ADB

Economics of Climate Change in East Asia

Michael Westphal
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(Editors)

Asian Development Bank

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ISBN 978-92-9254-288-7 (Print), 978-92-9254-289-4 (PDF)
Publication Stock No. RPT125169-2

Cataloging-In-Publication Data

Westphal, Michael I.; Hughes, Gordon A.; Brömmelhörster, Jörn
Economics of climate change in East Asia.
Mandaluyong City, Philippines: Asian Development Bank, 2013.

1. Economics. 2. Climate change. 3. East Asia. I. Asian Development Bank.

Note:
In this publication, “$” refers to US dollars.

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Abbreviations

ACC	–	Abatement Cost Curve
ADB	–	Asian Development Bank
AIM	–	Asia-Pacific Integrated Model
APAN	–	Asia-Pacific Adaptation Network
BAU	–	business-as-usual
CCC	–	Copenhagen–Cancun Convergence
CDM	–	Clean Development Mechanism
CH_4	–	methane
CHRR	–	Center for Hazards and Risk Research
CIESIN	–	Center for International Earth Science Information Network
CO_2	–	carbon dioxide
DIVA	–	Dynamic Interactive Vulnerability Assessment
EACC	–	Economics of Adaptation to Climate Change
EPIC	–	Environmental Policy Integrated Climate
ETS	–	emissions trading scheme
EU	–	European Union
EWS	–	early warning system
GCM	–	general circulation model
GDP	–	gross domestic product
GLOBIOM	–	Global Biosphere Management Model
GRUMP	–	Global Rural-Urban Mapping Project
HDR	–	high discount rate
HVAC	–	heating, ventilation, and air-conditioning
IAM	–	integrated assessment model
IEA	–	International Energy Agency
IIASA	–	International Institute for Applied Systems Analysis
IMPACT	–	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	–	Intergovernmental Panel on Climate Change
J-VETS	–	Japan Voluntary Emissions Trading Scheme
LCS-RNet	–	International Research Network for Low Carbon Society
LDR	–	low discount rate
LECZ	–	low-elevation coastal zone
LED	–	light-emitting diode
LEWS	–	Livestock Early Warning Systems
MAC	–	marginal abatement cost
MAcMap	–	Market Access Map database
MEPS	–	Minimum Energy Performance Standard
N_2O	–	nitrous oxide
NDRC	–	National Development and Reform Commission
NoCC	–	without climate change
O&M	–	operation and maintenance
OECD	–	Organisation for Economic Co-operation and Development
PPP	–	purchasing power parity
PRC	–	People's Republic of China

REPN	–	Renewable Energy Policy Network
SEDAC	–	Socioeconomic Data and Applications Center
SMEs	–	small and medium-sized enterprises
TASF	–	Technical Assistance Special Fund
TEPCO	–	Tokyo Electric Power Company
UK	–	United Kingdom
UN	–	United Nations
UNDP	–	United Nations Development Programme
UNEP	–	United Nations Environment Programme
UNFCCC	–	United Nations Framework Convention on Climate Change
US	–	United States
WHO	–	World Health Organization

Weights and Measures

C	–	Celsius
cm	–	centimeter
Gt	–	gigaton
$GtCO_2e$	–	gigatons of carbon dioxide equivalent
GW	–	gigawatt
kg	–	kilogram
km^2	–	square kilometer
km/hr	–	kilometer per hour
km^2/year	–	square kilometer per year
kW	–	kilowatt
kWh/m^2/yr	–	kilowatt-hour per square meter per year
m	–	meter
m^3	–	cubic meter
mm	–	millimeter
m/s	–	meters per second
Mt	–	million tons
Mtce	–	million tons of coal equivalent
$MtCO_2$	–	million tons of carbon dioxide
$MtCO_2e$	–	million tons of carbon dioxide equivalent
Mtoe	–	million tons of oil equivalent
ppm	–	parts per million
tCO_2e	–	ton of carbon dioxide equivalent
Tmax	–	maximum temperature
Tmin	–	minimum temperature
$\mu g/m^3$	–	microgram per cubic meter

Foreword

I am glad to introduce this important study, the "Economics of Climate Change in East Asia," which is supported by the technical assistance "Economics of Climate Change and Low Carbon Growth Strategies in Northeast Asia" financed by the Asian Development Bank (ADB) and Korea International Cooperation Agency (KOICA).

This study addresses the economics of climate change in selected countries in the East Asian region, focusing on the People's Republic of China, Japan, the Republic of Korea, and Mongolia. It is one in a series that ADB has been conducting for the Asia and the Pacific region, starting with the "Economics of Climate Change in Southeast Asia: A Regional Review," and the "Economics of Climate Change in the Pacific." Further studies in preparation include similar topics in South Asia and Central West Asia.

The importance of the East Asian region in terms of addressing the impact of climate change has significant consequences that cross regional boundaries and affect the world. East Asia is a uniquely important region for climate change. As an export-oriented industrial powerhouse, the region accounts for roughly 30% of the world's total energy-related emissions. This suggests that initiatives to mitigate climate change must include the region. From a country perspective, the region is vulnerable to the impact of climate change. For instance, three urban areas or megacities in the region—Guangzhou and Shanghai in the People's Republic of China (PRC), and Osaka/Kobe in Japan—are among the top 10 urban areas in the world severely exposed to sea-level rise. Further, climate change, if not addressed, may reduce yields of key crops in the PRC, thus increasing reliance upon food imports, and could exacerbate land degradation and desertification in Mongolia.

This study is an advance over previous global and regional studies on climate change economics in several important ways. It explores the economics of climate change adaptation at a subnational scale (i.e., provinces or regions), incorporates more climate scenarios, and examines climate uncertainty in more depth than previous work. Moreover, this study explicitly combines the costs of adaptation and mitigation into a single framework, while exploring linkages with the global economy.

Several important messages emerge from the study. First, the cost of climate change adaptation is outweighed by the cost of inaction. Second, there are different policy actions that each country could undertake. These include, country-specific climate-proofing of various types of infrastructure, addressing the current adaptation deficit to weather risk (especially in the PRC), and avoiding large investments in greenhouse gas-intensive power plants in the PRC and Mongolia. Third, adaptation and mitigation policies should not be examined in isolation. Climate change strategies must consider the combined effects of mitigation and planned adaptation, and the resulting damage costs of climate change under the various adaptation policies. Fourth, climate change not only brings challenges to East Asia, but also opportunities. A significant portion of the mitigation potential in the region, including energy efficiency measures, generates a positive economic return without consideration of climate change. Fifth, regional cooperation, as this study shows, pays dividends. The overall cost of reducing emissions could be decreased by 25% or more if the countries in the region pool their emissions targets and create a regional carbon market.

Let me express my gratitude to KOICA that financed this study jointly with ADB, and productively participated in the workshops and discussions that precluded it. Jörn Brömmelhörster from ADB's East Asia Department led the technical assistance and edited the study together with Gordon Hughes (University of Edinburgh, United Kingdom) and Michael Westphal (Lead Consultant, United States). Team members came from more than 10 leading universities and think tanks in Asia, North America, and Europe, providing access to best available databanks and models on climate change. I am very grateful for this successful international collaboration.

Effective planning requires a solid foundation of knowledge. I am certain that this study adds to the understanding on the economic costs and benefits of unilateral and regional actions on climate change mitigation and adaptation, and helps to catalyze further work in this area. I believe that many of the findings will have a significant positive impact on raising climate change awareness resulting in the implementation of improved regional climate change policies in the region. As the study shows, while climate change is a threat, solutions do exist. I am confident that East Asia has the resources and the willingness to confront this challenge and to move along a sustainable and climate-resilient future.

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Acknowledgments

The Economics of Climate Change and Low-Carbon Growth Strategies in Northeast Asia project was led by the Asian Development Bank (ADB) and jointly cofinanced by ADB and the Korea International Cooperation Agency.

Michael I. Westphal (ADB lead consultant, United States [US]), Gordon A. Hughes (University of Edinburgh, United Kingdom), and Jörn Brömmelhörster (ADB) led the team, wrote, and edited the report.

The report is based on background papers and other inputs provided by members of the team, which consisted of Safiya Aftab (ADB consultant, Pakistan), Franziska Albrecht (International Institute for Applied Systems Analysis, Austria), Aline Chiabai (Basque Centre for Climate Change, Spain), Paul Chinowsky (University of Colorado at Boulder, US), Jargal Dorjpurev (Energy and Environment Research Consulting, Mongolia), Kazuya Fujiwara (Mizuho Information and Research Center, Japan), Susan Hanson (University of Southampton, United Kingdom [UK]), Petr Havlik (International Institute for Applied Systems Analysis, Austria), Jochen Hinkel (Potsdam Institute for Climate Impact Research, Germany), Gordon A. Hughes, Nikolay Khabarov (International Institute for Applied Systems Analysis, Austria), Junguo Liu (Beijing Forestry University, People's Republic of China [PRC]), Aline Mosnier (International Institute for Applied Systems Analysis, Austria), Yuko Motoki (Mizuho Information and Research Center, Japan), Robert Nicholls (University of Southampton, UK), Michael Obersteiner (International Institute for Applied Systems Analysis, Austria), Gerardo Sanchez (Basque Centre for Climate Change, Spain), Erwin Schmid (University of Natural Resources and Life Sciences, Austria), Kenneth Strzepek (Massachusetts Institute of Technology, US), and Suphachol Suphachalasai (formerly ADB, now World Bank). Hilary Gopnik and Hugh Finlay provided technical editing and Hrishi Patel provided geographic information systems support. Further support was provided through country reports on climate change vulnerabilities, impacts, and policies. The Japan study team was led Kotaro Kawamata (formerly ADB, now Ministry of the Environment, Japan) and was supported by the National Institute for Environmental Studies, Japan, and Institute for Global Environmental Strategies, Japan. The Mongolia study team consisted of Namjil Enebish (National Renewable Energy Centre, Mongolia) and Jamsran Batbold (Mongolian Environmental Civil Council, Mongolia). The study on the PRC was conducted by Tsinghua University in close cooperation with the National Development and Reform Commission (NDRC) and was led by Wenying Chen (Tsinghua University, PRC). The study on the Republic of Korea was led by Dong-Kun Lee (Seoul National University, Republic of Korea) and Myung-Kyoon Lee (Keimyung University, Republic of Korea). Tae Yong Jung, ADB staff and later as director of the Global Green Growth Institute, Republic of Korea, started the project and provided valuable support throughout the project.

The study also benefited from the inputs of steering committee members from all four countries. These included Masaru Moriya and Taku Ohmura from the Global Environment Bureau, Ministry of the Environment, Government of Japan, as well as Tomonori Sudo from the Japan International Cooperation Agency. Members from Mongolia included Altangerel Enkhbat from the Ministry of Nature, Environment and Tourism, and Amarkuu Erdenepurev from the Ministry of Mineral Resources and Energy. The steering committee members in the PRC included Zhaoli Jiang from the NDRC, and Jixi Gao from the Ministry of Environmental Protection. Members from the Republic of Korea included Yeon-Cheol Yoo from the Presidential Committee on Green Growth, Kangho Lee from the Ministry of Strategy and Finance, and Won-Ho Cho from the Korea International Cooperation Agency, in addition to Tae Yong Jung from the Global Green Growth Institute. Other steering committee members included Young-Woo Park, regional director of the United Nations Environment Programme office for Asia and the Pacific, and Rae Kwon Chung, director of the Environment and Sustainable Development Division in the United Nations Economic and Social Commission for Asia and the Pacific.

Earlier versions of the report were peer reviewed by Preety Bhandari (ADB), Jane Ebinger (World Bank), Michael Rattinger (ADB), and Anbumozhi Venkatachalam (Asian Development Bank Institute).

Maria Luisa Panlilio (ADB) and Edgar Cua (deputy director general of the East Asia Department, ADB) provided essential support in project administration and final review, respectively. Janice Gabriel (ADB) provided editing support.

Klaus Gerhaeusser, Director General of the Central and West Asia Department initiated the project in his former capacity as director general of the East Asia Department of ADB. Ayumi Konishi, Director General of the East Asia Department oversaw the project.

Executive Summary

The concentration of carbon dioxide (CO_2) in the atmosphere has recently passed 400 parts per million (ppm). Over the last 20 years, energy-related emissions of greenhouse gases have tracked or exceeded the A2 high emissions scenario of the Intergovernmental Panel on Climate Change (IPCC), and this pattern seems likely to continue for a decade or more. New power plants and the capital invested in other energy-using equipment mean that slowing the growth in global CO_2 emissions may take many years. As a consequence, an increase of 2° Celsius (C) in the global average temperature by 2050 is almost unavoidable.

This study examines how strategies for adapting to embedded climate change over the next 40 years can be combined with measures to lower and reverse the growth in CO_2 emissions in East Asia. Adaptation will minimize the costs of climate change in the next 40 years. However, adaptation cannot be the only response as the rate of climate change—and, thus, its costs—is expected to accelerate after 2050 if the concentration of greenhouse gases continues to increase. The costs of reducing CO_2 emissions in East Asia can be controlled by focusing on the most efficient abatement options, particularly those which overlap with measures designed to improve local environmental conditions.

All of the chapters in the report use the same set of socioeconomic projections for East Asia and present values in constant 2005 dollars.

Context

The climate in East Asia has been getting warmer since 1960 and this will continue. Current projections suggest that, relative to the average for 1961–1990, mean temperatures will be 1.9°–2.6° C higher across the region in 2050, and 3.8°–5.2° C higher in 2090. The rate of increase in mean temperatures is likely to be greater in the north of the region—Mongolia and northern People's Republic of China (PRC)—than in the south. Projected trends in total precipitation are more variable, over both space and time. Projections up to 2050 indicate that annual precipitation will increase in most of the region but may decline in southeastern PRC. However, by 2090 almost all of the region will be significantly wetter than in the second half of the 20th century. The additional rainfall will be concentrated in the spring and summer months.

Analysis of the probable impacts of climate change highlights four primary areas of concern:

- **Water resources and flooding**, since higher levels and greater variability of rainfall will increase the likelihood of both minor and major floods.
- **Coastal zones**, which will be exposed both to sea-level rise and the increased frequency and/or severity of tropical storms associated with higher sea temperatures.
- **Agriculture**, which may become more prone to droughts in important areas, such as the northern plain of the PRC, while higher daytime temperatures will tend to reduce yields of major crops.

- **Heat waves**, which tend to increase mortality and morbidity rates for various reasons unless housing and other infrastructure are adapted to provide better cooling and ventilation.

As a center of industrial production, East Asia is responsible for about 30% of energy-related global emissions of CO_2 and must contribute to mitigating climate change. Since electricity and heat production accounts for almost half of energy-related CO_2 emissions, particular attention is given to this sector. For the longer term the study draws upon global models to assess the impact and costs of addressing climate change.

