR3 Hadley GCM run with the A2a forcings scenario available from www.worldclim.org/futdown.htm, and fourth assessment report A2 runs using the CSIRO and NCAR models.[22] At one time the A2 scenario was considered an extreme scenario although recent findings suggest it may not be. We assume that all climate variables change linearly between their values in 2000 and 2050. This assumption eliminates any random extreme events such as droughts or high rainfall periods and also assumes that the forcing effects of greenhouse gas (GHG) emissions proceed linearly; that is, we do not see a gradual speedup in climate change. The effect of this assumption is to underestimate negative effects from climate variability.

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[21] SIMMETEO is a software that generates sequences of daily weather data for solar radiation, maximum and minimum temperatures, and precipitation for a certain period, with daily averages and standard deviations depending on wet and dry days.

[22] NCAR and CSIRO AR4 data downscaled by Kenneth Strzepek and colleagues at the Massachusetts Institute of Technology's Center for Global Change Science. We acknowledge the international modeling groups for providing their data for analysis, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for collecting and archiving the model data, the JSC/CLIVAR Working Group on Coupled Modeling (WGCM) and their Coupled Model Intercomparison Project (CMIP) and the Climate Simulation Panel for organizing the model data analysis activity, and the IPCC WG1 TSU for technical support. The IPCC Data Archive at Lawrence Livermore National Laboratory is supported by the Office of Science, United States Department of Energy.

A brief description and characterization of the "family" of scenarios used in the 3rd and 4th IPCC assessments is shown in Figure A.3, to give the reader a better idea of the assumptions on underlying driving forces of change.

Other agronomic inputs

Six other agronomic inputs are key: soil characteristics, crop variety, cropping calendar, CO_2 fertilization effects, irrigation, and nutrient levels.

Soil characteristics

The DSSAT model uses many different soil characteristics in determining crop progress through the growing season. John Dimes of the International Crops Research Institute for the Semi-Arid Tropics and Jawoo Koo of IFPRI collaborated to classify the FAO soil types into 27 meta-soil types. Each soil type is defined by a triple of soil organic carbon content (high/medium/low), soil rooting depth as a proxy for available water content (deep/medium/shallow), and major constituent (sand/loam/clay).

Crop variety

DSSAT includes many different varieties of each crop. For the results reported here, we use the maize variety Garst 8808, a winter wheat variety, a large-seeded Virginia runner type groundnut variety, a maturity group five soybean variety, and for rice, a recent International Rice Research Institute *Indica* rice variety and a *Japonica* variety. The rice varieties are assigned by geographic area according to whichever is more commonly cultivated within the region.

Figure A5.3: Characterization of Global IPCC Scenarios (SRES)[a]

	Growth-Focused Policy Objectives	Eco-Friendly Policies
More Globally Integrated	A1 More integrated world with cooperation Rapid economic growth Global population reaches 9 billion by 2050 then declines gradually afterward Quick spread of new efficient technologies	B1 More integrated world with policies more friendly toward the environment and emphasis on global solutions to economic, social, and environmental issues Rapid economic growth (like A1)—but more directed toward a service-oriented information economy Global population reaches 9 billion by 2050 then declines (like A1) Reduction in materially-intensive consumption and introduction of clean, resource-efficient technologies
More Divided Geo-Politically	A2 More divided world with less cooperation between nations Regionally oriented economic development, with lower per capita growth Continually increasing population growth Slower and more fragmented spread of technologies	B2 More divided, but still eco-friendly world Intermediate levels of economic development and growth Continually increasing population (but slower than under A2) Less rapid and more fragmented pattern of technological change (compared to A1 and B1)

SRES = Special Report on Emissions Scenarios.

[a] These scenarios were developed for the 3rd IPCC Assessment Report in 2001 and also used for the 4th (AR4) assessment in 2007, to make different assumptions for future greenhouse gas pollution, land use changes, and their underlying driving forces.

Cropping calendar

Climate change will alter the cropping calendar in some locations, shifting the month in which a crop can be safely planted forward or back. Furthermore, in some locations crops can be grown in 2000 but not in 2050, or vice versa. For rainfed crops, we assume that a crop is planted in the first month of a four month contiguous block of months where monthly average maximum temperature does not exceed 37 degrees Celsius or °C (about 99 degrees Fahrenheit or °F), monthly average minimum temperature does not drop below 5°C (about 41°F) and monthly total precipitation is not less than 60 mm. See Figure A.4 to Figure A.7.

For irrigated crops, we assume that precipitation is not a constraint and only temperature matters, avoiding freezing periods. The starting month of the irrigated growing season is identified by four contiguous months where the monthly average maximum temperature does not exceed 45 °C

Figure A5.4: Rainfed Crop Planting Month, 2000 Climate

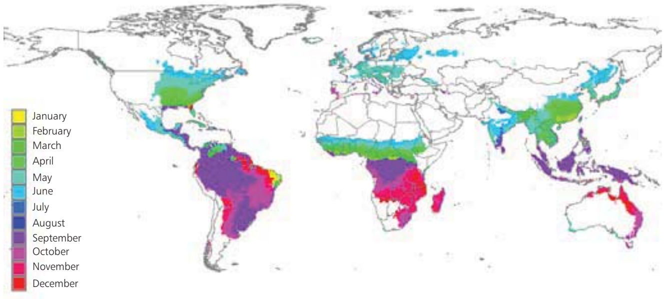


Figure A5.5: Rainfed Crop Planting Month, 2050 Climate, Hadley GCM A2a Scenario (AR3)

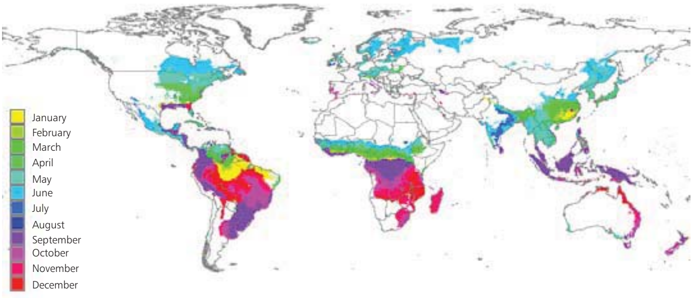


Figure A5.6: Rainfed Crop Planting Month, 2050 Climate, CSIRO GCM A2 Scenario (AR4)

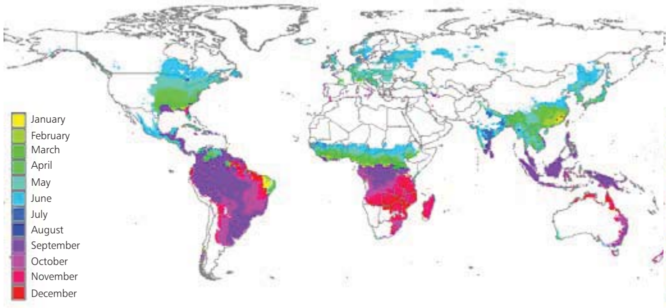
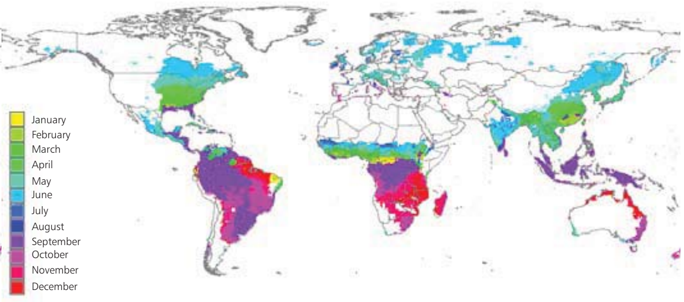


Figure A5.7: Rainfed Crop Planting Month, 2050 Climate, NCAR GCM A2 Scenario (AR4)



(about 113 °F) and the monthly average minimum temperature does not drop below 8.5 °C (about 47 °F) See Figure A.8 to Figure A.11.

Developing a climate-based growing season algorithm for winter wheat was challenging. Our solution was to treat winter wheat differently from other crops. Rather than using a cropping calendar, we let DSSAT use planting dates throughout the year and choose the date that provides the best yield for each pixel.