Adaptation

As the climate changes it is inevitable that countries and their populations will adapt to higher temperatures and changed patterns of precipitation. The question is not whether adaptation will occur but how and at what cost. In many sectors, such as agriculture, individuals and businesses will adjust in a multitude of ways to changes in climate and the associated market signals. Such autonomous adaptation, as it is called, will affect methods of production and patterns of living as people learn to cope with different climate conditions. Public authorities and civil organizations can contribute to such adaptation by collecting and disseminating information on the impacts of, and potential responses to, climate change by promoting research and development, providing education and training, and encouraging communities to develop and implement collective measures as appropriate.

Reliance upon autonomous adaptation will not be sufficient in sectors with large stocks of capital whose performance may be affected by changes in climate conditions. If it is expected that road pavements will melt as a consequence of warmer summers or be washed away by flooding due to changes in rainfall, then clearly it is sensible to think ahead and consider how road networks that are vulnerable to such climate impacts ought to be built or maintained differently. This is planned adaptation and it may require a combination of ex-ante actions, e.g., building new roads to resist future climate conditions, and ex-post modifications, e.g., reconstructing and/or maintaining existing roads to ensure that they can withstand new climate stresses.

The essence of planned adaptation is thinking ahead, so that long-lived assets are built to cope with the changes in the climate stresses which they may experience over their life. This is not straightforward since it involves changes in engineering and design practice as well as dealing with uncertainty about the precise nature of future climate change and choosing the length of the time horizon that should be adopted. Under some circumstances, it may be best to invest in the capacity to adapt in the future, i.e., to keep options open, rather than committing resources to assets that cannot easily be modified if the climate changes in ways that differ from what was expected.

The analysis of planned adaptation in this study focuses on three key sectors: infrastructure (including water resources and flooding), coastal zones (including sea-level rise), and agriculture. In each case the expected impacts of climate change are examined in detail for a range of climate scenarios. The costs of planned adaptation are estimated after allowing for the contribution of autonomous adaptation by households and businesses.

Total costs. The total cost of adaptation for East Asia may be large but it is manageable. Averaged over the period 2010–2050 using a medium climate scenario, the cost of adaptation for the infrastructure sector (ignoring cyclone damage and flooding) is $22.9 billion per year, for coastal protection it is $4.2 billion per year, and for agriculture it is $9.5 billion per year (all in 2005 dollars). There is substantial uncertainty about the costs of adaptation across climate outcomes. In specific sectors they may be 3–4 times the average under the worst climate scenario. However, even under the most pessimistic assumptions the cost of adaptation is less than 0.3% of regional gross domestic product (GDP) over the period.

Infrastructure. The costs of planned adaptation up to 2050 for infrastructure, which covers a wide range of assets from energy networks to schools and housing, are estimated to be about 1% of baseline spending on infrastructure averaged over all climate scenarios with a maximum of 2.7% under the worst climate scenario. In relative terms, the cost of adaptation is low for the PRC and high for Mongolia and Japan. The total costs of adaptation are highest for housing and roads, but in relative terms it is roads that stand out, with an average cost of planned adaptation equivalent to nearly 8% of baseline spending.

There is large variation in the costs of climate proofing (ex-ante planned adaptation), with a range from $3 billion to $44 billion per year for 2010–2050 across climate scenarios for the PRC, and from $50 million to $560 million per year for Mongolia. The worst scenarios tend to be those which are among the wettest and most humid for the country or region.

Despite the uncertainty about future climate conditions, climate proofing is economically justified for some but not all types of infrastructure in the region. This means that the initial costs of investment in ex-ante planned adaptation, plus the associated operation and maintenance costs, are less than the probable costs of replacing and/or operating and maintaining infrastructure that was not designed to cope with future climate change. For Japan and the Republic of Korea, climate proofing is justified now for most types of infrastructure. On the other hand, for the PRC and Mongolia, climate proofing is justified for water and sewers, roads, and (only in Mongolia) housing.

The increase in the economic impacts of cyclones is projected to be minor in the PRC in 2050 but substantial in Japan and the Republic of Korea. However, the costs of cyclone proofing buildings to protect against increases in wind damage due to climate change are modest. While this study did not explore the adaptation deficit in great detail, about 85% of the cost of adapting buildings to wind damage from cyclones in the PRC is associated with the adoption of more efficient design standards to protect buildings against 1-in-100-year storms under current climate conditions.

If measures are not taken to improve flood defenses, areas in east and southeast PRC are at great risk of much heavier losses caused by both cumulative and short-term flooding due to climate change. The highest costs are associated with cumulative flooding in major river basins such as the Yangtze caused by episodes of extreme upstream precipitation. These flood risks can be greatly reduced by adopting a higher and consistent standard for flood defenses designed to provide protection against 1-in-50-year or 1-in-100-year floods under the projected climate for 2050 and beyond. Adopting higher design standards for both flood and storm (cyclone) protection would be economically justified in that the costs incurred are much lower than the expected value of the damage that can be avoided.

Overall, the costs of climate proofing infrastructure are a complex function of local geography. There appears to be no straightforward relationship between adaptation costs and the GDP of a country or region. It is critical to understand the details of local weather and climate and their impacts on infrastructure. While climate uncertainty in the region is large, this is no excuse for inaction: there no guarantee that future climate uncertainty will diminish. As a prudent and low-cost first step, all countries should ensure that design standards and new assets fully reflect the current climate and weather variability.

Coastal protection. The combination of sea-level rise and higher storm surges will lead to heavy losses without planned adaptation, especially in the PRC. These losses will encompass the submergence and/or erosion of dryland areas, the disappearance of coastal wetlands, and the forced migration of tens or hundreds of thousands of people. The disruption and loss of economic output caused by forced migration account for the major part of the damage associated with sea-level rise. Even without climate change, coastal subsidence, partly caused by urban development and the extraction of groundwater, will require significant expenditures on coastal protection in the PRC.

Planned adaptation to sea-level rise will include investments in the construction of sea dikes and port upgrades, plus regular expenditure on dike maintenance and beach nourishment. The net cost of adaptation after allowing for the effects of subsidence without climate change is less than $9 billion per year for the region under the worst scenario. The costs of adaptation for the PRC—building sea defenses and upgrading ports—are less than 10% of the expected losses under the worst scenario, so that the net benefits of adaptation are very large. In part, this is because the PRC has invested less in coastal protection than could be justified even without considerations of climate change, so that the benefits of moving to a higher level of coastal protection are substantial. The same conclusion does not apply to Japan and the Republic of Korea, for which the cost of full adaptation exceed the expected losses even under the worst scenario. In these countries a strategy of partial rather than full adaptation may be more efficient.

Agriculture. Up to 2050 the biophysical impacts of climate change—changes in temperature and precipitation—are expected to increase total crop production (measured in calories) in Japan and the Republic of Korea but to reduce it by up to 10% in the PRC. Wheat is the major crop whose yield may be most affected by climate changes, with declines of nearly 24% in the PRC in 2050 under the driest scenario. Allowing for autonomous adaptation in response to changes in world prices and trade reinforces the increase in crop production in Japan and the Republic of Korea, leads to an increase in Mongolia, and reduces the decline in the PRC to 1%–4%. Overall, the changes in crop prices in 2050 and the impact on consumers would be particularly severe in Mongolia, with an increase in crop prices of up to 40% in the worst scenario, largely because of its dependence on imports of wheat. Average calorie consumption in Mongolia could fall by up to 8% of baseline consumption in 2050 without climate change.

Planned adaptation may take the form of (i) investment in irrigation and research and development, thereby increasing the growth in crop yields; and/or (ii) the provision of consumer subsidies. The level of consumer subsidies required to maintain household welfare varies greatly across scenarios but would be less than $10 billion in 2050 for all of East Asia if expenditures on irrigation and research and development are increased by about $1 billion per year. Such adaptation should benefit farmers in the PRC and the trade partners of Japan, Mongolia, and the Republic of Korea. The consumer subsidy results in a significant increase in domestic production in the PRC in 2050. However, opportunities to expand production in the other countries in East Asia are more constrained, so most of the increase in consumption will be supplied from net imports.

Poverty. Without climate change, economic growth is expected to reduce poverty by over 80% in both the PRC and Mongolia by 2050 using the $2 per day poverty standard. The impact of climate change on poverty rates is estimated to be small, with the worst outcome being an increase of less than 1 percentage point in southwest PRC. High food prices due to climate change will tend to decrease poverty because the benefits of higher rural employment will exceed their impact on the cost of living.

Mitigation

As a basis for examining opportunities to reduce emissions of greenhouse gases (expressed in CO_2-equivalent units), the study has constructed marginal abatement cost curves by country for key sectors including industry, energy production, transport, residential, and commercial. Payback periods based on a discount rate of 5% for the low-discount scenario and discount rates of 10%–33% for the high-discount scenario have been used to assess the economic viability of alternative technologies. Particular attention is given to technologies that could reduce emissions before or in 2030 at a cost of no more than $100 per ton of CO_2 equivalent (tCO_2e).

The results suggest that emissions in Japan and the Republic of Korea could be reduced in 2030 by 22%–31% of their baseline level at a cost below this threshold. Of these reductions, 64% in Japan and 68% in the Republic of Korea would actually have a negative net cost using the low discount rate—i.e. the benefits of lower energy bills, improved air quality, and lower resource requirements would exceed the direct costs of reducing emissions. The potential for reducing emissions in the PRC and Mongolia is even greater—reductions of 36%–43% are possible in the PRC and 43%–45% in Mongolia—but the proportions of these which have a negative cost are much lower, at 25% in the PRC and 20% in Mongolia. In absolute terms, the reductions in emissions for the PRC in 2030 that could be achieved at a marginal abatement cost of less than $100 per tCO_2e amount to 6.3 gigatons of CO_2 equivalent under the high-discount scenario and to 7.4 gigatons of CO_2 equivalent under the low-discount scenario.

The kind of measures that have a negative cost include small trucks fuelled by compressed natural gas in the PRC, hybrid passenger cars in Japan and the Republic of Korea, and high-efficiency rail rolling stock and trucks in the PRC and Mongolia. However, many of the opportunities to abate emissions at negative cost rely upon improvements in energy efficiency that have proved difficult to implement in practice because they involve high initial costs, uneven distribution of risks, and mixed incentives for different agents—e.g., owners and tenants.

Delaying measures to reduce emissions from the power sector in the PRC and Mongolia, even by 5 years, reduces the amount of abatement that can be achieved by 2030 or even 2050 as a consequence of the "lock-in" effect linked to the long life of capital equipment used in this sector. A 5-year delay reduces the total abatement potential in 2030 in the PRC by 15% and in Mongolia by 22%.

There are large opportunities in the PRC and Mongolia to take advantage of the overlap between the health benefits of reducing local air pollution and reductions in emissions of greenhouse gases. Improvements in energy efficiency, especially in transport and residential uses of fuel, could have a major impact on exposure to pollutants such as particulates, sulfur dioxide, and nitrous oxides in large cities and other urban areas.

This part of the study uses an integrated assessment model (PAGE09) to examine combinations of adaptation and mitigation on the costs of climate change in East Asia. The models assume that the various forms of damage caused by climate change can be expressed as exponential functions of temperature either at global or country level. As a consequence, the costs of climate change increase rapidly after 2050. Under the business-as-usual (BAU) scenario, in which current patterns of development continue, the average losses in East Asia due to climate change could amount to 5.3% of its annual GDP by 2100.

Minimizing the losses due to climate change will require a combination of planned adaptation to changes that are inevitable plus emissions abatement to slow and eventually reverse the accumulation of greenhouse gases in the atmosphere. Adaptation can make a substantial contribution to reducing the damages due to climate change but it is not sufficient on its own to reduce the expected cost of climate change to a low level. Under the BAU scenario, planned adaptation reduces the residual damage of climate change to an average of 1.6% of GDP in 2100 at an expected adaptation cost of 0.4% of GDP over the period. Clearly, the benefits of planned adaptation greatly outweigh the costs that will be incurred, but this can only be one element of an overall strategy.

Up until 2020 it is possible to achieve a substantial reduction in CO_2 emissions by implementing negative-cost and zero-cost abatement options, but reliance upon a win–win approach will not prevent emissions from increasing substantially from 2020 to 2050. Alternative paths for reducing emissions can be derived by reference to targets for emissions and the concentration of greenhouse gases or by setting maximum values for the marginal abatement cost which increase over time. The first approach is the basis for the Copenhagen–Cancun Convergence (CCC) scenario that aims to stabilize the concentration of CO_2 at 450 ppm and to cap the expected increase in the global mean temperature at about 2.5° C. The second approach provides the basis for alternative strategies under which emissions are reduced more gradually.

Under the CCC scenario, the gains from regional pooling of emission caps and abatement action are large—up to 25% of the costs of implementation if each country acted separately. Even with regional pooling, the total and marginal costs of abatement under this scenario increase rapidly up to 2050 and more slowly thereafter. This is unlikely to be economically efficient when discounting and intergenerational equity are taken into account.

Any comparison of alternative strategies to address climate change must consider the combined effects of mitigation and planned adaptation as well as taking account of the costs of any residual damage. It is also necessary to consider the impact of national policies on the rest of the world. Without discounting, the strategy that has the lowest cost for countries in East Asia on their own would rely upon negative-cost and zero-cost abatement of emissions only, plus planned adaptation to climate conditions in 2100. Under this strategy the level of CO_2 emissions in 2100 would be similar to that in 2010. However, if this strategy is adopted by all countries, the global mean temperature would increase by up to 4°C and average sea level rise might be 0.65 meters, so that any reduction in costs in East Asia would be more than offset by the costs of adaptation and damage due to climate change incurred by other countries.

A better strategy after allowing for such spillovers would involve a gradual reduction in emissions associated with a phased increase in the marginal cost of abatement from $50 per tons of carbon dioxide (tCO_2) in 2030 to $200 per tCO_2 in 2100. In this case the 90% range for the average cost of adaptation is 0.1%–0.5% of GDP over 2010–2100, while the cost of the residual impacts of climate change in 2100 is estimated at 0.7% of GDP.

Policy Responses

East Asia needs to shift toward a model of economic growth focused on low carbon emissions and more efficient use of resources. The region is moving in this direction by establishing targets for improvements in energy efficiency and making investments in clean energy. Additional investments will be required to ensure that infrastructure and communities are resilient to future climate risks.

Market arrangements to price carbon, via either carbon trading or carbon taxes, remain underdeveloped. The PRC, Japan, and the Republic of Korea have made some initial progress in this regard, but much remains to be done. Without a combination of price signals and incentives it will be difficult to stimulate the investment that is required to underpin the transition to low-carbon options in sectors such as energy, manufacturing, and transport.

The public sector has a critical role in promoting the development and deployment of low-carbon technologies. In addition, and as important, public agencies and regulatory bodies must ensure that technical standards for buildings, infrastructure, and other assets are modified to take full account of current weather risks and future climate conditions. Planned adaptation to climate change need not be very costly but this will only be the case if governments take the lead in collecting and disseminating the information required for coherent planning and action with respect to minimizing future climate impacts.

The benefits from regional cooperation in mitigation programs are likely to be substantial. In all of the mitigation scenarios examined, the overall cost of reducing emissions can be reduced by 25% or more if emissions targets are pooled via a regional trading scheme or through adoption of a uniform carbon price. The opportunities for reducing emissions in the PRC are large relative to current and projected emissions, so that a pooling arrangement will involve transfers from Japan and the Republic of Korea to fund reductions in emissions in the PRC. As part of this arrangement, both the PRC and Mongolia would gain from technology transfers, especially those concerning the improvement of energy efficiency.

The benefits from regional cooperation would extend beyond the purely monetary. For the PRC, measures to reduce emissions of greenhouse gases should lead to significant improvements in local air quality, thus reducing the damage to the health of urban populations.

A regional climate network to promote collaborative research and the dissemination of information on regional climate change would contribute to the efforts being made by individual countries. There are, in particular, common issues such as adaptation to sea-level rise, the development of updated technical standards for buildings and infrastructure, the compilation and analysis of databases of weather and climate data, and the promotion of research and development into low-carbon technologies for which cooperation may yield large benefits to all partners. The network could encompass the development of online knowledge platforms and tools. This would provide a base for sharing experience in mitigation and adaptation strategies as well as best practices on policies, programs, and technologies for addressing climate change.

Introduction

The Project

The project built on an earlier successful initiative by the Asian Development Bank (ADB), which focused on climate change mitigation and adaptation in Southeast Asia. It also complements parallel studies being conducted for South Asia, Central and West Asia, and the Pacific. This study covers four member countries— the People's Republic of China (PRC), Japan, the Republic of Korea, and Mongolia. The research was made possible thanks to a grant from ADB's Technical Assistance Special Fund (TASF-others) and assistance from the Government of the Republic of Korea, through the Korea International Cooperation Agency.

The project aimed to contribute to the regional debate on climate change mitigation and adaptation, raising awareness about the urgency of climate change challenges. To achieve this goal, the project supported domestic workshops bringing together country experts to provide background material for each country, which was then discussed in regional workshops. The background material, the notes, and guidance from the workshops provided the basis of this study.[1]

The key objectives of this study were to (i) calculate the costs of climate change adaptation to 2050 using sector-based approaches; (ii) explore the total mitigation potential in East Asia and examine the marginal abatement cost of specific technologies for 2020 and 2030; (iii) calculate the economy-wide impacts of climate change in East Asia to 2100 and the costs of policies for both mitigation and adaptation using top-down integrated assessment modeling; (iv) raise awareness on the urgency of the climate change challenge; and (v) make climate change policy recommendations, including those related to regional cooperation.

[1] The following background reports provide the basis for this book: Kawamata, K. 2011. *Japan Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report). Manila; Chen W. et al. 2012. *People's Republic of China Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report). Manila. The full report was published as Climate Change Impacts: Mitigation and Adaptation Actions Writing Group. 2012. *Climate Change Impacts: Mitigation and Adaptation Actions.* Beijing: Tsinghua University Press (in Chinese language). Lee D.K. and M.K. Lee. 2011. *Republic of Korea Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report). Manila; Batbold, J. and N. Enebish. 2011. *Mongolia Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report). Manila; Hughes, G. A. and P. Chinowsky. 2012. *Adapting to Climate Change for Infrastructure in East Asia* (TA 7465 report). Manila; Nicolls, R., S. Hanson and J. Hickel. 2013. *Cost of Adaptation to Rising Coastal Water Levels for the People's Republic of China, Japan, and the Republic of Korea.* Manila; Mosnier A., P. Havlik, N. Khabarov, E. Schmid, J. Liu, F. Albrecht, and M. Obersteiner. 2012. *Globally Consistent Climate Adaptation in Agriculture for the People's Republic of China, Japan, Republic of Korea, and Mongolia* (TA 7465 report). Manila; Hughes, G. A. 2012. *The Impact of Climate Change on Poverty in the People's Republic of China and Mongolia* (TA 7465 report); *Mizuho Information and Research Institute. 2011. Marginal Abatement Cost Curves for Japan, People's Republic of China, and Mongolia* (TA 7465 report). Manila; Suphachalasai S. 2013. *Integrated Assessment Modeling in East Asia* (TA 7465 report). Manila; Sanchez Martinez, G. and A. Chiabai. 2012. *Public heath adaptation to climate change and its economic implications for People's Republic of China, Japan, Republic of Korea, and Mongolia* (TA 7465 report). Manila; Strzepek, K. 2012. *Indicators to Understanding the Impact of Climate Variability and Change to Flood Risk* (TA 7465 report). Manila; Strzepek, K. 2012. *A Basin Scale Indicator Approach to Understanding the Risk of Climate Variability and Change to Water Resources Development and Management* (TA 7465 report). Manila. For further information see: http://www.adb.org/projects/43421-012/main.

Organization of the Report

This report first provides an overview of the East Asia study region (the PRC, Japan, the Republic of Korea, and Mongolia). It presents key greenhouse gas emission data, summarizes trends in historical climate and future climate projections from global climate models (General Circulation Models [GCMs]), and discusses climate change impacts for the region (Chapter 1). The report then presents the results of analyses of the costs of climate change adaptation to 2050 for three critical sectors for the region: infrastructure (Chapter 2), coastal protection (Chapter 3), and agriculture (Chapter 4). Chapter 5 explores possible poverty impacts of climate change in Mongolia and the PRC. Chapter 6 looks at the costs of greenhouse gas abatement, the costs of sector-specific mitigation options, and the total abatement potential in East Asia in 2020 and 2030. Chapter 7 provides a long-term perspective of climate change implications in East Asia (up to 2100), using top-down integrated assessment modeling to consider the uncertainties associated with climate impacts and adaptation–mitigation linkages. Finally, Chapter 8 reviews climate change policies and initiatives in the countries of East Asia, discusses gaps, and makes recommendations on areas of regional cooperation.

As much as possible, the study has sought to maintain consistency. For example, the sector-based adaptation analyses employ projections from the same set of GCMs[2] (in the case of the infrastructure and agriculture chapters) and consider the same emissions scenarios (A2 high emissions scenario). By nature, each sector has different methodological and modeling approaches, so complete congruence is not possible. For example, the infrastructure sector analysis is more advanced, and thus can explore issues related to how adaptation actions vary over time, maladaptation, and optimal decision making under uncertainty. The sector-based chapters on the costs of adaptation and the chapter on integrated assessment modeling all incorporate climate uncertainty (Box 1). All of the chapters in the report use the same set of socioeconomic projections for East Asia and present values in constant 2005 dollars.

The time frames across chapters do differ for several important reasons. The cost of adaptation for each sector was calculated out to 2050.[3] This is a reasonable development time frame, and beyond that the costs of calculating the sector impacts become more uncertain. Chapter 6 only considers the years 2020 and 2030, because beyond that it is difficult to foresee what specific technologies will be in use. Lastly, the integrated assessment modeling analysis (Chapter 7) includes the costs of mitigation and adaptation from 2010 to 2050, but also to 2100, in order to take a longer perspective on climate change policies.

Each chapter can be read as a separate piece of analysis.

Key Considerations for the Economics of Climate Change Adaptation

As this report is focused largely on adaptation, it is important to explain the approach in more detail. The adaptation parts (Chapters 2–4) follow the World Bank's global study on the Economics of

2 Although for the agricultural analysis, only three GCMs are used, not 17 as in the infrastructure study. The agriculture trade model, Global Biosphere Management Model (GLOBIOM), is computationally intensive, and so only three climate scenarios could be considered.

3 There are slight differences in the time frame for each chapter. The infrastructure chapter presents the annual adaptation costs from 2011 to 2050, while the coastal protection chapter presents the annual costs from 2010 to 2050. The agriculture chapter simply presents the costs of adaptation in 2050.

Adaptation to Climate Change (EACC)[4] and circumscribe the costs of adaptation to only include the impacts and costs of future climate change; the so-called "adaptation deficit" to current climate is not considered in the cost calculations. Moreover, the costs of measures that would have been undertaken even without climate change are not included in adaptation costs. The adaptation costs presented are only those resulting from *planned* adaptation, not *autonomous* or *spontaneous* adaptation on the part of communities or households without public intervention and finance. Lastly, it is assumed that countries adapt to the same level of welfare in the (future) world as they would have in the absence of climate change.

The choice of sectors for the sector-based economic analysis of climate change adaptation—infrastructure, coastal zone, and agriculture—was illuminated by the World Bank's EACC study (footnote 4). In terms of total adaptation costs worldwide between 2010 and 2050, the four top sectors considered in the EACC were infrastructure ($13.0 billion–$27.5 billion per year); coastal zones ($27.6 billion–$28.5 billion per year); water supply and flood protection ($14.4 billion–$19.7 billion per year); and agriculture, forestry, and fisheries ($2.5 billion–$3.0 billion per year). In the current study, the infrastructure chapter includes analyses related to the water sector, such as adapting water and sewer infrastructure to changing precipitation patterns, as well as the economic impacts of inland flooding.

The sector-based analyses were focused on the costs of adaptation to 2050 using the GCM projections for the A2 emissions scenario, but there was no attempt to examine more extreme warming (e.g., the A1F1 emissions scenario[5]).

Careful attention was paid to avoid double-counting costs in the infrastructure and coastal zone analyses. The infrastructure analysis addresses the costs of adaptation—not only changes in infrastructure demand and climate-proofing infrastructure across a broad suite of infrastructure classes (transport, especially roads, rail, and ports; electricity; water and sanitation; and communications) but also urban and social infrastructure (such as urban drainage, urban housing, health and educational facilities [both rural and urban], and public buildings). The impacts of sea-level rise and storm surge are excluded from this infrastructure analysis. The coastal zone analysis examines these impacts on wetland and dryland loss and forced migration, and the costs associated with adaptation measures, such as beach nourishment and dike upgrade and maintenance. Moreover, while both chapters explore the impacts of tropical storms, the infrastructure chapter only considers wind damage, while the coastal zone chapter only examines coastal flooding.

Human health was not explicitly included in economic analysis in this study, although the health impacts are reviewed in Chapter 1 and human health enters into the sector analyses implicitly. Adapting infrastructure to climate change (e.g., flooding and heat waves) has significant human health benefits, although there are limits to the extent to which infrastructure improvements can ameliorate the human health impacts of climate change (Chapter 1, Table 7 and Chapter 2, Box 1). The agriculture sector analysis calculates the costs of consumer subsidies needed to maintain the level of food consumption in the absence of climate change.

[4] World Bank. 2009. *The Costs to Developing Countries of Adapting to Climate Change: New Methods and Estimates.* Washington, DC; World Bank. 2010. *Economics of Adaptation to Climate Change: Synthesis Report.* Washington, DC. The costs were revised in the latter publication.

[5] World Bank. 2012. *Turn Down The Heat: Why a 4°C Warmer World Must Be Avoided*. Washington, DC.

Box 1 Climate Scenarios and Uncertainty

The sector-based chapters (Chapters 2–4) on the costs of climate change adaptation make use of projections from climate models (General Circulation Models [GCMs]) from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report.[a] The model projections represent reasonable climate futures, but one does not know which scenario—if any—will eventuate. Moreover, these projections are often from one or just a few model runs. Thus, the costs of adaptation are presented as ranges across these scenarios, showing the climate uncertainty, but there are no probability distributions of costs.

The integrated assessment models (IAMs) in Chapter 7 are fundamentally different models. They couple climate impacts, mitigation, and adaptation together into one framework. They start by using socioeconomic projections to project greenhouse gas emissions. IAMs then relate greenhouse gas concentrations to increases in global mean temperature (and sea-level rise). IAMs in turn translate warming into impacts in region- or country-specific economic sectors (e.g., agriculture, water, biodiversity) through damage functions. Moreover, they include functions that calculate the cost of adaptation actions. All of these functions can be probabilistic, taking into consideration uncertainty. Thus, the IAM results in this report for warming; sea-level rise; and impact, mitigation, and adaptation costs are presented as distributions.

[a] Solomon, S. et al., eds. 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York: Cambridge University Press.

Combining Analyses of Mitigation and Adaptation

The analysis in Chapter 7 builds upon the examination of adaptation and abatement options discussed in previous chapters. Adaptation expenditures reduce the damage which would otherwise be caused by climate change but they cannot provide complete protection against the impacts of climate change. Equally, the most ambitious abatement strategy will take time to slow and stabilize the accumulation of greenhouse gases in the atmosphere. As a consequence, the chapter focuses on the implications of adopting combined strategies that incorporate both mitigation and adaptation rather than relying upon either exclusively.

Adaptation is largely a national concern, but strategies to mitigate climate change require a high degree of international cooperation if they are to succeed. Hence, the integrated assessment model used in this chapter provides a framework for analyzing the global linkages which underpin the climate system and the international economy. This model – the PAGE09 model – is the current version of a model which was used in previous ADB studies of the economics of climate change.

The estimates of the damage caused by climate change as well as of the costs of mitigation and/or adaptation are based on highly simplified relationships linked to global temperature and emissions. They are intended to provide orders of magnitude but inevitably they are sensitive to assumptions which are built into the analysis. The absolute magnitudes are indicative but they should not be treated as forecasts. What is important is that the integrated assessment model provides a framework for comparing alternative strategies for responding to climate change.

Chapter 1

Climate Change Impact on East Asia

Key Messages

- **East Asia is a unique region. It is critically important to global mitigation efforts.** The region—consisting of about one-quarter of the global population—is responsible for about 30% of the world's energy-related greenhouse gas emissions, although per capita energy-related emissions in the People's Republic of China (PRC) and Mongolia are half the Organisation for Economic Co-operation and Development (OECD) average.
- **The region has made great strides in reducing the energy intensity of its economies.** In the PRC, energy intensity has decreased 55% during 1990–2010; in Mongolia it has decreased 50% over the same period.
- **However, per capita emissions have been increasing in the region.** Per capita emissions in OECD countries decreased slightly from 10.49 tons of carbon dioxide (CO_2) per capita in 1990 to 10.10 tons per capita in 2010. In contrast, the PRC's per capita emissions almost trebled over the same period, from 1.95 tons of CO_2 per capita in 1990 to 5.39 tons per capita in 2010. Similarly, per capita emissions more than doubled in the Republic of Korea, from 5.35 tons of CO_2 per capita in 1990 to 11.52 tons per capita in 2010.
- **The region is also quite vulnerable to some impacts of climate change, particularly those associated with sea-level rise, cyclones, and flooding.** Three cities in East Asia—Guangzhou and Shanghai in the PRC and Osaka/Kobe in Japan—are in the top 10 in the world in terms of current exposed population.
- **Countries in East Asia are exposed to a variety of climate-related natural disasters because of their size and location.** Cyclones, floods, and droughts cause significant mortality and economic losses. Managing the risks of climate-related natural disasters is already a major concern and will become even more important in future.
- **East Asia is warming.** Annual mean temperatures have risen across the region since 1970, but there are no clear trends in mean annual precipitation or the number of wet days per year.
- **Climate models project a warmer and wetter East Asia.** At the country level, global climate models (General Circulation Models [GCMs]) project that by 2050 average temperatures in East Asia will be between 1.9° Celsius (C) (Japan and the Republic of Korea) to 2.6° C (Mongolia) higher than the 1961–1990 baseline using a scenario consistent with recent trends in emissions. Most GCMs project that the region will become wetter by 2050, with the exception of southeastern PRC. By 2100, mean annual precipitation is projected to rise for almost the entire region, with country averages increasing by 44 millimeters (mm) for Mongolia and 97 mm for the Republic of Korea.