CO_2 fertilization effects

Plants produce more vegetative matter as atmospheric concentrations of CO_2 increase. The effect depends on the nature of the photosynthetic process used by the plant species. So-called C3 plants use CO_2 less efficiently than C4 plants so C3 plants are more sensitive to higher concentrations of CO_2. It remains an open question whether these laboratory results translate to actual field conditions. DSSAT has an option to include CO_2 fertilization effects at different levels of

Figure A5.8: Irrigated Crop Planting Month, 2000 Climate

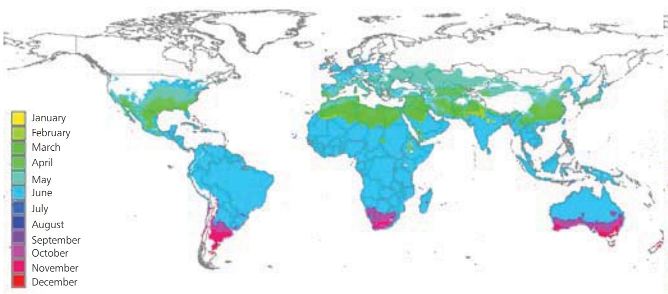


Figure A5.9: Irrigated Crop Planting Month, 2050 Climate, Hadley GCM A2a

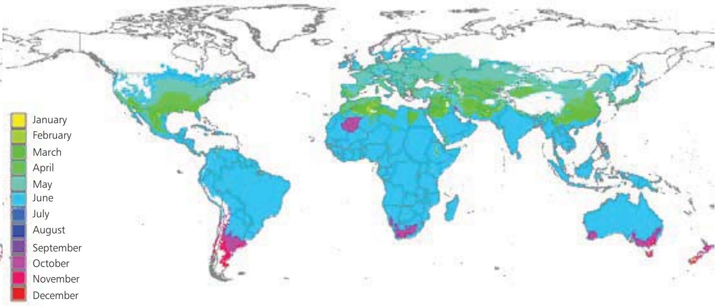


Figure A5.10: Irrigated Crop Planting Month, 2050 Climate, CSIRO GCM A2 Scenario (AR4)

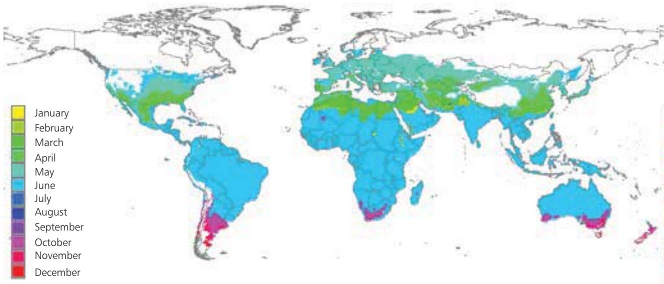
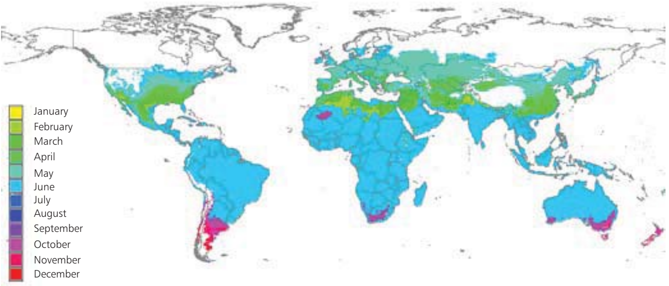


Figure A5.11: Irrigated Crop Planting Month, 2050 Climate, NCAR GCM A2 Scenario (AR4)



CO_2 atmospheric concentration. To capture the uncertainty in actual field effects, we simulate two levels of atmospheric CO_2 in 2050: 369 ppm (the level in 2000) and 532 ppm, the expected CO_2 levels in 2050 actually used in the A2 scenario.

Irrigation

Rainfed crops receive water either from precipitation at the time it falls or from soil moisture. Soil characteristics influence the extent to which previous precipitation events provide water for growth in future periods. Irrigated crops receive water automatically in the DSSAT model as needed. Soil moisture is completely replenished at the beginning of each day in a model run.

Nutrient level

The DSSAT model allows a choice of nitrogen application amounts and timing. We vary the amount of elemental N from 15 to 200 kilograms (kg) per hectare (ha) depending on crop, management system (irrigated or rainfed) and country.

From DSSAT to a Reduced Form Estimating Function—the Crop Model-Neural Net Output

The DSSAT crop model is computationally intense. To allow multiple simulations of climate effects for the entire surface of the globe, we developed a reduced form implementation. We ran the crop model for each crop and variety with a wide range of climate and agronomic inputs and then estimated a feed-forward neural net for each of the 27 soil categories. We obtained a continuous and differentiable approximation of the crop model results that allows us to find the maximum possible yield and corresponding nitrogen input needed based on location-specific geophysical characteristics and climate. The results of this estimation process were fed into the IMPACT model.

The IMPACT2009 Model

The IMPACT model[23] was initially developed by the International Food Policy Research Institute (IFPRI) for projecting global food supply, food demand, and food security up to year 2020 and beyond (Rosegrant et al. 2001). It is a partial equilibrium agricultural model with 32 crop and livestock commodities, including cereals, soybeans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes and meals, sugar, and fruits and vegetables. IMPACT has 115 country (or in a few cases country aggregate) regions, within each of which supply, demand, and prices for agricultural commodities are determined. Large countries are further divided into major river basins. The result, portrayed in Figure A.12, is 281 spatial units, called food production units (FPUs). The model links the various countries and regions through international trade using a series of linear and nonlinear equations to approximate the underlying production and demand relationships. World agricultural commodity prices are determined annually at levels that clear international markets. Growth in crop production in each country is determined by crop and input prices, exogenous rates of productivity growth and area expansion, investment in irrigation, and water availability. Demand is a function of prices, income, and population growth and contains four categories of commodity demand—food, feed, biofuels feedstock, and other uses.

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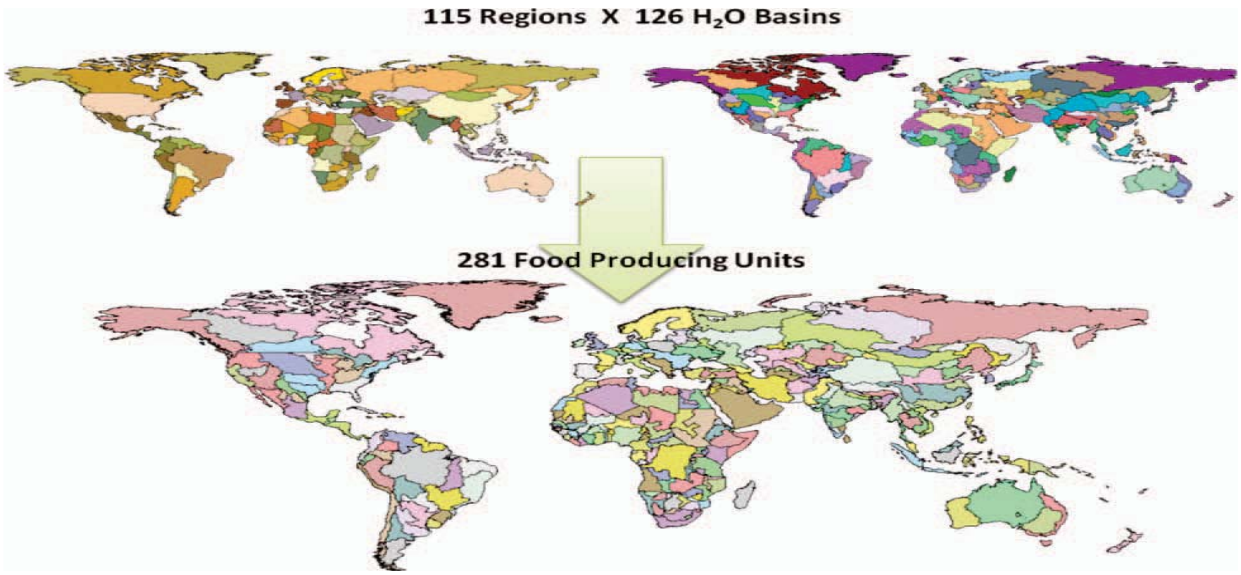
[23] Refer to Rosegrant et al. (2008a) for technical details.