Study Area

For the purposes of this study, East Asia consists of the People's Republic of China (PRC),[1] Japan, the Republic of Korea, and Mongolia. It contains the world's second- and third-largest economies,[2] and close to one-quarter of its population.[3]

The region is unique in that it is a large emitter of greenhouse gases, with critical importance to global mitigation efforts, yet it also may experience some significant climate change impacts. In 2010, the PRC, Japan, and the Republic of Korea ranked in the top 15 countries for total greenhouse gas emissions.[4] In 2007, the PRC became the largest source of energy-related emissions,[5] and it accounted for almost one-quarter of the global total, although its per capita emissions were only one-third of those of the United States and 25% lower than the overall average for the European Union.[6] Coastal areas in East Asia are very prone to the impacts of sea-level rise and increased storm surge that will come with climate change. There are food security concerns in the PRC that could be amplified by climate change. In Mongolia, continued warming may exacerbate existing natural resource concerns, such as a diminution of water resources and desertification, the latter already affecting 78% of the country which is quite dependent on agriculture.[7]

The PRC dwarfs the other countries in the region, with a land area of more than 9.6 million square kilometers (km^2) and a population of 1.34 billion. With a population of just 2.7 million in an area of more than 1.5 million km^2, Mongolia has a population density less than half that of the other countries in the group. The PRC and Mongolia have experienced much more rapid gross domestic product (GDP) growth rates early this century than Japan and the Republic of Korea; the PRC, growing at an average annual rate of 10% between 2000–2012, eclipsed Japan as the world's second-largest economy in the world in 2010 with a GDP of about $8.2 trillion in 2012. The structures of the economies are also quite different. The Japanese and Korean economies are dominated by the service sectors, responsible for 71% of GDP in Japan and 58% in the Republic of Korea; this is typical of mature economies.[8] In the PRC, manufacturing remains the largest sector, accounting for 47% of output in 2011. In Mongolia, which has recently experienced a mining boom, agriculture has a declining share of GDP, although it still comprised 15% of the economy in 2011.

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1 This report does not include the PRC's special administrative regions (Hong Kong, China and Macao, China).
2 *World Bank World Development Indicators.* http://data.worldbank.org/indicator
3 United Nations Department of Economic and Social Affairs, Population Division. World Population Prospects, the 2010 Revision. http://esa.un.org/unpd/wpp/unpp/panel_population.htm
4 Data on total emissions of greenhouse gases (GHGs) refers to estimates excluding land use change and forestry (LUCF) which have been extracted from version 2 (beta) of the Climate Analysis Indicators Tool developed by the World Resources Institute http://cait2.wri.org. Accessed August 2013.
5 Energy-related carbon dioxide (CO_2) emissions are synonymous with CO_2 emissions from fossil fuel combustion. This includes everything where fossil fuels are burned—electricity and heat, industry and manufacturing energy use (but not cement kilning), and transport (e.g., cars, trucks, etc.).
6 Data on energy-related CO_2 emissions are published by the International Energy Agency (IEA) and were extracted from the IEA database. http://www.iea.org/media/statistics/CO2Highlights2012.xls – assessed August 2013.
7 Batbold, J. and N. Enebish. 2011. *Mongolia Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report).
8 Data on share of sectors in national economies from ADB Key Indicators, updated as of 30 June 2012.

Greenhouse Gas Emissions

East Asia is responsible for about 30% of the world's energy-related emissions

East Asia is an export-oriented industrial powerhouse, heavily dependent on energy-intensive production systems. Thus, in 2010, it produced about 30% of the world's energy-based CO_2 emissions,[9] with the PRC the world's largest emitter at over 7.2 billion tons (24% of the world's total).[10] Concomitant with the rise of the PRC as an economic power, energy-related CO_2 emissions increased more than 200% during 1990–2010. Similarly, energy-based CO_2 emissions in the Republic of Korea have increased by 145% over the period, while they have changed little in Japan and declined slightly in Mongolia (Table 1). In all four countries, electricity and heat production are the biggest source of energy-related CO_2 emissions, and in Mongolia this sector contributes to a majority of the energy-based CO_2 emissions. Manufacturing is responsible for a greater percentage of energy-based CO_2 emissions in the PRC (33%) than in the rest of the region, while in Japan and the Republic of Korea transport is relatively more important, comprising about 20% of the total energy-based CO_2 emissions in each country (Table 2).

Per capita energy-related emissions in the People's Republic of China and Mongolia are half the Organisation for Economic Co-operation and Development average

In 2010, the Republic of Korea had the highest per capita energy-related CO_2 emissions (11.5 tons), closely followed by Japan (8.97 tons)—roughly comparable to the Organisation for Economic Co-operation and Development (OECD) average of 10.10 tons (Table 3). However, per capita energy-related CO_2 emissions in the PRC and Mongolia were about half the OECD average, and only slightly more than the world average of 4.4 tons (footnote 10). Per capita energy-related CO_2 emissions increased in the PRC (by 176%), the Republic of Korea (by 115%), and Japan (4.2%) during 1990–2010, while per capita emissions decreased in Mongolia.

While emissions in the PRC have increased dramatically, the country's per capita income and energy-related CO_2 emissions lag behind those of Japan, the Republic of Korea, the United States, and the European Union (Figure 1).

Energy intensity has declined significantly in East Asia

Energy intensity has decreased over time in all four countries, although the rate of decrease has been far greater in the PRC (55%) and Mongolia (50%) during 1990–2010 (Table 4). In absolute terms, Japan is the least energy-intensive economy in the region, emitting 0.29 kilograms (kg) of CO_2 per unit of GDP. Mongolia is the most energy intensive (1.19 kg of CO_2 per unit of GDP), more than five times greater than Japan and 2.7 times greater than the world average (0.44 kg of CO_2 per unit of GDP) (footnote 10). Many opportunities exist to deploy energy efficiency technologies in Mongolia. Figure 2 shows how energy intensity in East Asia compares with that of other countries.

The energy sector is the largest contributor to total greenhouse gas emissions in East Asia, except for Mongolia where it is agriculture

The previous sections on emissions concerned only energy-related CO_2 emissions, i.e., from fossil fuel combustion. However, this ignores other major greenhouse gases—methane (CH_4), nitrous

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9 Synonymous with CO_2 emissions from fossil fuel combustion.

10 International Energy Agency. 2012. *CO_2 Emissions from Fuel Combustion.* Paris. Note that the IEA reports separate estimates for the PRC and Hong Kong, China. For consistency in comparisons with 1990 the figures for the PRC shown in the tables do not include Hong Kong, China.

Table 1 Total Energy-Related Carbon Dioxide Emissions, 1971–2010 ($MtCO_2$)

Country	1971	1975	1980	1985	1990	1995	2000	2005	2007	2008	2009	2010	% Change (1990–2010)
PRC	800.4	1,051.2	1,405.3	1,704.9	2,211.3	2,986.1	3,037.3	5,062.4	6,028.4	6,506.8	6,800.7	7,217.1	226.4
Japan	758.8	856.3	880.7	878.1	1064.4	1,147.9	1,184	1,220.7	1,242.3	1,154.3	1,095.7	1143.1	7.4
Republic of Korea	52.1	76.8	124.4	153.3	229.3	358.6	437.7	467.9	490.3	501.7	515.5	563.1	145.6
Mongolia	…	…	…	11.6	12.7	10.1	8.8	9.5	11.1	11.2	12	11.9	(6.3)

… = not available, $MtCO_2$ = million tons of carbon dioxide, PRC = People's Republic of China.

Note: Based on the bottom-up, sector approach.

Source: International Energy Agency. 2012. *CO_2 Emissions from Fuel Combustion.* Paris.

Table 2 Sector Breakdown of Energy-Related Carbon Dioxide Emissions in 2010 ($MtCO_2$)

Country	Total CO_2 Emissions (2010)	Electricity and Heat Production	Industry (Own Use)	Manufacturing and Construction	Transport	Other
PRC	7,217.1	3,549.2 (49%)	275.5 (4%)	2,327.6 (32%)	508.8 (7%)	556.8 (8%)
Japan	1,143.1	463.5 (41%)	44.0 (4%)	249.8 (22%)	222.7 (19%)	163.1 (14%)
Republic of Korea	563.1	279.2 (50%)	36.2 (6%)	98.6 (18%)	86.8 (15%)	62.3 (11%)
Mongolia	11.9	8.1 (68%)	0	1.3 (11%)	1.4 (12%)	1.0 (8%)

CO_2 = carbon dioxide, $MtCO_2$ = million tons of carbon dioxide, PRC = People's Republic of China.

Note: Figures in parentheses represent percentage of total.

Source: International Energy Agency. 2012. *CO_2 Emissions from Fuel Combustion*. Paris.

Table 3 Per Capita Energy-Related Carbon Dioxide Emissions ($MtCO_2$)

Country	1971	1975	1980	1985	1990	1995	2000	2005	2007	2008	2009	2010	% Change (1990–2010)
PRC	0.95	1.15	1.43	1.62	1.95	2.48	2.41	3.88	4.57	4.91	5.13	5.39	176.4
Japan	7.23	7.66	7.52	7.25	8.61	9.14	9.33	9.55	9.72	9.04	8.58	8.97	4.2
Republic of Korea	1.58	2.18	3.26	3.76	5.35	7.95	9.31	9.72	10.12	10.32	10.57	11.52	115.3
Mongolia	…	…	…	6.08	5.71	4.43	3.69	3.72	4.25	4.24	4.49	4.31	(24.5)

… = not available, ( ) = negative, $MtCO_2$ = million tons of carbon dioxide, PRC = People's Republic of China.

Note: Based on the bottom-up, sector approach.

Source: International Energy Agency. 2012. *CO_2 Emissions from Fuel Combustion.* Paris.

oxide (N_2O), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Moreover, CO_2 is also produced by sources other than fossil fuel combustion, such as cement production and deforestation. In 2010, the energy sector[11] produced the vast majority of total greenhouse gas emissions (Figure 3) in Japan (89%), the PRC (82%), and the Republic of Korea (79%). However, in Mongolia, the land use change and forestry (44%) and agriculture (28%) sectors (largely through livestock production)[12] produce the majority of emissions.

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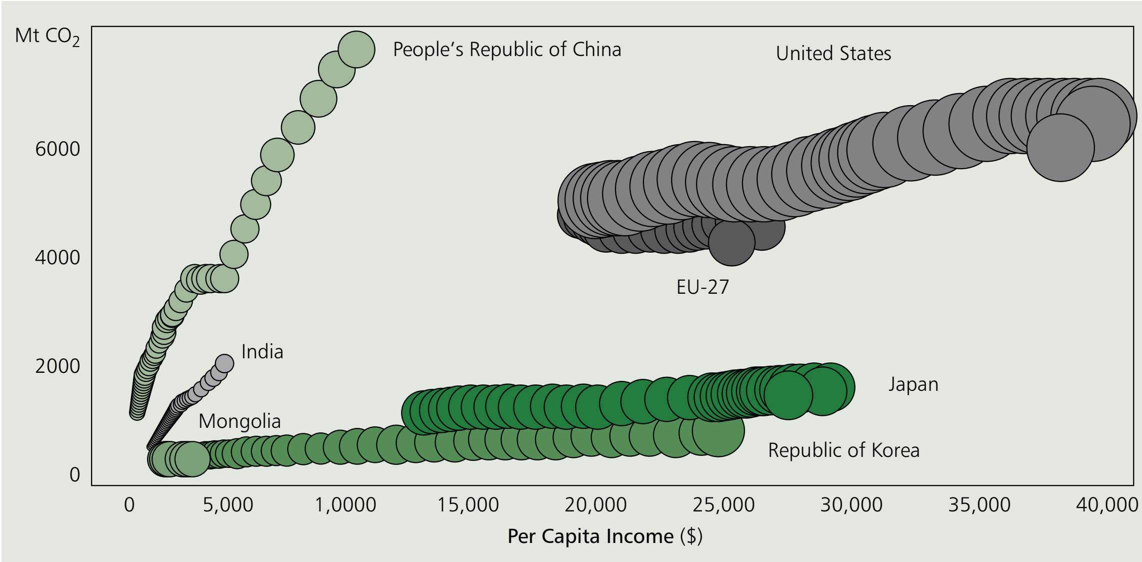
[11] The energy sector includes not only CO_2 emissions from fossil fuel combustion but also fugitive emissions of CH_4 and N_20 (oil and gas flaring, coal mining) and N_20 from combustion (biomass burning).

[12] This includes CH_4 and N_20 emissions from enteric fermentation, livestock manure management, rice cultivation, and agricultural soils.

Figure 1 Total Energy-Related Emissions in East Asia and Other Countries versus Per Capita Income, 1971–2009



$MtCO_2$ = million tons of carbon dioxide.

Notes: The size of the circle indicates per capita emissions. Gross domestic product data are in constant dollars 2000 (purchasing power parity).

EU-27 = Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.

Source: International Energy Agency. 2011. *CO_2 Emissions from Fuel Combustion.* Paris.

Historical Climate Change and Climate Variability

Climate-related natural disasters have had large impacts in East Asia

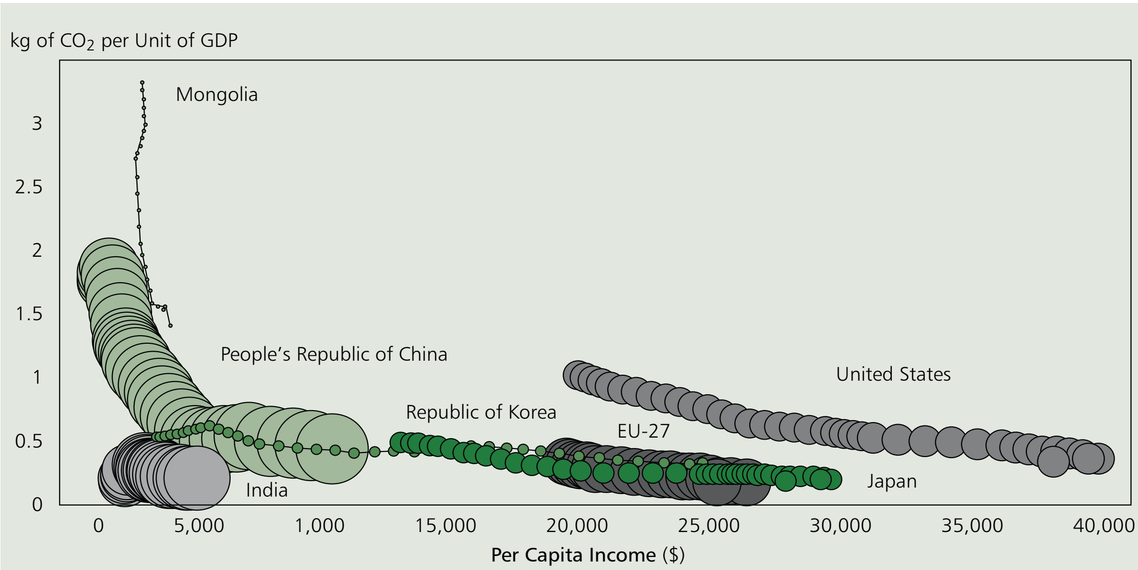
Because of their size and location, countries in East Asia are highly vulnerable to natural disasters of all kinds—from earthquakes to floods and droughts. The economic losses from climate-related natural disasters since 1970 have been significant in absolute terms: $259 billion in the PRC, $64 billion in Japan, $15 billion in the Republic of Korea, and $2 billion in Mongolia. The losses amount to less than 0.2% of GDP over the period but they are highly concentrated, both geographically and in their impact on subgroups of the population.

Economic growth has increased the value of assets at risk, so that indicators that rank disasters by the absolute value of the economic losses experienced show a rising trend in the number of climate-related disasters (Figure 4). On the other hand, there has been no trend in economic losses as a proportion of GDP or in the total number of people affected by climate-related natural disasters in any country.

The PRC is particularly vulnerable to flood disasters. Floods in the Yangtze and Songhua Rivers in May–June 1998 rank as the second costliest flood disaster in the world between 1980–2012, causing losses of more than $30 billion and over 4,000 deaths.[13] Japan and the Republic of Korea are at particular risk from tropical cyclones. Each of the 10 costliest typhoons in the North Pacific during 1980–2012 affected either Japan or the Republic of Korea.

[13] Munich Re NatCatService: http://www.munichre.com/en/reinsurance/business/non-life/georisks/natcatservice/default.aspx Accessed August 2013.

Figure 2 **Energy Intensity in East Asia and Other Countries versus Per Capita Income, 1971–2009** (kilograms of CO_2 per unit of GDP)



CO_2 = carbon dioxide, GDP = gross domestic product, kg = kilogram.

Notes: The size of the circle indicates per capita emissions. GDP data are in constant dollars 2000 (purchasing power parity).

EU-27 = Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.

Source: International Energy Agency. 2011. *CO_2 Emissions from Fuel Combustion.* Paris.

Table 4 **Energy Intensity** (kilograms of CO_2 per unit of GDP)

Country	1971	1975	1980	1985	1990	1995	2000	2005	2007	2008	2009	2010	% Change (1990–2010)
PRC	1.80	1.90	1.85	1.35	1.20	0.91	0.61	0.64	0.59	0.58	0.56	0.79	(55.3)
Japan	0.61	0.58	0.48	0.39	0.37	0.37	0.36	0.35	0.34	0.32	0.32	0.29	(11)
Korea, Rep. of	0.65	0.67	0.73	0.59	0.53	0.57	0.54	0.46	0.44	0.44	0.45	0.43	(13.1)
Mongolia	…	…	…	3.29	2.97	2.72	2.09	1.64	1.60	1.49	1.62	1.19	(49.8)

… = not available, ( ) = negative, CO_2 = carbon dioxide, GDP = gross domestic product, PRC = People's Republic of China.

Note: GDP data are in constant dollars 2000 (purchasing power parity).

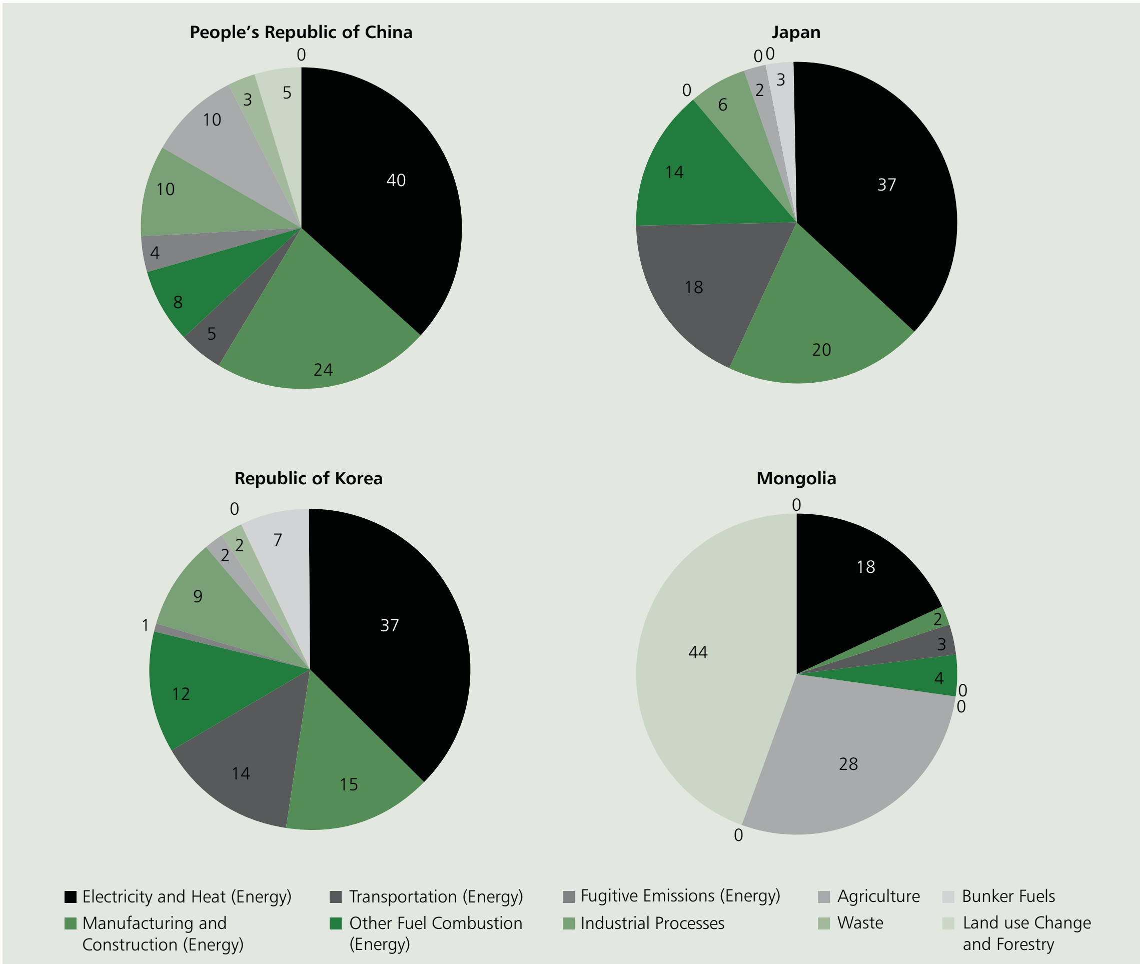
Source: International Energy Agency. 2012. *CO_2 Emissions from Fuel Combustion.* Paris.

There is a clear warming trend in the region

To assess whether there are any annual trends in climate in East Asia, five variables were considered: annual precipitation, the number of wet days (precipitation $\geq$ 0.1 millimeter [mm]) per year, mean annual temperature per year, mean monthly daily minimum temperature per year, and mean monthly daily maximum temperature per year.[14] Across the entire region for every political unit considered (i.e., provinces for the PRC and Mongolia, larger regions for Japan and the Republic of Korea), there

[14] The data are from the Climate Research Unit of the University of East Anglia, United Kingdom (CRU TS 3.0). The data have a spatial resolution of 0.5° worldwide and cover 1901–2006 on a monthly basis. The data were obtained from the CGIAR-Consortium for Spatial Information. http://csi.cgiar.org/cru_climate.asp

Figure 3 Sector Shares of Total Greenhouse Gas Emissions in East Asia, 2010 (%)



$MtCO_2e$ = million tons of carbon dioxide equivalent.

Source: World Resources Institute Climate Analysis Indicators Tool http://cait2.wri.org /. See also World Resources Institute. 2013. CAIT 2.0: Country GHG Sources and Methods http://cait2.wri.org/docs/CAIT2.0_CountryGHG_Methods.pdf

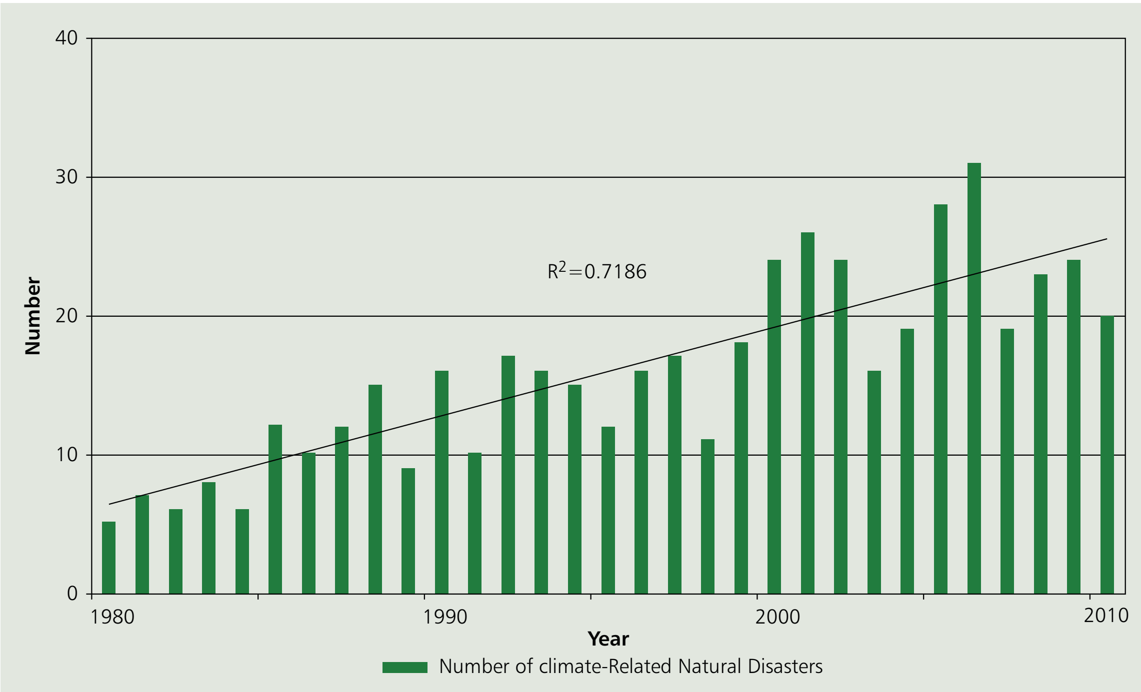
are distinct increasing annual trends[15] in mean annual temperature during 1961–2006. Moreover, there have been increasing trends in mean monthly daily minimum and daily maximum temperature across most of the region. However, there are no statistically significant robust trends in mean annual precipitation or the number of wet days per year over almost all of East Asia over the last half century, with the exception of a few areas in both the PRC and Mongolia.

Projected Climate Change

Climate projections from 17 General Circulation Models (GCMs) were considered for the analyses of the economics of climate change adaptation in this study (Appendix). Of the four "pillar" emission

15 Using Mann-Kendall Trend Analysis. See Mann, H. B. 1945. Nonparametric Tests against Trend. *Econometrica* 13, 245–59; and Karabörk, M. C. 2007. Trends in Drought Patterns in Turkey. *Journal of Environmental Engineering and Science* 6: 45–52.

Figure 4 Climate-Related Natural Disasters in the People's Republic of China, 1970–2011



Note: Climate-related includes drought, flood, extreme temperature, mass movement dry, mass movement wet, storm, and wildfire. Flood-related disaster includes flood, mass movement wet, and storm. R^2 measures how well the trend line shown fits the annual observations with a value 0 meaning a very poor fit and 1 a perfect fit.

Source: EM-DAT, Centre for Research on the Epidemiology of Disasters, Université Catholique de Louvain. http://www.emdat.be/advanced-search. Accessed 15 February 2012.

scenarios of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (A1, A2, A1B, and B2),[16] only projections for the A2 high emissions scenarios were used for the adaptation component of the study.[17] There are several reasons for this. There are no significant differences across scenarios in their warming projections until 2030; moreover, even by mid-century, the variation between models (e.g., in precipitation projections) within one emission scenario tends to be greater than the variation between model means calculated across the emission scenarios. Most importantly, recent energy-related CO_2 emissions have tracked or exceeded the A2 scenario (Figure 5). While the IPCC emissions scenarios incorporate projections on GDP, population, and technological development,[18] for the purposes of this study only the emissions themselves are considered, and separate socioeconomic projections are used (Chapter 2).

Climate models project a warmer and wetter East Asia

East Asia is expected to become significantly warmer this century. At the country level, on average, GCMs project that the region will warm by 1.94° Celsius (C) (Japan and the Republic of Korea) to

[16] Solomon, S. et al., eds. 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, United Kingdom (UK) and New York: Cambridge University Press, IPCC.

[17] There is a higher emissions scenario, A1F, but relatively few models for the IPCC Fourth Assessment Report provide projections for this scenario.

[18] Nakicenovic, N. and R. Swart, eds. 2000. *Emissions Scenarios*. Cambridge, UK: Cambridge University Press, IPCC. p. 570.

2.56° C (Mongolia) by 2050, and by 3.81° C (the PRC) and 5.16° C (Mongolia) by 2090 (based on the GCM ensemble median) (Table 5, Figures 6–7). The greatest warming is projected to be in the northern parts of the region, especially Mongolia and western PRC.

Most of the GCMs project that the region will become wetter by 2050, with the exception of southeastern PRC (Figures 8–9, Table 6). But by 2100, increased precipitation is projected for almost the entire region, with very strong degree of model agreement. At the country level, on average, mean annual precipitation is projected to increase 20 millimeters (mm) (Mongolia) to 91 mm (the Republic of Korea) by 2050, and 44 mm (Mongolia) to 97 mm (the Republic of Korea) by 2090 (based on the GCM ensemble median). Precipitation is also projected to increase on average in every season by the end of the century across the four countries. By 2090, only one province in the PRC (Hainan) is projected on average to show a slight decline in mean annual precipitation; all provinces and regions in Japan, Mongolia, and the Republic of Korea are expected to experience precipitation increases. Projections for the change in mean annual runoff[19] largely mirror those of mean annual precipitation, although there are more areas with projected declines in 2090 and there is more model disagreement.