Figure A5.12: IMPACT Model Units of Analysis, the Food Production Unit (FPU)



Climate change effects on crop productivity enter into the IMPACT model by affecting both crop area and yield. Yields are altered through the intrinsic yield growth coefficient, gy_{tni}, in the yield equation (1) as well as the water availability coefficient (*WAT*) for irrigated crops. These growth rates range depending on crop, management system, and location. For most crops, the average of this rate is about 1% per year from effects that are not modeled. But in some countries, the growth is assumed to be negative while in others, it is as high as 5% per year for some years.

$$YC_{tni} = \beta_{tni} \times (PS_{tni})^{\gamma_{iin}} \times \prod_k (PF_{tnk})^{\gamma_{ikn}}$$
$$\times (1 + gy_{tni} CY_{tni}) - \Delta YC_{tni}(WAT_{tni}) \qquad (1)$$

We generate relative climate change productivity effects by calculating location-specific yields for each of the five crops modeled with DSSAT for 2000 and 2050 climate as described above and then constructing a ratio of the two. The ratio is then used to alter gy_{tni}. Rainfed crops react to changes in precipitation as modeled in DSSAT. Irrigated crop effects are captured as part of the hydrology model built into IMPACT. It is a semi-distributed macro-scale hydrology module that covers the global land mass except the Antarctica and Greenland. It conducts continuous hydrological simulations at monthly or daily time steps at a spatial resolution of 30 arc-minutes. The hydrological module simulates the rainfall–runoff process, partitioning incoming precipitation into evapotranspiration and runoff, which are modulated by soil moisture content. A unique feature of the module is that it uses a probability distribution function of soil water-holding capacity within a grid cell to represent spatial heterogeneity of soil properties, enabling the module to deal with sub-grid variability of soil. A temperature-reference method is used to judge whether precipitation comes as rain or snow and determines the accumulation or melting of snow accumulated in conceptual snow storage. Model parameterization was done to minimize the differences between simulated and observed runoff processes, using a genetic algorithm. The model is spun up for 5 years at the beginning for each simulation run to minimize any arbitrary assumption of initial conditions. Finally, simulated runoff and evapotranspiration at 30 arc-minute grid cells are aggregated to the 281 food production units of IMPACT model.

Spatial Aggregation Issues

Food production units (FPUs) are large areas. For example, the Ganges FPU is the entire length of the Ganges River. Within an FPU, there can be large variation in climate and agronomic characteristics. A major challenge was to come up with an aggregation scheme to take outputs from the crop modeling process to the IMPACT FPUs. The process we used proceeds as follows.

First, within an FPU, choose the appropriate ISPAM data set, with a spatial resolution of 5 arc-minutes (approximately 10 km at the equator) that corresponds to the crop/management combination. The physical area in the ISPAM data set is then used as the weight to find the weighted-average-yield across the FPU. This is done for each climate scenario (including the baseline). The ratio of the weighted-average-yield in 2050 to the baseline yield is used to adjust the yield growth rate in equation (1) to reflect the effects of climate change.

Harvested areas in the IMPACT model are affected by climate change in a similar way as yields, though with a slight complication. In any particular FPU, land may become more or less suitable for any crop and will impact the intrinsic area growth rate, ga_{tni} in the area growth calculation. Water availability will affect the *WAT* factor for irrigated and rainfed crops as with the yields.

$$AC_{tni} = \alpha_{tni} \times (PS_{tni})^{\varepsilon_{iin}} \times \prod_{j \neq i} (PS_{tnj})^{\varepsilon_{ijn}} \times (1 + ga_{tni} A_{tni}) - \Delta AC_{tni}(WAT_{tni}) \qquad (2)$$

Crop calendar changes due to climate change cause two distinct issues. When the crop calendar in an area changes so that a crop that was grown in 2000 can no longer be grown in 2050, we implement an adjustment to ga_{tni} that will bring the harvested area to zero—or nearly so—by 2050. However, when it becomes possible to grow a crop in 2050 where it could not be grown in 2000, we do not add this new area. An example is parts of Ontario, Canada that have too short a growing season in 2000 will be able to grow maize in 2050, according to the climate scenarios used. As a result, our estimates of future production are biased downward somewhat. The effect is likely to be small, however, as new areas have other constraints on crop productivity, in particular soil characteristics.

Modeling the Costs of Adaptation to Climate Change

This section describes the methodology used to provide estimates of the costs of adapting to climate, with investments in two areas:

(i) Direct investment in agricultural research and development spending, and
(ii) Investment in key sectors that are strongly linked to agricultural productivity growth—roads and irrigation.

A key issue is what to use as the metric for adaptation. We use the human well-being measure of malnutrition among the highly vulnerable preschool children that is tracked in IMPACT, and average per capita calorie consumption. The malnutrition value is determined in part by per calorie availability but also includes access to clean drinking water and maternal education.

We use investments in agricultural research, roads, and irrigation to estimate the impact upon calorie availability and child malnutrition estimates. The approach is to estimate the productivity growth needed to meet a malnutrition or calorie availability target and then estimate the investment expenditures needed in research, irrigation, and road to generate that productivity growth.

Agricultural Research Investments

The process of estimating agricultural research investments involves using expert opinion to estimate yield responsiveness to research expenditures, and estimating future expenditures based on historical expenditure growth rates. The main portion of the data on public agricultural research is from the ASTI data set (Agricultural Science and Technology Indicators, 2009) converted into 2000 US dollar values by the GDP deflator obtained from the IMF International Financial Statistics data set. For the remaining countries, OECD Science and Technology Indicators data and Eurostat data on gross domestic expenditure on R&D for agricultural sciences are used after being converted to 2000 US dollar values.[24] For the PRC, the MOST data set (Ministry of Science and Technology, various years) for public agricultural research spending is used. For some countries, where public agricultural research data is not available, ASTI estimates of public agricultural research are used.[25] For these countries, ASTI uses agricultural GDP of the country and the average intensity ratio of the region where the country is located to generate this estimate.

The 2050 baseline research expenditures are generated by applying different rates of growth to the historical growth rates at 2000 US dollar values. These historical growth rates, g_h, are obtained from observed or estimated data on agricultural and research spending discussed above. The historical growth rate for each country is computed as an average of the annual historical growth rates for the last 10 years or less when data is not available. For the remaining countries, regional average historical growth rates are computed from the data set and used for individual countries. The assumed baseline growth rates of research expenditure, g_a, are given in Table A5.1.

We assume that the yield elasticity with respect to research expenditures ($e^{Yield}_{Research}$) is 0.296 for all countries and regions based on expert assessment.

Agricultural research investment (AR_n) for every year after 2000 is calculated as follows:

$$AR_n = \left[\left(\frac{g_h g_a}{100}\right) + 1\right] * AR_{n-1}$$

$$AR_{baseline} = \sum_{year = 2000}^{2050} AR_{year}$$

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[24] There are no data or estimates for Afghanistan, Armenia, Azerbaijan, Belarus, Djibouti, Georgia, Equatorial Guinea, Kazakhstan, North Korea, the Kyrgyz Republic, Singapore, Somalia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.

[25] These countries are Algeria, Angola, Antigua and Barbuda, Bahrain, Bhutan, Bolivia, Cambodia, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Democratic Republic of Congo, Ecuador, Guinea Bissau, Guyana, Iraq, Israel, Jamaica, Kuwait, Lebanon, Lesotho, Liberia, Libya, Luxembourg, Mongolia, Mozambique, Namibia, Peru, Qatar, Rwanda, Sao Tome and Principe, Saudi Arabia, Sierra Leone, Surinam, Swaziland, Trinidad and Tobago, Turkey, United Arab Emirates, Venezuela, and Zimbabwe.

Table A5.1: Assumed Multipliers of Historic Growth Rates of Agricultural Research Expenditures

Period	Multiplier of Historic Growth Rate (%)
2000–2010	9
2011–2020	8
2021–2030	7
2031–2040	6
2040–2050	5

Source: Authors.

For a given scenario, we determine the change in spending that is implied by the final outcome for agricultural performance. This change is calculated with respect to the level of spending in the baseline case described above.

In order to do this, we use 2050 cereal yield for baseline and the respective scenario. The scenario agricultural research costs ($AR_{Scenario}$) are computed as follows:

$$AR_{scenario} = \left[1 + \frac{\dfrac{(yld_{2050}^{scenario} - yld_{2050}^{Baseline})}{Yld_{2050}^{Baseline}}}{e_{Research}^{Yield}} \right] AR_{Baseline}$$

The resulting level of spending ($AR_{Scenario}$) represents the change needed to achieve the new level of productivity to achieve the target.

Rural Roads

Higher yields and more cropped areas require maintaining and increasing the density of rural road networks to increase access to markets and reduce transaction costs. We consider two relationships between roads and agricultural production—between area expansion and rural roads, and between rural roads and yield growth.

Area effect

We assume that any growth in cropped area requires a similar growth in rural roads and that it is a one-to-one relationship. Rural road length data are available from World Road Statistics 2002. We use information from the latest available year, typically 2000, to calculate rural road length (r_{2000}) as total roads minus highways minus motorways. Rural road investments are calculated by multiplying the extra road length between 2000 and 2050 by the road investment unit cost per km (C_r) numbers in Table A5.2.

We calculate the extra road length required due to area increase (r_a) as follows:

$$r_a = r_{2000} \times \left(\frac{a_{2050} - a_{2000}}{a_{2000}} \right)$$

$$\text{if } a_{2050} - a_{2000} < 0 \text{ then } r_a = 0$$

Finally we multiply r_a by road unit cost to get the cost of new roads needed to support crop area expansion (RR_a).

$$RR_a = r_a C_r$$

Yield effect

In addition, any yield increase is assumed to require road expansion. The percent yield increase due to rural road expansion ($yldinc_{Roads}$) is assumed to be 0.33 for all countries.