GCMs do a much better job of projecting long-term changes (in the order of decades) in average monthly or annual variables (e.g., temperature); there is much less certainty about projections on smaller time scales, such as temperature or precipitation forecast for individual years.[20] As they are coarse-scale models (typically 100–400 kilometers), smaller-scale components, such as clouds and topographic features, are simplified. Phenomena such as tropical cyclones are not reproduced well in most GCMs.[21] Extreme precipitation events are difficult to model, not only because of this spatial resolution issue but also because, by definition, they are rare events.[22] Nevertheless, there is very good model agreement in East Asia (including the four countries of this study) that the 1-in-20-year maximum daily precipitation event is likely to be more like a 1-in-4-year to 1-in-15-year event by the end of this century (A2 emissions scenario). Moreover, the 1-in-20-year hottest day is likely to become a 1-in-2-year or yearly event by the end of this century. [23]

Climate Change Impacts

Water resources

Possible increased flooding. The projected increase in annual precipitation together with greater seasonal variation and more severe extreme events will increase the frequency and severity of floods unless measures are implemented to strengthen flood defenses and/or to reduce vulnerability to flooding. Chapter 2 provides more detail and suggests that current standards for the level of protection against both cumulative and short-term flooding need to be raised significantly in order to reduce the impact of flooding in 2050.

More variable water resources. Even though total precipitation is expected to increase, it is changes in the seasonal pattern of run-off that are more important for agriculture. The averages shown in

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19 Runoff is a function of both precipitation and temperature (evaporation) (see Appendix).

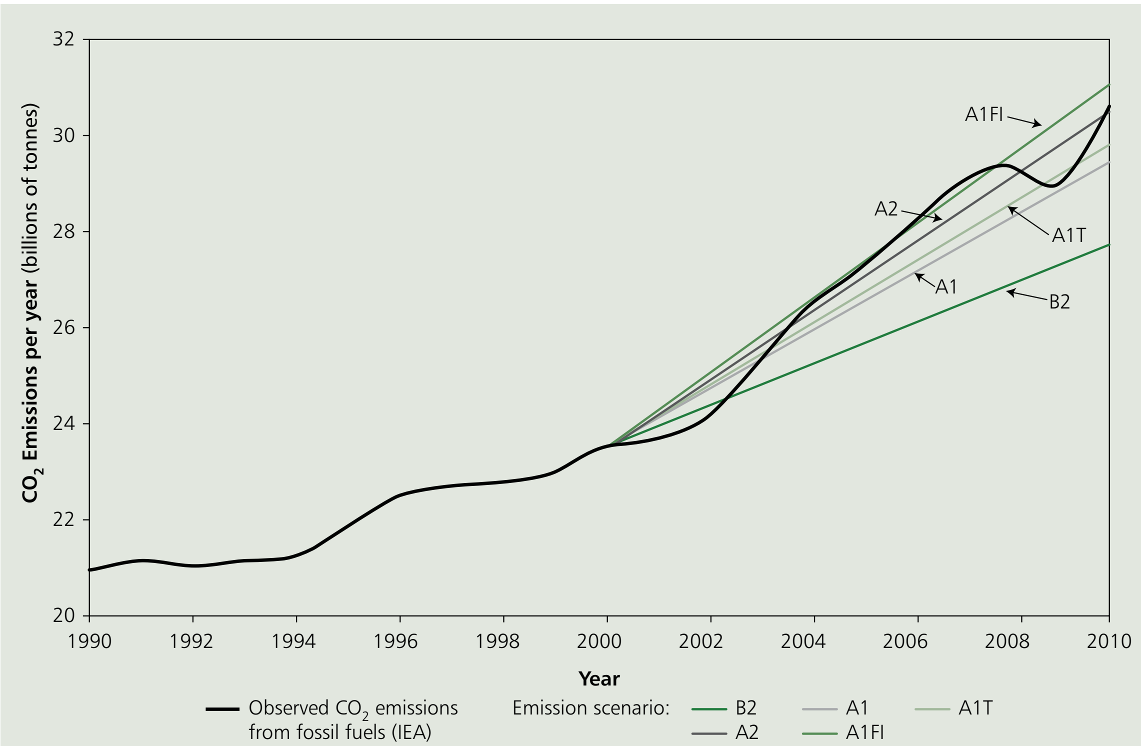
20 Wilby, R. L. et al. 2009. A Review of Climate Risk Information for Adaptation and Development Planning. *International Journal of Climatology* 29: 1,193–215.

21 Grossmann, I. and M. Granger Morgan. 2011. Tropical Cyclones, Climate Change, and Scientific Uncertainty: What Do We Know, What Does it Mean, and What Should Be Done? *Climatic Change* 108: 543–79; Real Climate: http://www.realclimate.org/index.php/archives/2008/05/climate-change-and-tropical-cyclones-yet-again/

22 Southwest Climate Change Network. http://www.southwestclimatechange.org/climate/modeling/regional-scale

23 IPCC. 2012. *Summary for Policymakers. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Edited by C. B. Field et al. Cambridge, UK and New York: Cambridge University Press, 1–19 (Figure SPM.4A and SPM.4B).

Figure 5 Comparison of Actual Energy-Related Emissions with Intergovernmental Panel on Climate Change Projections, 1990–2010



Source: Skeptical Science: http://www.skepticalscience.com/graphics.php?g=20. The International Energy Agency (IEA) emissions data up to 2008 are from: IEA. 2011. *CO_2 Emissions From Fuel Combustion: Highlights*. Paris. The data for 2009 and 2010 are unpublished IEA numbers. http://www.iea.org/index_info.asp?id=1959

Table 5 Country Averages for the General Circulation Models Ensemble Median for the Change in Mean Annual Temperature in East Asia (°C)

Country	2030	2050	2090
People's Republic of China	1.40	2.30	4.65
Japan	1.33	1.94	3.81
Republic of Korea	1.29	1.94	4.05
Mongolia	1.58	2.56	5.16

Notes: A2 emissions scenario. Projections for 17 General Circulation Models (GCMs) are included. "2030" means the change in mean annual temperature for 2026–2035 compared to 1961–1990, similarly for the other time periods (Appendix).

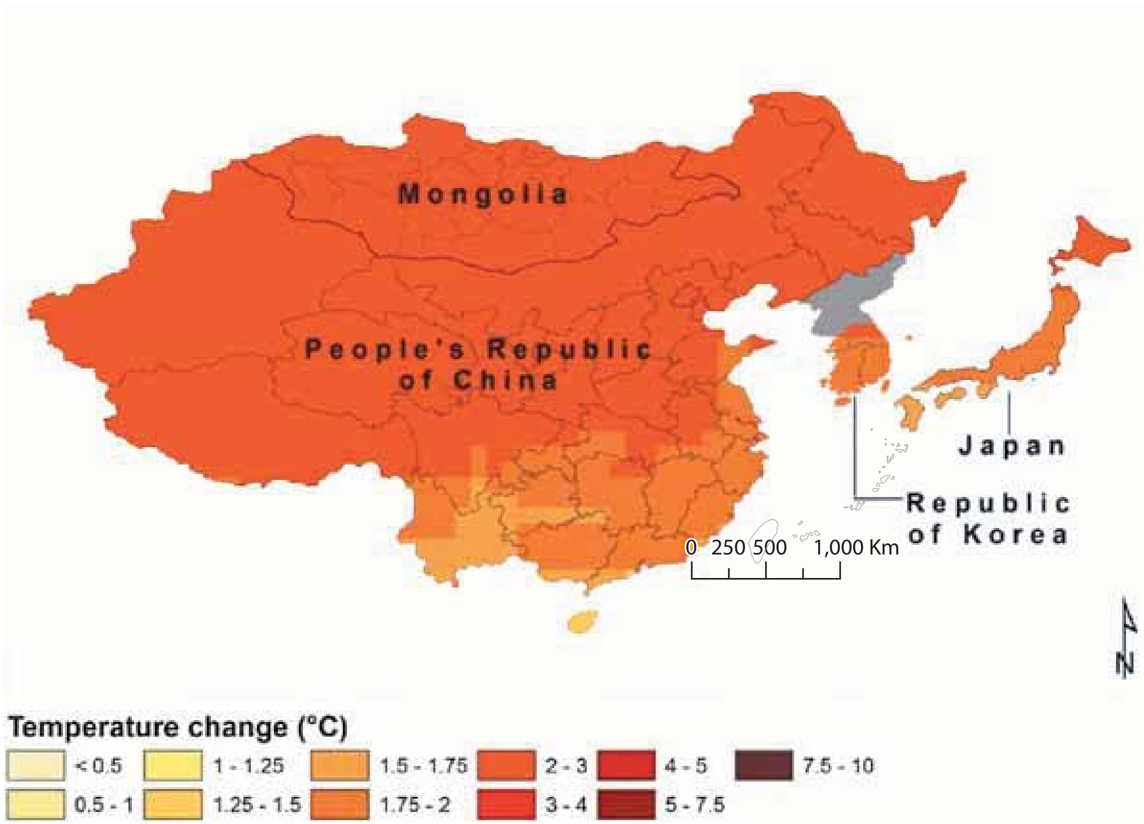
First the median value for each grid cell is selected across projections from individual GCMs. The resulting spatial coverage is then averaged at the appropriate scale, e.g., country or province or region. This methodology is used throughout.

Source: Asian Development Bank project team.

Table 6 do not indicate a general problem, but detailed analysis for key river basins is required in order to assess the interactions between changes in monthly precipitation and requirements for water storage to manage the availability of water for crop use. Earlier snowmelt will advance spring flows, but equally the growing season will start earlier so that the net effect is uncertain.

Another source of uncertainty concerns the role of glacier melt. Glaciers are equivalent to huge volumes of unmanaged storage in the upper segments of some river basins. In the short term, a reduction in

Figure 6 Change in Mean Annual Temperature for East Asia, 2050 (2046–2055 versus 1961–1990) (°C)



Notes: A2 emissions scenario, 17 General Circulation Models, multi-model median.

Source: Asian Development Bank project team.

the volume of glacier storage will increase the water available for irrigated agriculture in semi-arid western areas of the PRC. However, in the longer term the reduction in glacier volumes will increase the variability in water flows. Large investments in managed water storage will be required to offset the loss of glacier storage. Over the last 6 decades in the PRC, 82% of the glaciers have retreated, mostly those on the fringes of the Qinghai-Tibetan Plateau.[24] Most studies suggest that glacier melt may peak during 2030–2050 and decline thereafter, but the exact timing and magnitude of "tipping points" for glacial melt for each glacier are uncertain.[25]

Agriculture

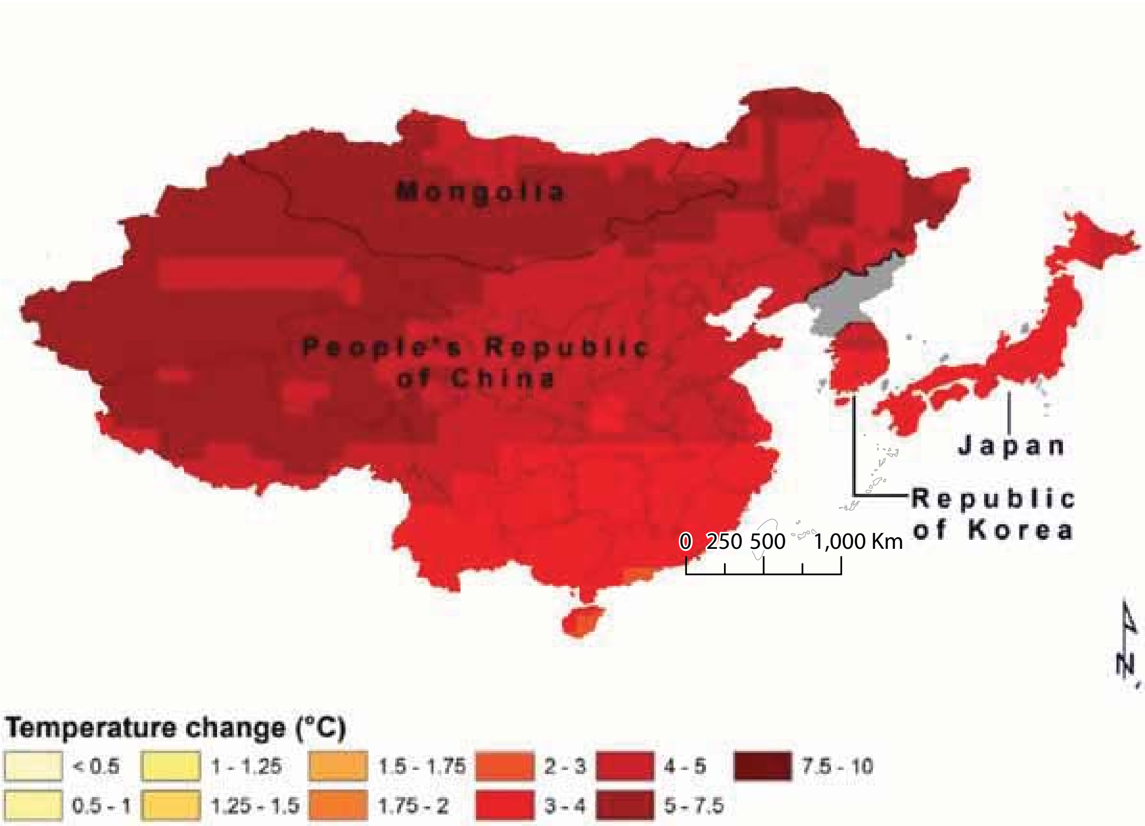
There are major concerns about the impact of climate change on food security in the People's Republic of China. Although the PRC has a huge land area, only 7% of it is arable and available to feed the population.[26] Wheat, corn, and rice are the main crops, accounting for 54% of the total sown

[24] National Development and Reform Commission. 2012. *Second National Communication on Climate Change of the People's Republic of China.* Beijing, p.12.

[25] Piao, S. et al. 2010. The Impacts of Climate Change on Water Resources and Agriculture in the PRC. *Nature* 467: 43–51.

[26] Zhang, T. and Y. Huang. 2012. Impacts of Climate Change and Inter-Annual Variability on Cereal Crops in the PRC from 1980 to 2008. *Journal of the Science of Food and Agriculture* 92: 1,643–52.

Figure 7 Change in Mean Annual Temperature for East Asia, 2090 (2086–2095 versus 1961–1990) (°C)



Notes: A2 emissions scenario, 17 General Circulation Models, multi-model median.