We use the following information (Table A5.2) on road costs, derived from various World Bank road construction project documents and deflated to 2000 US dollars.

Table A5.2: Road Construction Costs (2000 $ per km)

Region	Cost
South Asia	575,000
Sub-Saharan Africa	600,000
Middle East and North Africa	585,000
Latin America and Caribbean	580,000
East Asia and Pacific	555,000
Eastern Europe and Central Asia	590,000
Developed countries	621,000

km = kilometer.

Source: World Bank project documents.

We calculate the increase in road investment due to a yield increase (RR_y) as follows:

$$RR_y = \frac{\left(\frac{yld_{2050}}{yld_{2000}} - 1\right) \times yldinc_{Roads}}{e^{Yield}_{Roads}} + 1$$

Total effect

The total investment in rural roads (RR) is calculated as follows:

$$RR_{baseline} = RR_a + RR_y$$

We use the cereal yield in 2050 from the baseline and the respective scenario model run, elasticity of yield with respect to roads (e^{Yield}_{Roads}) and the share of yield from rural roads (s^{Yield}_{Roads}) (equal to 0.33 everywhere) to calculate the target costs of rural roads ($RR_{Scenario}$) as follows:

$$RR_{Scenario} = \left[1 + S^{Yield}_{Roads}\,\frac{\frac{\left(yld^{Scenario}_{2050} - yld^{Baseline}_{2050}\right)}{yld^{Baseline}_{2050}}}{e^{Yield}_{Roads}}\right] RR_{Baseline}$$

Irrigation

Irrigation investments include two components: costs for expanding irrigated area and costs related to the increase of irrigation water use efficiency.

Area expansion

The total investments in irrigation are calculated by multiplying the estimated net irrigated area increase between 2000 and 2050 by the cost of irrigation per hectare. Total irrigated area data that are produced by IMPACT have to be adjusted for cropping intensity (r_n) (FAO 2000) because the data include multiple cropping seasons, and therefore, overstates the physical area.

We calculate net irrigated area (a^{Net}_n) for each year n as follows:

$$a^{Net}_n = \frac{a_n}{\frac{1000}{r_n}} \times 100$$

The annual changes in net irrigated area for each year are given by

$$\Delta a^{Net}_n = a^{Net}_{n+1} - a^{Net}_n$$

$$if\ \Delta a^{Net}_n < 0\ then\ \Delta a^{Net}_n = 0$$

The year-to-year changes are summed for the entire period between 2000 and 2050 to get aggregate net irrigated area change $(\Delta a^{Net}_{2000-2050})$. The aggregate year-to-year change between 2000 and 2050 is multiplied by irrigation unit cost (c_{Irrig}) to get the total costs of increased irrigation between 2000 and 2050 (IR).

$$IR = \Delta a^{Net}_{2000-2050} \times c_{irrig}$$

Irrigation unit costs vary by region, as indicated in Table A5.3. In a few countries where better information is available, it is used instead.

Table A5.3: Irrigation Investment Cost (2000 $ per hectare)

Region	Irrigation Cost
South Asia	6,023
East Asia and Pacific	9,916
Eastern Europe and Central Asia	4,997
Latin America and Caribbean	15,929
Middle East and North Africa	9,581
Sub-Saharan Africa	18,252

Source: Literature review of World Bank, Food and Agriculture Organization (FAO), and International Water Management Institute (IWMI) documents, project reports, and meta-evaluations directly related to completed and ongoing irrigation projects.

Changes in irrigation efficiency

Irrigation efficiency needs to increase to ensure that sufficient water is available to meet future food needs. In IMPACT, we use the concept of basin efficiency (BE) to account for changes of irrigation efficiency at all levels. Basin efficiency describes irrigation water use efficiency at the river basin scale (Keller and Keller 1995; Haie and Keller 2008). It fully takes into account the portion of diverted irrigation water that returns back to river or aquifer systems and thus can be re-used repeatedly, usually by downstream users, thus avoiding the limitation of the conventional irrigation efficiency concept that basically treats return flow as “losses.” Basin efficiency is defined as the ratio of beneficial irrigation water consumption (BC) to total irrigation water consumption (TC):

$$BE = BC / TC$$

Our base year basin efficiency values range from 0.4 to 0.7. Given trends in investment in water use efficiency enhancements, and the need to use water more efficiently under growing water scarcity, we project small enhancements in BE over time, with BE levels increasing to 0.5–0.8 by 2050 under the business-as-usual scenario. An upper level of BE is set at 0.85 given that it is impossible to reach overall efficiency levels of 100%. To account for the investment costs associated with increasing irrigation efficiency, we assumed 1/3 of the cost of recent irrigation modernization projects using sprinklers as a proxy. Based on a literature review of World Bank, Food and Agriculture Organization (FAO), and International Water Management Institute (IWMI) documents, project reports, and meta-evaluations directly related to completed and ongoing irrigation projects, we identified per hectare investment cost of $2144 for East, South, Southeast and Central Asia; $4311 for Sub-Saharan Africa, and Latin America; and $953 for the Middle East and North Africa. For the various climate change scenarios, we calculated investment costs in irrigation efficiency enhancement. For the aggressive agricultural investment cost scenarios, we exogenously increased BE values by 0.15 and also calculated associated investment costs. This was done as follows:

Let subscript “0” denote the baseline and “1” denote an alternative irrigation investment scenario and assume that additional area that adopts sprinkler irrigation under the alternative scenario accounts for a share of X out of total irrigated area in 2050 for the region, and we have:

$$\begin{aligned} TC1 &= BC0 * (1 - X) / BE0 + BC0 * X / 1 \\ &= TC0 * (1 - X) + BC0 * X \end{aligned} \qquad \text{(Eq 2)}$$

(here we assume all consumption of sprinkler irrigation is beneficial consumption).

Now, we assume that beneficial consumption is the same in the baseline as in the alternative scenario, therefore,

$$BE1 = BC0 / TC1 \qquad \text{(Eq 3)}$$

Bring Eq. 2 into Eq. 3 and simplify, we get:

$$X = \left(1 - \frac{BE0}{BE1}\right) \Big/ (1 - BE0) \qquad \text{(Eq 4)}$$

Given that most irrigated area is located in Asia, we see that the highest irrigation efficiency costs are also occurring in that region.

How We Represent the Future

All simulations use standard IMPACT model assumptions for elasticities and intrinsic productivity and area growth changes. Income elasticities decline with income growth. For population growth, we use the 2006 UN medium variant projections. For income growth, we use the average of five recent models from the various climate change scenarios. All income and price values are in constant 2000 US dollars.

We report results for three climate scenarios: the Hadley GCM A2a scenario from AR3, and the NCAR and CSIRO GCMs with the A2 scenario from AR4. For each of the three 2050 scenarios, we use crop model results with 369 ppm CO_2 to be the no-CO_2 fertilization results and with 532 ppm CO_2 to represent CO_2 fertilization results. For these outcomes, we keep intrinsic productivity growth and related expenditures constant.

Then we simulate agricultural productivity increases in the developing world that are sufficient to bring child malnutrition in 2050 down to levels that would have prevailed *without* climate change. Because agricultural trade is a potentially important stabilizing force in response to climate change, we also explore briefly two scenarios—a complete liberalization of agricultural trade beginning in 2010 and a doubling of protection in 2010.

It is also important to state what we do not model as these will generally affect agriculture negatively. The assumption of a linear change in climate variables between 2000 and 2050 means that we do not include any extreme events—droughts or floods—in our assessment of the effects of climate change. We do not include any effects of sea-level rise in this chapter, although this could potentially have serious negative effects on crop production in parts of Asia. Finally, we do not consider the effects of the disappearance of glaciers in maintaining river flows, and therefore, the ability of rivers to provide irrigation water throughout the year in South Asia and part of East and Southeast Asia.

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Glossary

Adaptation: Changes in practices, both short-and long-term, that take into account the impacts of climate change (IFPRI 2009).

Anticipatory adaptation: Takes place before impacts of climate change are observed. Also referred to as *proactive adaptation* (IPCC 2007a).

Autonomous adaptation: Does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as *spontaneous adaptation* (IPCC 2007a).

Planned adaptation: Result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state (IPCC 2007a).

Adaptation costs: Costs of planning, preparing for, facilitating, and implementing *adaptation* measures, including transition costs (IPCC 2007a)

Adaptation Fund: Established to finance concrete adaptation projects and programs in developing countries, which are Parties to the Kyoto Protocol, that are particularly vulnerable to the adverse effects of climate change. It is financed from a share of proceeds from *clean development mechanism* (CDM) project activities and other sources of funding. The share of proceeds is 2% of certified emission reductions (CERs) issued for a CDM project activity (UNFCCC 2009).

Adaptive capacity (in relation to climate change impacts): The ability of a system to adjust to *climate change* to moderate potential damages, take advantage of opportunities, or cope with the consequences (IPCC 2007a).

Additionality: Reduction in emissions by sources or enhancement of removals by sinks that are in addition to any that would occur in the absence of a mitigation activity.

Afforestation: Direct human-induced conversion of land—that has not been forested for a period of at least 50 years—to forested land through planting, seeding, and/or the human-induced promotion of natural seed sources (IPCC 2007b).

Agriculture: Includes farming, fishing, hunting, and forestry.

Agroecological zone: Defines zones based on combinations of soil, landform, and climatic characteristics. The particular parameters focus on the climatic and edaphic requirements of crops and on the management systems under which the crops are grown (FAO 1996).

Anthropogenic: Resulting from human activities (IPCC 2007c).

Annex I countries: The group of countries included in Annex I (as amended in 1998) to the *United Nations Framework Convention on Climate Change* (UNFCCC), including all the Organisation for Economic Co-operation and Development (OECD) countries and economies in transition (IPCC 2007b).

Annex II countries: The group of countries included in Annex II to the UNFCCC, including all OECD countries (IPCC 2007b).

Annex B countries: The countries included in Annex B to the Kyoto Protocol that have agreed to a target for their greenhouse gas (GHG) emissions, including all the Annex I countries (as amended in 1998) except for Turkey and Belarus (IPCC 2007b).

Asia Pacific Carbon Fund (APCF): Under the Carbon Market Initiative of the Asian Development Bank, the APCF is an upfront financing facility that will enable developing countries to participate in projects that mitigate the adverse impact of climate change (ADB 2006).

Baseline/reference: The state against which change is measured. It is either a "current baseline," representing observable, present-day conditions, or a "future baseline," a projected future set of conditions excluding the driving factor of interest (IPCC 2007a).

Benefit transfer: An application of monetary values from one particular analysis to another policy–decision setting, often in a geographic area different from the one in which the original study was performed (IPCC 2007b).

Biodiversity: The total diversity of all organisms and *ecosystems* at various spatial scales (from genes to entire biomes) (IPCC 2007a).

Bioenergy: The use of plants to produce energy-related products, including fuel and electricity (IFPRI 2009).

Biofuel: A fuel produced from organic matter or combustible oils produced by plants.

C3 plants: Plants that produce a three-carbon compound during photosynthesis, including most trees and agricultural crops such as rice, wheat, soybeans, potatoes, and vegetables (IPCC 2007c). These plants tend to suppress their photo-respiration activity when exposed to increased CO2 level, making them more water efficient, in contrast to C4 plants (UNFCCC 2000).

C4 plants: Plants that produce a four-carbon compound during photosynthesis, mainly of tropical origin (IPCC 2007c).

Capacity building: In the context of *climate change*, capacity building is developing the technical skills and institutional capabilities in developing countries and economies in transition to enable their participation in all aspects of *adaptation* to, *mitigation* of, and research on *climate change*, and in the implementation of the Kyoto Mechanisms, etc. (IPCC 2007a).

Cap: Mandated restraint as an upper limit on emissions (IPCC 2007b).

Cap and trade: An environmental policy tool that delivers results with a mandatory cap on emissions while providing sources, with flexibility in how they comply (USEPA 2009).

Carbon cycle: Describes the flow of carbon (in various forms, e.g., *carbon dioxide*) through the atmosphere, ocean, terrestrial biosphere, and lithosphere (IPCC 2007a).

Carbon dioxide (CO_2): A by-product of burning fossil fuels from fossil carbon deposits, of burning biomass, and of land use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a *global warming potential* (GWP) of 1 (IPCC 2007c).

Carbon dioxide equivalent (CO_2eq): The universal unit of measurement used to indicate the *GWP* of each of the six GHG. It is used to evaluate the impacts of releasing (or avoiding the release of) different GHG (Ecoagriculture 2009).

Carbon fertilization: The effect of additional concentrations of CO_2 in the atmosphere on plant growth (IFPRI 2009).

Carbon intensity: The amount of emissions of CO_2 per unit of GDP (IPCC 2007b).

Carbon leakage: The part of emission reductions in Annex B countries that may be offset by an increase of the emissions in the non-constrained countries above their baseline levels (IPCC 2007b).

Carbon Market Initiative (CMI): The CMI of ADB helps developing countries tap into the growing global carbon market to systematically address the low-carbon transition needed in the region (ADB 2009).

Carbon pool: Above-ground biomass, below-ground biomass, litter, dead wood, and soil organic carbon (IPCC 2007b).

Carbon price: What has to be paid (to a public authority as a tax rate, or on an emission permit exchange) for the emission of one ton of CO_2 into the atmosphere (IPCC 2007b).

Carbon sequestration: The process by which carbon sinks remove CO_2 from the atmosphere. This can be done naturally by plants, or artificially, for instance, by removing CO_2 from coal-fired power plant emissions (IFPRI 2009).

Carbon sink: A reservoir of carbon—not in a GHG—that can remove carbon from another part of the carbon cycle and store it for an indefinite period (IFPRI 2009).

Certified Emission Reduction Unit (CER): Equal to one metric ton (mt) of CO_2-equivalent emissions reduced or sequestered through a CDM project, calculated using GWP (IPCC 2007b).

Clean Development Mechanism (CDM): An arrangement under the Kyoto Protocol allowing industrialized countries with a GHG reduction commitment to invest in projects that reduce emissions in developing countries—as an alternative to more expensive emission reductions in their own countries (IFPRI 2009).

Clean Energy Financing Partnership Facility (CEFPF): Established by the Asian Development Bank, CEFPF aims to improve the energy security of ADB's developing country members and decrease the rate of climate change through increased use of clean energy (ADB 2007).

Climate: The statistical description of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state—including a statistical description—of the climate system. The classical period of time is 30 years, as defined by the World Meteorological Organization (WMO) (IPCC 2007a).

Climate change: Refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (IPCC 2007c).

Climate feedback: An interaction mechanism between processes in the climate system is a climate feedback when the result of an initial process triggers changes in secondary processes that in turn influence the initial one. A positive feedback intensifies the initial process; a negative feedback reduces the initial process (IPCC 2007b).

Climate forecast: See *climate prediction.*

Climate model (spectrum or hierarchy): A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. Climate models are applied as a research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal, and interannual climate predictions (IPCC 2007c).

Climate prediction: The result of an attempt to produce an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual, or long-term time scales. Such predictions are usually probabilistic in nature. Also called as *climate forecast* (IPCC 2007c).

Climate projection: A projection of the response of the climate system to emission or concentration scenarios of GHG and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are subject to substantial uncertainty (IPCC 2007c).

Climate proofing: Actions to protect infrastructure, systems, and processes against climate impacts (Parry, Hammill, and Drexhage 2005).

Climate scenario: A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as on the observed current climate (IPCC 2007c).

Climate sensitivity: Refers to the equilibrium change in annual mean global surface temperature following a doubling of the atmospheric CO_2-equivalent concentration (IPCC 2007b).

Effective climate sensitivity: Related measure that circumvents computational problems by avoiding the requirement of equilibrium. It is evaluated from model output for evolving non-equilibrium conditions. It is a measure of the strengths of the feedbacks at a particular time and may vary with forcing history and climate state. The climate sensitivity parameter refers to the equilibrium change in the annual mean global surface temperature following a unit change in radiative forcing ($K/W/m^2$) (IPCC 2007b).

Transient climate response: Change in the global surface temperature, averaged over a 20-year period, centered at the time of CO_2 doubling. It is a measure of the strength and rapidity of the surface temperature response to GHG forcing (IPCC 2007b).

Climate threshold: The point at which the atmospheric concentration of GHG triggers a significant climatic or environmental event, which is considered irreversible such as widespread bleaching of corals or a collapse of oceanic circulation systems (IPCC 2007b).

Climate variability: Variations in the mean state and other statistics of the climate on all spatial and temporal scales beyond that of individual weather events (IPCC 2007c).

Codex Alimentarius: A collection of standards, codes of practice, guidelines, and other recommendations related to a food or group of foods, or to the operation and management of food production processes, or to the operation of government regulatory systems for food safety and consumer protection. ftp://ftp.fao.org/codex/Publications/understanding/Understanding_EN.pdf?bcsi_scan_B90AE85AF6AB15C6=0&bcsi_scan_filename=Understanding_EN.pdf

Community Climate System Model version 3 (CCSM): CCSM was created by the National Center for Atmospheric Research (NCAR) in 1983 as a freely available global atmosphere model for use by the wider climate research community. CCSM version 3 is generally released to the public. www.ccsm.ucar.edu/models/ccsm3.0/ (CCSM 2009).