Source: Asian Development Bank project team.

area and 89% of the grain yield in 2007. The main issue for agriculture is seasonal and interannual water availability. Since 54% of the PRC's own area is irrigated, competition for water could limit the water available for agricultural production.[27] There is particular concern about an increase in the frequency of droughts affecting the northern plain of the PRC, whose impact would be exacerbated by an increase in water demand per unit of cropped area due to higher temperatures.

Projections of the impact of climate change on agricultural yields vary greatly because of differences across regions and crops as well as in assumptions about the effect of carbon fertilization (Chapter 4). Recent warming has resulted in a longer growing season, allowing earlier planting and later harvesting, while the range of rice cultivation has expanded northwards. It is believed to have increased rice yields in the northeast because of higher nighttime temperatures, but higher daytime temperatures may have reduced yields of wheat and maize.

In Mongolia the impact of climate change on livestock is the major concern. Droughts in combination with the *dzud* (episodes of extreme cold and heavy snow) lead to major losses of livestock. For example, almost 30% of livestock died as a consequence of the *dzud* of 2010, affecting more than

[27] Wang, J. et al. 2009. The Impact of Climate Change on PRC's Agriculture. *Agricultural Economics* 40: 323–37.

Table 6 Country Averages for the General Circulation Model Ensemble Median for the Change in Mean Annual Precipitation and Mean Seasonal Precipitation in East Asia (millimeters)

Country	Annual 2030	Annual 2050	Annual 2090	
PRC	(6)	21	66	
Japan	15	40	57	
Republic of Korea	35	91	97	
Mongolia	12	20	44	
	DJF 2030	MAM 2030	JJA 2030	SON 2030
PRC	1	0	(4)	(5)
Japan	6	7	15	(6)
Republic of Korea	7	13	20	(17)
Mongolia	4	7	(1)	1
	DJF 2050	MAM 2050	JJA 2050	SON 2050
PRC	3	8	7	1
Japan	9	14	33	(12)
Republic of Korea	18	18	43	5
Mongolia	5	9	2	3
	DJF 2090	MAM 2090	JJA 2090	SON 2090
PRC	5	21	27	8
Japan	2	21	44	10
Republic of Korea	11	46	41	11
Mongolia	13	16	11	7

( ) = negative, DJF = December, January, February; JJA = June, July, August; MAM = March, April, May; PRC = People's Republic of China; SON = September, October, November.

Notes: A2 emissions scenario. Projections for 17 GCMs are included. "2030" means the change in mean annual temperature for 2026–2035 compared to 1961–1990, similarly for the other time periods.

Source: Asian Development Bank project team.

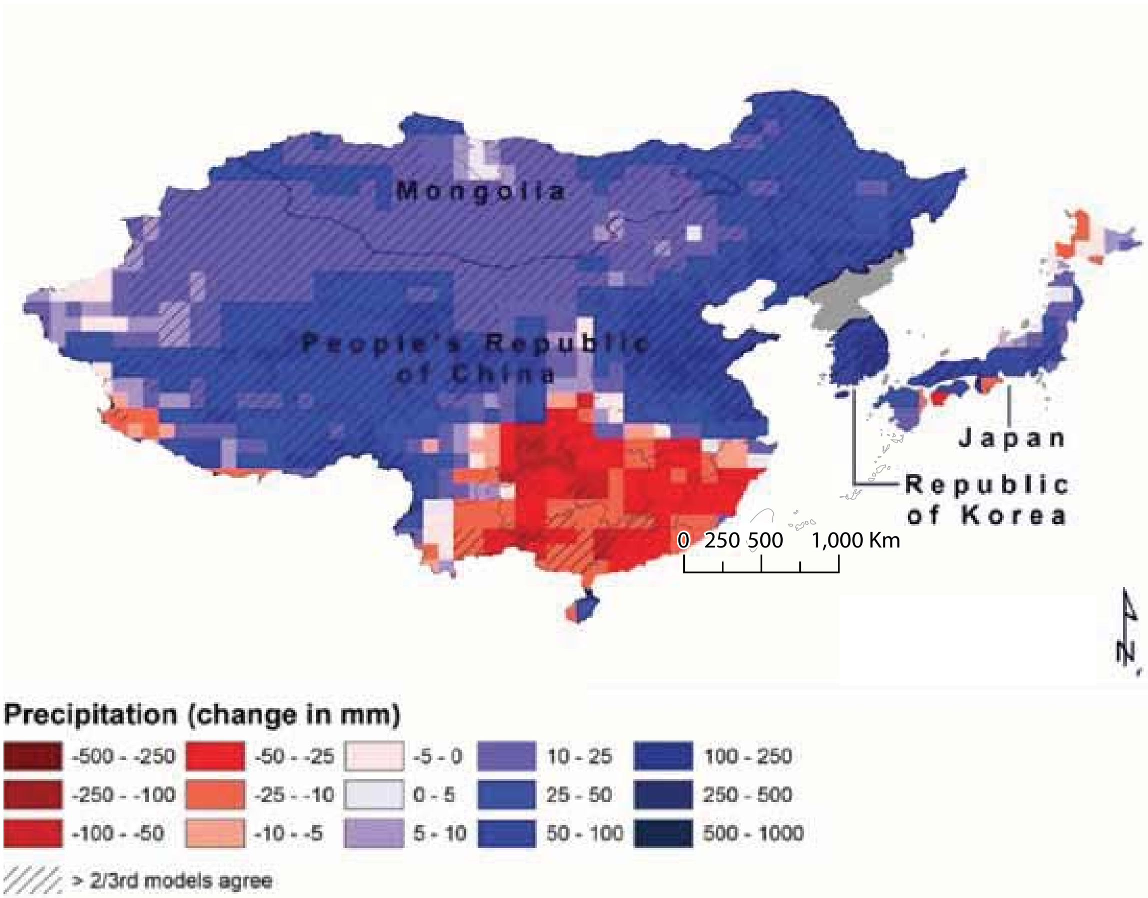
200,000 households in a country of 2.8 million.[28] If climate change is associated with greater annual variability in climate conditions, the frequency of *dzuds* may increase, notwithstanding the overall increase in average temperatures. Higher temperatures and greater seasonal variation in precipitation may exacerbate the degradation of pasture land.

Agriculture contributes a much smaller share of GDP in Japan and the Republic of Korea, but it remains important to many elderly and often low-income households. The impact of climate change is likely to be mixed with the yields of some crops increasing because of longer growing seasons and higher precipitation, while the yields of other crops may be affected by higher daily maximum temperatures. The effect of alternative climate scenarios on agricultural production and incomes is examined in Chapter 4.

Japan and the People's Republic of China are highly vulnerable to the impacts of sea-level rise. Three cities in East Asia—Guangzhou and Shanghai in the PRC and Osaka/Kobe in Japan—are in

[28] World Bank. 2010. Reducing Human Vulnerability: Helping People Help Themselves. *World Development Report 2010: Development and Climate Change*. Washington, DC.

Figure 8 Change in Mean Annual Precipitation for East Asia, 2050 (2046–2055 versus 1961–1990) (millimeters)



Notes: A2 emissions scenario, 17 General Circulation Models, multi-model median. Hatching indicates areas where at least two-thirds of the models agree with the sign of the change (strong model agreement).

Source: Asian Development Bank project team.

the top 10 in the world in terms of current exposed population. In terms of value of assets exposed, three Japanese cities are in the top 10: Nagoya, Osaka/Kobe, and Tokyo.[29] A significant portion of the population in both Japan (24.0%) and the PRC (11.4%) live in a low-elevation coastal zone (LECZ).[30]

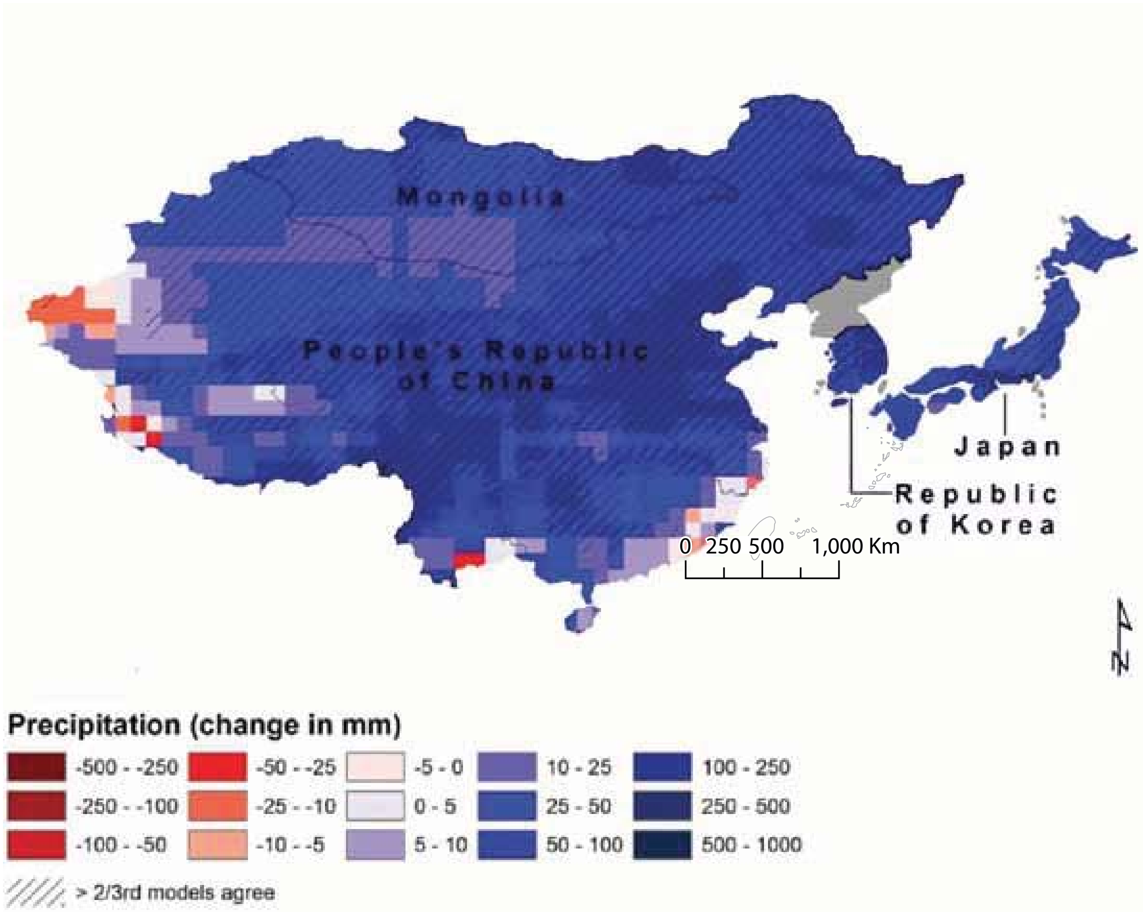
Biodiversity and ecosystems

The impacts of climate change on ecosystems are expected to include a shift in species ranges and increased coral bleaching together with the risk of increased desertification. It can be difficult to project the impacts of climate change on biodiversity, as species distributions and population sizes are a complex function of biotic interactions and abiotic factors, such as climate. In general, species ranges will shift northward in East Asia, species phenology will change (e.g., flowering and fruiting),

[29] Nicholls, R. J. et al. 2008. Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates. *OECD Environment Working Papers* No. 1. Paris: OECD Publishing. http://dx.doi.org/10.1787/011766488208

[30] LECZs are areas below 10 meters elevation. CIESIN. 2012. Low Elevation Coastal Zone urban–rural estimates, Global Rural-Urban Mapping Project (GRUMP), Alpha Version. New York: Socioeconomic Data and Applications Center (SEDAC), Columbia University. http://sedac.ciesin.columbia.edu/data/collection/lecz

Figure 9 Change in Mean Annual Precipitation for East Asia, 2090 (2086–2095 versus 1961–1990) (millimeters)



Notes: A2 emissions scenario, 17 General Circulation Models, multi-model median. Hatching indicates areas where at least two-thirds of the models agree with the sign of the change (strong model agreement).

Source: Asian Development Bank project team.

the species composition of ecosystems will become altered, and invasive alien species and pests will become more common. Coastal areas in East Asia can expect more coral bleaching, exacerbating existing stresses on coral reefs in the PRC.

In Japan, for example, climate change may lead to the loss of beech forests in their southern range. It has been estimated that, if mean annual temperatures increase by about 1.7° C, this will reduce the suitable beech habitat by 39%, while a 3.2° C increase would lead to a 68% reduction in habitat.[31] In the Republic of Korea, suitable habitat for the two major types of pine forest may be reduced by about one-third by 2060, whereas suitable habitat for evergreen broadleaved forest will expand.[32] In the PRC, temperate coniferous and broadleaved forest will likely move northward with an expansion of warm-temperate deciduous broadleaved forests. In general, northern forest types will be replaced by southern types, alpine meadows will be replaced by tropical savannas, and total forest area as well

[31] Kawamata, K. 2011. *Japan Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report).

[32] Lee D.K. and M.K. Lee. 2011. *Republic of Korea Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report).

as the area of evergreen conifer forests will increase.[33] The risk of desertification in Mongolia and the PRC may increase as a result of higher temperatures and increased seasonal variability in precipitation.

Health

An increase in heat-related mortality and morbidity is likely to be the most significant climate change impact on health. Climate change can have both direct and indirect effects on human health.[34] Direct effects include heat-related mortality due to heat stroke and aggravation of respiratory and cardiovascular diseases. Indirect effects include the impacts of extreme weather events (e.g., typhoons, flooding) which increase the transmission of water- and vector-borne diseases and changes in the abundance, survival, and range of animals that transmit disease (i.e., vectors). Many of the major diseases transmitted by water and contaminated food, such as severe diarrheal diseases, are influenced by climatic variables.[35] For a summary of the general relationships between various climatic exposures and impacts on human health, see Table 7.

Table 7 The Main Impacts of Climatic Exposures on Health

Climatic Exposure	Impacts On Human Health
Warm spells, heat waves, and stagnant air masses	• Heat stroke (largest effect on the elderly) • Increase in respiratory diseases • Increase in cardiovascular illnesses
Cold spells, cold waves, and blizzards	• Hypothermia (largest effects on socially deprived groups) • Frostbite • Aggravation of several chronic conditions
Warmer temperatures and disturbed rainfall patterns	• Increase in diseases carried by mosquitoes, rodents, and ticks such as malaria, dengue, and Japanese encephalitis
Heavy precipitation	• Increase in diseases due to consumption of unsafe drinking water and food
Droughts	• Malnutrition (largest effect on children's growth and development) • Reduced crop yields resulting in stress for farmers and their families
Extreme weather (cyclones, strong storms)	• Loss of life, injuries, and disability • Forced migration resulting in stress and other health effects

Source: Asian Development Bank project team.