Compliance: Compliance is whether and to what extent countries adhere to the provisions of an accord (IPCC 2007b).

Conference of the Parties (COP): The supreme body of the UNFCCC, comprising countries with right to vote that have ratified or acceded to the convention. The first session of the Conference of the Parties (COP-1) was held in (i) Berlin (1995), followed by (ii) Geneva (1996), (iii) Kyoto (1997), (iv) Buenos Aires (1998), (v) Bonn (1999), (vi) The Hague/Bonn (2000, 2001), (vii) Marrakech (2001), (viii) Delhi (2002), (ix) Milan (2003), (x) Buenos Aires (2004), (xi) Montreal (2005), and (xii) Nairobi (2006), (IPCC 2007b).

Conventional agriculture: An industrialized agricultural system characterized by mechanization, monocultures, and the use of synthetic inputs such as chemical fertilizers and pesticides, with emphasis on maximizing productivity and profitability. Industrialized agriculture has become "conventional" only since World War II (Eicher 2003).

Coping: "…use of existing resources to achieve various desired goals during and immediately after unusually, abnormal, and adverse conditions of a hazardous event or process. The strengthening of coping capacities, together with preventative measures, is an important aspect of adaptation and usually builds resilience to withstand the effects of natural and other hazards (Agrawal 2008)." From http://sitemaker.umich.edu/aid_climate_change/glossary_of_terms (accessed on 13 August 2009).

Cost: The consumption of resources such as labor time, capital, materials, fuels and so on as the consequence of an action. In economics, all resources are valued at their opportunity cost, being the value of the most valuable alternative use of the resources (IPCC 2007b).

Deforestation: The conversion of forested areas to non-forested land for uses such as crops, pasture, or urban use (IPCC 2007c).

Desertification: Reduction or loss in arid, semi-arid, and dry sub-humid areas of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including those arising from human activities and habitation patterns (UNCCD).

Downscaling: A method that derives local- to regional-scale (10 to 100 km) information from larger-scale models or data analyses. Two main methods are dynamical downscaling and empirical/statistical downscaling (IPCC 2007c).

Dynamical method: Uses the output of regional *climate models,* global models with variable spatial resolution, or high-resolution global models (IPCC 2007c).

Empirical and/or statistical methods: Develops statistical relationships that link large-scale atmospheric variables with local and/or regional climate variables (IPCC 2007c).

Drought: A deficiency that results in a water shortage for some activity or for some group (Heim 2002).

Agricultural drought: Relates to moisture deficits in the topmost 1-meter or so of soil (the root zone) that affects crops (IPCC 2007c).

Hydrologic drought: Related to below-normal streamflow, lake, and groundwater levels (IPCC 2007c).

Megadrought: A pervasive drought, usually lasting a decade or more (IPCC 2007c).

Meteorological drought: A prolonged deficit of precipitation (IPCC 2007c).

Drought-resistant crops: Crops that grow well in dry conditions, either naturally or as a result of seed modification (IFPRI 2009).

Ecosystem: A dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit (IFPRI 2009).

Ecosystem resilience: A measure of how much disturbance an ecosystem can handle without shifting into a qualitatively different state (SRI 2009).

Ecosystem services: The benefits people obtain from ecosystems (IFPRI 2009).

El Niño-Southern Oscillation (ENSO): The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with a basin-wide warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere-ocean phenomenon, with preferred time scales of 2 to about 7 years, is collectively known as the El Niño-Southern Oscillation (ENSO). The cold phase of ENSO is called *La Niña* (IPCC 2007c).

Direct emissions: GHG emissions from sources that are owned or controlled by the reporting company (Del Pino, Levinson, and Larsen 2006).

Indirect emissions: GHG emissions that are a consequence of the reporting company operations but occur at sources owned or controlled by another company (Del Pino, Levinson and Larsen 2006).

Emission factor: The rate of emission per unit of activity, output, or input (IPCC 2007b).

Emission permit: A non-transferable or tradable entitlement allocated by a government to a legal entity to emit a specified amount of a substance (IPCC 2007b).

Tradable permit: An economic policy instrument under which rights to discharge pollution can be exchanged through either a free or a controlled permit market (IPCC 2007b).

Emission quota: The portion of total allowable emissions assigned to a country or group of countries within a framework of maximum total emissions (IPCC 2007b).

Emissions Reduction Unit (ERU): Equal to one mt of CO_2-equivalent emissions reduced or sequestered arising from a *Joint Implementation* (defined in Article 6 of the Kyoto Protocol) project. See *also certified emission reduction unit and emissions trading* (IPCC 2007b).

Emission scenario: A plausible representation of the future development of emissions of substances that are potentially radiatively active, based on a coherent and internally consistent set of assumptions about driving forces and their key relationships (IPCC 2007c).

Emission standard: A level of emission that by law or by voluntary agreement may not be exceeded (IPCC 2007b).

Emissions trading: A market-based approach to achieving environmental objectives. It allows those reducing GHG emissions below their emission cap to use or trade the excess reductions to offset emissions at another source inside or outside the country (IPCC 2007b).

Energy: The amount of work or heat delivered. Energy is classified in a variety of types and becomes useful to human ends when it flows from one place to another or is converted from one type into another (IPCC 2007b).

Embodied energy: The energy used to produce a material substance, taking into account energy used at the manufacturing facility (zero order), energy used in producing the materials that are used in the manufacturing facility (first order), and so on (IPCC 2007b).

Energy efficiency: The ratio of useful energy output of a system, conversion process, or activity to its energy input (IPCC 2007b).

Energy intensity: The ratio of energy use to economic output. At the national level, energy intensity is the ratio of total domestic primary energy use or final energy use to gross domestic product (IPCC 2007b).

Primary energy (also referred to as energy sources): The energy embodied in natural resources that has not undergone any anthropogenic conversion (IPCC 2007b).

Renewable energy: Obtained from the continuing or repetitive currents of energy occurring in the natural environment, including non-carbon technologies such as solar energy, hydropower, wind, tides and waves, and geothermal heat, as well as carbon-neutral technologies such as biomass (IPCC 2007b).

Secondary energy: The primary energy transformed by cleaning, refining, or conversion into electricity or heat. When secondary energy is delivered at the end-use facilities it is called final energy, where it becomes usable energy (IPCC 2007b).

Environmental services: Ecosystem services that do not pass through a market (IFPRI 2009).

Environmentally sustainable technologies: Technologies that are less polluting, use resources in a more sustainable manner, recycle more of their wastes and products, and handle residual wastes in a more acceptable manner than the technologies that they substitute (IPCC 2007b).

Equivalent carbon dioxide (CO_2) concentration: CO_2 concentration that would cause the same amount of radiative forcing as a given mixture of CO_2 and other GHG (IPCC 2007c).

Equivalent carbon dioxide (CO_2) emission: The amount of CO_2 emission that would cause the same integrated radiative forcing, over a given time horizon, as an emitted amount of a well-mixed GHG or a mixture of well-mixed GHG. The equivalent CO_2 emission is obtained by multiplying the emission of a well-mixed GHG by its GWP for the given time horizon. For a mix of GHG, it is obtained by summing the equivalent CO_2 emissions of each gas (IPCC 2007c).

Exposure: The biophysical impacts of climate change, which can vary in magnitude, frequency, and duration.

Externality, external cost, external benefit: Externalities arise from a human activity, when agents responsible for the activity do not take full account of the activity's impact on others' production and consumption possibilities and no compensation exists for the impact. When the impact is negative, so are external costs. When positive they are referred to as external benefits (IPCC 2007b).

Extreme weather event: An event that is rare at a particular place and time of year, normally as rare as or rarer than the 10th or 90th percentile of the observed probability density function (IPCC 2007c).

Food security: A situation in which people have secure access to sufficient amounts of safe and nutritious food for normal growth, development, and an active and healthy life (IPCC 2007a).

Fossil fuels: Carbon-based fuels from fossil hydrocarbon deposits (IPCC 2007b).

Fossil fuel emissions: Emissions of GHG (in particular CO_2) resulting from the combustion of fuels from fossil carbon deposits (IPCC 2007c).

Future Carbon Fund (FCF): Established by ADB in 2008, the FCF can stimulate new investments in clean energy projects even before a new international agreement is reached. Participants in the fund may include both public and private sector entities in ADB's developing member countries (ADB 2008).

General Circulation Model (GCM): One of a class of computer-driven models for forecasting weather, understanding climate, and projecting climate change. Also known as *Global Climate Models* (IFPRI 2009).

Global Environment Facility (GEF): Established in 1991 to help developing countries fund projects and programs that protect the global environment. GEF grants support projects related to biodiversity, climate change, international waters, land degradation, the ozone layer, and persistent organic pollutants (IPCC 2007b).

Global warming: Refers to the gradual increase—observed or projected—in global surface temperature, as one of the consequences of radiative forcing caused by anthropogenic emissions (IPCC 2007b).

Global Warming Potential (GWP): The number of units of CO_2 emissions that would have the same effect as a unit of emission of another GHG (in terms of mass) (IFPRI 2009).

Governance: An inclusive concept recognizing the contributions of various levels of government and the roles of the private sector, nongovernment actors, and civil society (IPCC 2007b).

Greenhouse effect: Greenhouse gases effectively absorb thermal infrared radiation, emitted by the earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the earth's surface. Thus, GHG trap heat within the surface-troposphere system (IPCC 2007c).

Greenhouse gas (GHG): Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the earth's surface, the atmosphere itself, and by clouds. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary GHG in the earth's atmosphere. Moreover, there are a number of entirely human-made GHG in the atmosphere (IPCC 2007c).

Gross domestic product (GDP): The monetary value of all goods and services produced within a nation (IPCC 2007a).

Gross national product (GNP): The monetary value of all goods and services produced by a nation's economy, including income generated abroad by domestic residents, but excluding income generated by foreigners (IPCC 2007a).

Group of 77 and the PRC (G77/the PRC): Originally 77, now more than 130 developing countries that act as a major negotiating bloc in the UNFCCC process. G77/the PRC is also referred to as Non-Annex I countries in the context of the UNFCCC (IPCC 2007b).

Hadley Center Coupled Model 3 (HadCM3): HadCM Version 3 was developed from the earlier HadCM2 model. Various improvements were applied to the 19-level atmosphere model and the 20-level ocean model, and as a result the model requires no artificial flux adjustments to prevent excessive climate drift (GCMD 2008).

International Energy Agency (IEA): Established in 1974, the agency is linked with the OECD. It enables OECD member countries to take joint measures to meet oil supply emergencies, share energy information, coordinate their energy policies, and cooperate in developing rational energy-use programs (IPCC 2007b).

Integrated agriculture-aquaculture (IAA): A small-scale farming system that diversifies by integrating crops, vegetables, livestock, trees, and fish and thus increases production stability, resource-use efficiency, and environmental conservation (FAO/IIRR/WorldFish Center 2001).

Internal Renewable Water (IRW): Precipitation that falls in the unit of analysis available as groundwater and surface water discharge within the unit.

Irrigation water-use efficiency: The amount of biomass or seed yield produced per unit irrigation water applied, typically about 1 ton of dry matter per 100 millimeter water applied (IPCC 2007a).

Irrigation water supply reliability (IWSR): The ratio of irrigation water consumption to irrigation water requirement, reflecting the degree that irrigation water requirement is satisfied.

Joint Implementation (JI): A market-based implementation mechanism defined in Article 6 of the Kyoto Protocol, allowing Annex I countries or companies from these countries to implement projects jointly that limit or reduce emissions or enhance sinks, and to share the Emissions Reduction Units. JI activity is also permitted in Article 4.2(a) of the UNFCCC (IPCC 2007b).

Kyoto Mechanisms (also called Flexibility Mechanisms): Economic mechanisms based on market principles that parties to the Kyoto Protocol can use in an attempt to lessen the potential economic impacts of greenhouse gas emission-reduction requirements. They include *Joint Implementation* (Article 6), *Clean Development Mechanism* (Article 12), and *Emissions Trading* (Article 17) (IPCC 2007b).

Kyoto Protocol: A protocol to the international Framework Convention on Climate Change, it aims to reduce greenhouse gases in an effort to prevent human-induced climate change. The treaty entered into force in February 2005, and as of October 2008, 182 countries had ratified the Protocol (IFPRI 2009).

La Niña: See *El Niño-Southern Oscillation (ENSO)*.

Land degradation: Human-induced processes acting upon the land that reduce its value, health, and productivity. Causes include deforestation, agricultural depletion of soil nutrients, overgrazing, and irrigation. The impacts, including desertification, can be intensified by climate change (IFPRI 2009).

Land use: Human modification of the earth's land surface (IFPRI 2009).

Land use and land use change: Land use refers to the total arrangements, activities, and inputs undertaken in a certain land cover type. (It is also used in the social and economic purposes for which land is managed, e.g., grazing, timber extraction, and conservation.) Land use change refers to a change in the use or management of land by humans, which may lead to a change in land cover (IPCC 2007c).

Land use, land use change, and forestry (LULUCF): Activities that can provide relatively cost-effective ways of offsetting emissions, either by increasing the removal of GHG from the atmosphere or by reducing emissions. However, drawbacks include the difficulty of estimating GHG removals and emissions resulting from activities of LULUCF. In addition, GHG may be unintentionally released into the atmosphere if a sink is damaged or destroyed (UNFCCC 2008a).

Leakage: *See carbon leakage*.

Least Developed Country Fund (LDCF): LDCF was established to support work programs for the Least Developed Country Parties of the UNFCCC to carry out, *inter alia*, the preparation and implementation of National Adaptation Program of Action (NAPAs).

Low-carbon technology: A technology that, over its life cycle, causes less CO_2-eq. emissions than other technological options. See also *environmentally sustainable technologies* (IPCC 2007b).

Maladaptation: An action or process that increases vulnerability to climate change-related hazards. Maladaptation often includes planned development policies and measures that deliver short-term gains or economic benefits but lead to exacerbated vulnerability in the medium to long-term (UNDP 2006).

Meeting of the Parties (to the Kyoto Protocol) (MOP): The Conference of the Parties (COP) of the UNFCCC serves as the Meeting of the Parties (MOP), the supreme body of the Kyoto Protocol, since the latter entered into force on 16 February 2005. Only parties to the Kyoto Protocol may participate in deliberations and make decisions (IPCC 2007b).

Methane (CH_4): One of the six GHG to be mitigated under the Kyoto Protocol. It is the major component of natural gas and associated with all hydrocarbon fuels, animal husbandry, and agriculture. It is produced as part of anaerobic decomposition of organic material (IPCC 2007b).

Methane recovery: The capture and subsequent use as fuel or chemical feedstock of methane emissions (IPCC 2007b).

Millennium Development Goals (MDG): A list of ten goals adopted in 2000 by the UN General Assembly, i.e., 191 States, to be reached by 2015. The MDGs commit the international community to an expanded vision of development and have been commonly accepted as a framework for measuring development progress (IPCC 2007a).

Mitigation: Actions to reduce GHG emissions and increase carbon sequestration (IFPRI 2009).

Monsoon: A tropical and sub-tropical seasonal reversal in both surface winds and associated precipitation (IPCC 2007a).

Nationally Appropriate Mitigation Action (NAMA): A measurable, reportable, and verifiable commitment or action that includes quantified emission limitations and reduction objectives while ensuring the comparability of efforts among them (UNFCCC 2008b).

National Adaptation Programs of Action (NAPA): A process for least developed countries (LDCs) to identify priority activities that respond to their urgent and immediate needs to adapt to climate change (UNFCCC 2002).

Nitrogen oxides (NOx): Any of several oxides of nitrogen (IPCC 2007a).

Non-Annex I Countries/Parties: The countries that have ratified or acceded to the UNFCCC but are not included in Annex I (IPCC 2007b).

Non-Annex B Countries/Parties: The countries not included in Annex B of the Kyoto Protocol (IPCC 2007b).

Offsets and mitigation: The idea that environmental restoration or pollution reductions in one place can compensate for (offset or mitigate) environmental degradation or pollution elsewhere (Ecoagriculture 2009).

Organic agriculture: A type of farming that relies on the earth's own natural resources to grow and process food (Ecoagriculture 2009).

Ozone: The triatomic form of oxygen (O_3) and a gaseous atmospheric constituent. In the troposphere, it is created both naturally and by photochemical reactions involving gases resulting from human activities (IPCC 2007a).

Payment for environmental services: Payments given to natural resource users for providing environmental services (IFPRI 2009).

Potential: In the context of climate change, potential is the amount of mitigation or adaptation that could be—but is not yet—realized over time. Potential levels are identified as market, economic, technical, and physical (IPCC 2007b).

Economic potential: In most studies, used as the amount of GHG mitigation that is cost-effective for a given carbon price, based on social cost pricing and discount rates, including energy savings, but without most externalities.

Market potential: The amount of GHG mitigation that might be expected to occur under forecast market conditions, including policies and measures in place at the time. It is based on private unit costs and discount rates, as they appear in the base year and as they are expected to change in the absence of any additional policies and measures.

Physical potential: The theoretical (thermodynamic) and at times uncertain upper limit to mitigation.

Technical potential: The amount by which it is possible to reduce GHG emissions or improve energy efficiency by implementing a technology or practice that has already been demonstrated. No explicit reference to costs is made but adopting "practical constraints" may take into account implicit economic considerations.

Proactive adaptation: See also *anticipatory adaptation.*

Projection: The potential evolution of a quality or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions to emphasize that projections involve assumptions—concerning, for example, future socioeconomic and technological developments, that may or may not be realized—and are therefore subject to substantial *uncertainty.* See also *climate projection* and *climate prediction* (IPCC 2007a).

Reduced Emissions from Deforestation and Forest Degradation (REDD): In the negotiations for the successor to the Kyoto Protocol, funding and implementation mechanisms for REDD are a key goal of many developing countries.

Reference scenario: See *baseline and/or reference.*

Reforestation: The restocking of existing forests and woodlands that have been depleted.

Relative sea-level rise: See *sea-level rise*.

Resilience: The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change (IPCC 2007a).

Riparian: Relating to or living or located on the bank of a natural watercourse (such as a river) or sometimes of a lake or a tidewater (IPCC 2007c).

Risk: The result of the interaction of physically defined hazards with the properties of the exposed systems—i.e., their sensitivity or social vulnerability (APF 2005).

River discharge: Water flow within a river channel, for example expressed in cubic meters per second or m^3/s. A synonym for streamflow (IPCC 2007a).

Runoff: That part of precipitation that does not evaporate and is not transpired (IPCC 2007a).

Salinization: The accumulation of salts in soils (IPCC 2007a).

Salt-water intrusion and/or encroachment: Displacement of fresh surface water or groundwater by the advance of salt water due to its greater density (IPCC 2007a).

Scenario: A forward-looking description of events and series of possible actions that can be used in policy-oriented research (IFPRI 2009).

Sea-level change: Sea level can change, both globally and locally, due to (i) changes in the shape of the ocean basins, (ii) changes in the total mass of water and (iii) changes in water density (steric) (IPCC 2007c).

Sea-level rise: An increase in the mean level of the ocean (IPCC 2007a).

Eustatic sea-level rise: Change in global average sea level brought about by an increase in the volume of the world oceans (IPCC 2007a).

Relative sea-level rise: Occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land level subsidence (IPCC 2007a).

Sea wall: A human-made wall or embankment along a shore to prevent wave erosion (IPCC 2007a).

Semi-arid regions: Regions of moderately low rainfall that are not highly productive and are usually classified as rangelands. “Moderately low” is widely accepted as between 100 and 250 mm precipitation per year (IPCC 2007a)

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct or indirect (IPCC 2007c).

Sequestration: See *carbon sequestration.*

Sink: Any process, activity, or mechanism that removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas or aerosol from the atmosphere (IPCC 2007a).

Small Grants Program (SGP): Established in 1992 under the Global Environment Facility (GEF), the SGP supports activities of nongovernment and community-based organizations in developing countries toward climate change abatement, biodiversity conservation, international waters protection, organic pollutants reduction, and prevention of land degradation prevention while generating sustainable livelihoods (SGP-GEF 2006).

Social resilience: The ability of human communities to withstand and recover from stresses, such as environmental change or social, economic, or political upheaval (SRI 2009). This idea is similar to adaptive capacity.

Social safety net: Publicly-funded, non-contributory transfer programs targeted toward the poor and vulnerable of both developed and developing countries to ensure that the benefits of economic growth are shared widely across society (Alderman and Hoddinott 2007).

Special Climate Change Fund (SCCF): Established in 2001 to finance projects relating to adaptation; technology transfer and capacity building; energy, transport, industry, agriculture, forestry and waste management; and economic diversification.

Special Report on Emissions Scenarios (SRES): Issued by the Intergovernmental Panel on Climate Change (IPCC) in 2000. The SRES scenarios were constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions (IFPRI 2009).

Spill-over effect: The positive or negative effects of domestic or sector mitigation measures on other countries or sectors (IPCC 2007b).

Spontaneous adaptation: See *autonomous adaptation.*

Stakeholder: A person or an organization that has a legitimate interest in a project or entity, or would be affected by a particular action or policy (IPCC 2007a).

Subsidy: Direct payment from the government or a tax reduction to a private party for implementing a practice the government wishes to encourage (IPCC 2007b).

Surface runoff: The water that travels over the land surface to the nearest surface stream; runoff of a drainage basin that has not passed beneath the surface since precipitation (IPCC 2007a).

Sustainable development: Creating and maintaining prosperous social, economic, and ecological systems by fostering adaptive capabilities and creating opportunities (Holling 2001 as quoted in RA 2009).

Sustainable land management: Land use practices that ensure that land, water, and vegetation adequately support land-based production systems for current and future generations (IFPRI 2009).

Swidden: A temporary agricultural plot produced by cutting back and burning off vegetative cover. www.merriam-webster.com/dictionary/swidden).

Synergy: When the combined effect of several forces operating is greater than the sum of the separate effects of the forces (MA 2005).

Tax

Carbon tax: A levy on the carbon content of fossil fuels. Also called *carbon charge* (IPCC 2007b).

Energy tax: A levy on the energy content of fuels (IPCC 2007b).

Eco-tax: Designed to influence human behavior (specifically economic behavior) to follow an ecologically benign path (IPCC 2007b).

Harmonized tax: Commits participating countries to impose a tax at a common rate on the same sources because imposing different rates across countries would not be cost-effective (IPCC 2007b).

International carbon/emission/energy tax: A tax imposed on specified sources in participating countries by an international authority. The revenue is distributed or used as specified by this authority or by participating countries (IPCC 2007b).

Tax credit: Tax reduction to stimulate purchasing of or investment in a certain product.

Thermal expansion: In connection with *sea-level rise*, the increase in volume (and decrease in density) that results from warming water (IPCC 2007a).

Tsunami: A large wave produced by a submarine earthquake, landslide, or volcanic eruption (IPCC 2007a).

Uncertainty: An expression of the degree to which an entity is unknown (IPCC 2007a)

Undernutrition: The temporary or chronic state resulting from intake of lower than recommended daily dietary energy and/or protein requirements, through either insufficient food intake, poor absorption, and/or poor biological use of nutrients consumed (IPCC 2007a).

United Nations Framework Convention on Climate Change (UNFCCC): Sets an overall agenda for intergovernment efforts to tackle the challenge posed by climate change. It has been ratified by 192 countries (IFPRI 2009).

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (IPCC 2007a). Vulnerability is often denoted as the antonym of resilience (SRI 2009).

Water consumption: Amount of extracted water irretrievably lost during its use. Water consumption is equal to water withdrawal minus return flow (IPCC 2007a).

Water productivity: The ratio of crop seed produced per unit water applied. In the case of irrigation, see *irrigation water-use efficiency*. For rainfed crops, water productivity is typically 1t/100 mm (IPCC 2007a).

Water stress: When the available freshwater supply relative to water withdrawals acts as an important constraint on development. Withdrawals exceeding 20% of renewable water supply have been used as an indicator of water stress. A crop is water-stressed if soil-available water, and thus actual evapotranspiration, is less than potential evapotranspiration demands (IPCC 2007a).

Water-use efficiency: Carbon gain in photosynthesis per unit water lost in evapotranspiration. It can be expressed on a short-term basis as the ratio of photosynthetic carbon gain per unit transpirational water loss, or on a seasonal basis as the ratio of net primary production or agricultural yield to the amount of available water (IPCC 2007a).

Water Financing Partnership Facility (WFPF): Established by the ADB in 2006, WFPF ensures mobilization of cofinancing and investments from development partners. It aims to deliver substantial investment, reform, and capacity development in three key areas—rural water services, urban water services, and river basin water management—and targets (i) 200 million people with safe drinking water and improved sanitation, (ii) 40 million people with better irrigation and drainage services, (iii) 100 million people with reduced flood risks, and (iv) integrated water resources management introduced in 25 river basins (ADB 2006b).

Building Climate Resilience in the Agriculture Sector of Asia and the Pacific

Building greater climate resilience into the agriculture sector in Asia and the Pacific must begin with an understanding of the likely added risks and vulnerabilities the sector will face from climate change. The Asian Development Bank–sponsored agriculture sector study, carried out by the International Food Policy Research Institute, uses predictions of global climate models to develop scenarios up to 2050 for Asia and to derive implications for food security. The study recommends cost-effective adaptation responses that could better equip vulnerable regions and countries to cope with the likely impact of climate change under alternative scenarios.

About the Asian Development Bank

ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries substantially reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to two-thirds of the world's poor: 1.8 billion people who live on less than $2 a day, with 903 million struggling on less than $1.25 a day. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

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