Assessing the overall impact of climate change on the health of populations in 2030 or 2050 is complicated by the role of autonomous adaptation. Micro studies provide evidence on the potential links between climate and specific conditions such as heat stroke. However, the macro impact of climate change on the health of a country or region depends upon how public health policies, medical care, infrastructure, and housing adjust to the new conditions. Heat stroke will be much more of a problem when buildings and social arrangements are adapted to a cooler climate in which heat waves are infrequent than if measures to adapt physical and social infrastructure are implemented. Such adaptation is likely to occur partly through the normal replacement of physical capital over time and partly in parallel with the structural changes linked to economic growth over the period to 2050.

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33 Chen W. et al. 2012. *People's Republic of China Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report).

34 For in-depth material for this entire section, see G. Sanchez and A. Chiabai. 2011. *Public Health Adaptation to Climate Change and Its Economic Implications for People's Republic of China, Japan, Republic of Korea, and Mongolia* (TA 7465 report). Manila.

35 World Health Organization (WHO). 2009. *Protecting Health from Climate Change: Connecting Science, Policy and People*. Geneva.

At the micro level, the most significant impact of climate change on health is likely to be associated with heat stress during heat waves (Box 1). Heat-related morbidity and mortality has long been a public health concern in Japan, a highly urbanized territory with a temperate climate which experiences intermittent spells of very hot weather. Hot summers in 1978, 1983, 1990, and particularly 1994, with periods in which the daily maximum temperature exceeded 38°C, have caused spikes in deaths and hospital admissions due to heat stroke.[36] The elderly are particularly vulnerable to heat stress, so that ageing populations will reinforce the impact of higher temperatures.

Similarly, many regions in the PRC are prone to heat waves. In Shanghai, total mortality increased by 13% during the 2003 heat wave relative to the normal summer level.[37] Apart from the elderly, vulnerability to heat stress tends to be highest among those with low educational attainments, low income and disabilities—e.g., the heat-related mortality rate of low-income Koreans is as much as 1.3–1.7 times higher than that of the general population.[38] Hence, economic growth and declining poverty rates may offset some of the effects of ageing and higher temperatures on heat-related health conditions.

In Mongolia, the main health concern related to episodes of extreme weather focuses on the *dzud* (winter periods of heavy snow or extreme cold), which has a large impact on the pastoral population because of the loss of livestock, malnutrition, and exposure. Losses due to more frequent or severe *dzud* episodes appear to have increased significantly since 1980 but it is not clear how far this pattern is linked to global climate trends rather than other climate oscillations.[39]

Other than heat stress, climate change may increase the occurrence of vector-borne diseases such as malaria, dengue, chykungunya, Japanese encephalitis, schistosomiasis, and tickborne encephalitis. The burden of such diseases is very low in the Republic of Korea and Japan,[40] and in the PRC it is concentrated in two provinces—Fujian and Guangdong.[41] The range of vectors such as mosquitoes and trematode flatworms is likely to shift north, especially as a consequence of higher winter temperatures. Public health policies have effectively controlled these diseases over the last 50 years but they may pose more of a problem to health systems in future.

Studies may suggest large increases in the relative risks of specific climate-related sources of mortality and morbidity, but this is only part of the story. Warmer temperatures will reduce mortality due to cardiovascular and respiratory diseases, especially in the colder regions of the PRC and Mongolia. Health impacts associated with malnutrition, diarrheal diseases, and flooding can be minimized by adaptation strategies discussed in the chapters which follow. Currently, heatstroke, malaria, and other vector-borne diseases account for a very small portion of the total burden of disease in East Asia. Without climate change, this share would fall as a consequence of higher incomes and urbanization, so that any increase in risk will apply to a very small base.

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36 Nakai, S., T. Itoh, and T. Morimoto. 1999. Deaths from Heat-Stroke in Japan: 1968–1994. *International Journal of Biometeorology* 43: 124–7; Hoshi, A. and Y. Inaba. 2007. Prediction of Heat Disorders in Japan. *Global Environmental Research* 11: 45–50; Hoshi, A. 2002. Mortality Rate of Heat Disorder Analyzed by Place of Occurrence Using Vital Statistics in Japan. *Japanese Journal of Biometeorology* 39 (1/2): 37–46.

37 Huang, W., H. Kan, and S. Kovats. 2010. The Impact of the 2003 Heat Wave on Mortality in Shanghai, [the PRC]. *Science of the Total Environment* 408: 2,418–20.

38 Kim, Y. and S. Joh. 2006. A Vulnerability Study of the Low-Income Elderly in the Context of High Temperature and Mortality in Seoul, [Republic of] Korea. *Science of the Total Environment* Vol. 371 (1–3): 82–8.

39 International Fund for Agricultural Development. 2006. Climate Change Vulnerability and Adaptation in the Livestock Sector of Mongolia. A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change Project No. AS 06.

40 WHO. 2009. Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks. Geneva. http://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf

41 Liang, L. et al. 2009. *Time Series Analysis of Dengue Fever and Weather in Guangzhou*, [the PRC]. BMC Public Health 9: 395.

Box 1 Are Heat Waves Responsible for Additional Mortality?

It has been postulated that a proportion of the mortality due to heat happens to individuals in advanced stages of chronic diseases or otherwise frail, so that the loss of expected years of life is relatively small.[a] The mortality profile of heat waves would suggest this—people over 65, people with preexisting conditions or chronic illnesses, institutionalized patients, and those socially isolated. This short-term mortality displacement, known as the "harvesting effect," has been statistically observed in connection with cold spells and air pollution.[b] However, no substantial harvesting effect was observed in the best studied, large-scale heat waves (i.e., Europe in the summer of 2003).[c] A recent comprehensive multi-city study[d] concluded that mortality displacement explained only a modest proportion of the excess mortality.

Time series studies of the impact of extreme episodes of air pollution on mortality in East Asia, for which harvesting effects have also been observed elsewhere, have not generally found a significant harvesting effect in data on general and cause-specific mortality. There are two main possible reasons why short-term mortality displacement may be less important in East Asia: (i) short-term mortality displacement requires a pool of highly susceptible individuals that is absent or small in countries that have not completed the demographic transition (e.g., the People's Republic of China and Mongolia), and/or (ii) the epidemiologic profile of heat-related deaths is not restricted to highly susceptible individuals.

a Hajat, S. et al. 2005. Mortality Displacement of Heat-Related Deaths: A Comparison of Delhi, São Paulo, and London. *Epidemiology* 16 (5): 613–20.
b Schwartz, J. 2000. Harvesting and Long Term Exposure Effects in the Relation between Air Pollution and Mortality. *American Journal of Epidemiology* 151 (5): 440–8.
c Poumadere, M. et al. 2005. The 2003 Heat Wave in France: Dangerous Climate Change Here and Now. *Risk Analysis* Vol. 25 (6): 1,483–94.
d Baccini, M. et al. 2008. Heat Effects on Mortality in 15 European Cities: Results of the PHEWE Project. *Epidemiology* 19 (5): 711–19.

At the macro level, the methods described in the background papers for the EACC study[42] have been extended to examine the impact of climate change on broad health indicators—infant and under-5 years mortality rates, the probability of surviving to age 65, and life expectancy—at provincial level in the PRC and for each country. For the PRC, the average impact of climate change on life expectancy for men and women averaged over provinces and climate scenarios is a reduction of 0.05% in 2050, or about 0.5 months. This must be compared with an increase of 10%–12% or about 7.5 years because of economic growth and socioeconomic change from 2010 to 2050. The difference is even more marked when considering infant and under-5 years mortality. For Japan, which may expect smaller improvements in life expectancy or infant mortality, the projected improvements in life expectancy or infant mortality are 5–10 times higher than the impact of climate change under the worst climate scenario.

Overall, the impacts of climate change on health up to 2050 are likely to be relatively small provided that appropriate adaptation policies for infrastructure, flooding, and agriculture are combined with vigilance and public health interventions to control the spread of vector-borne diseases and to manage vulnerability to heat stress, particularly among the elderly.

42 Pandey, K. 2010. Costs of Adapting to Climate Change for Human Health in Developing Countries. Discussion Paper No 11, Economics of Adaptation to Climate Change Program, World Bank.

Appendix: Historical Climate and Climate Change Projections

Historical Climate Databases

Two historical climate change databases have been employed in this study:

(i) **The Climate Research Unit Historical Dataset.** On a 0.5° basis (~50 kilometers [km] at the equator) worldwide for 1901–2006, the dataset contains (a) monthly mean precipitation, (b) mean temperature, (c) mean daily minimum temperature, (d) mean daily maximum temperature, and (e) number of wet days (number of days with precipitation > 0.1 millimeters).[43] The main advantage of this dataset is the degree of spatial detail in the climate variables, while the main disadvantage is the lack of temporal detail since the basic data consist of monthly averages for temperature and monthly totals for precipitation.

(ii) **The Geophysical Fluid Dynamics Laboratory Princeton (Global Meteorological Forcing) Dataset.**[44] This dataset includes a set of daily values of weather variables for 1948–2008 for 1° grid squares covering both land and oceans. The advantage of this data is that it permits the estimation of climate indexes that rely upon daily weather information—such as maximum precipitation in 1-day, 3-day, or 5-day periods—which are used for the analysis of short-term flooding. The 61-year time series is sufficient to estimate extreme-value distributions for maximum or minimum values for temperatures and precipitation. However, the coarser spatial resolution of the Princeton dataset and its time span means that it is less satisfactory than the Climate Research Unit dataset for monthly or annual average temperature and precipitation.

Climate Change Projections (General Circulation Models)

All of the General Circulation Model (GCM) projections used in the study were obtained from Kenneth Strzepek of the Massachusetts Institute of Technology's Joint Program on the Science and Policy of Global Change. These GCM projections were presented in the Intergovernmental Panel on Climate Change's Fourth Assessment Report.45 While there are 26 GCMs available globally, only 17 were used in this study because the remaining 9 GCMs do not provide the full set of monthly variables that are required for analysis. The GCMs all have varying spatial resolutions, so the data were first geo-spatially rescaled to a resolution of 1.0 degrees.

Runoff and Flood Projections

Once projected changes in monthly temperature and precipitation for the 2030s, 2050s, and 2090s were gathered from all 17 GCM scenarios, these projections were then combined with historical data for the baseline period—1961–1990 (Climate Research Unit data)—to produce absolute temperature and precipitation projections for each river basin. These absolute temperature and precipitation

[43] See Mitchell, T. D. and P. D. Jones. 2005. An Improved Method of Constructing a Database of Monthly Climate Observations and Associated High-Resolution Grids. *International Journal of Climatology* 25: 693–712. http://www.cru.uea.ac.uk/cru/data/hrg/

[44] Sheffield, J., G. Goteti, and E. F. Wood. 2006. Development of a 50-yr High-Resolution Global Dataset of Meteorological Forcings for Land Surface Modeling. *Journal of Climate* 19 (13): 3,88–311.

[45] Randall, D.A. et al. 2007. Climate Models and Their Evaluation. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by Solomon, S. et al. Cambridge, United Kingdom and New York: Cambridge University Press.

General Circulation Models Used in this Study

Model ID	Institution
BCCR_BCM20	Bjerknes Centre for Climate Research, Norway
NCAR_CCSM30	National Centre for Atmospheric Research, United States
CCCMA-CGM3 (T47)	Canadian Center for Climate Modeling and Analysis
CNRM_CM3	Centre National de Recherches Météorologiques, France
CSIRO_MK30	Commonwealth Scientific and Industrial Research Organisation, Australia
CSIRO_MK35	
MPI_ECHAM5	Max Planck Institute for Meteorology, Germany
GFDL_CM20	Geophysical Fluid Dynamics Laboratory, United States
GFDL_CM21	
GISS_ER	
INM_CM30	Institute for Numerical Mathematics, Russian Federation
IPSL_CM4	Institut Pierre Simon Laplace, France
MIROC32 (medres)	National Institute for Environmental Studies, Japan
MRI_CGCM232A	Meteorological Research Institute, Japan
NCAR_PCM	National Centre for Atmospheric Research, United States
UKMO_HADCM3	United Kingdom Meteorological Office
UKMO_HADGEM1	

Note: For more information, see the World Climate Research Programme's Coupled Model Intercomparison Project (Phase III): http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php

Source: Asian Development Bank project team.

projections were used to calculate projections for potential evapotranspiration using a modified Hargreaves equation.[46] The CLIRUN-II model was then used to project runoff.[47]

CLIRUN-II is a two-layer, one-dimensional rainfall runoff model that requires inputs of monthly precipitation and temperature, mean range in daily temperature for monthly potential evapotranspiration, and observed monthly runoff. The baseline climate variables and observed runoff are used for calibration, and both the baseline and projected climate variables are subsequently used for simulation, i.e., generation of modeled runoff outputs. The baseline and projected inputs for CLIRUN-II were synchronized at a 0.5° times 0.5° resolution, and then spatially aggregated using river basin boundaries in a geographic information system.

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46 Droogers, P. and R. G. Allen. 2002. Estimating Reference Evapotranspiration under Inaccurate Data Conditions. *Irrigation and Drainage Systems* 16: 33–45.

47 CLIRUN is an adaptation of WATBAL: Yates, D. 1996. WATBAL: An Integrated Water Balance Model for Climate Impact Assessment of River Basin Runoff. *Water Resources Development* 12: 121–39; Strzepek, K. M. and C. W. Fant. 2010. Water and Climate Change: Modeling the Impact of Climate Change on Hydrology and Water Availability. *University of Colorado Technical Note*. Boulder, Colorado.

Chapter 2

The Economics of Adaptation in the Infrastructure Sector

Key Messages

- **The total cost of climate-proofing (ex-ante adaptation) all infrastructure during 2011–2050 in East Asia ranges from $8 billion to $63 billion per year.** The costs vary greatly across climate scenarios: the ranges between the minimum and maximum costs are $3 billion to $44 billion per year for the People's Republic of China (PRC) and $50 million to $560 million per year for Mongolia. The climate scenarios which yield the highest costs of adaptation are among the wettest scenarios for each country.
- **Relative costs of adaptation, expressed as a proportion of baseline expenditures, are small in East Asia.** Mongolia and Japan have the highest relative costs of adaption—an average of 2.3% of baseline expenditures for Mongolia and 2.2% for Japan. The relative cost of adaptation is only 0.6% of baseline expenditures for the PRC.
- **Mongolia is the country most affected by the variability of adaptation costs.** The relative cost of adaptation in the worst climate scenario for Mongolia is 8.5% of baseline expenditures.
- **Roads have the highest relative costs of climate proofing.** The average cost of climate proofing roads is 8% of baseline expenditures, and the worst case is 12%. Road costs are driven by changes in both precipitation and temperature.
- **If the future climate were known, Japan and the Republic of Korea should climate proof all infrastructure built from now on. For the PRC, it is economic to climate proof roads but the benefits of ex-ante adaptation for other categories of infrastructure do not outweigh the costs incurred.** The best policy for adaptation depends upon the discount rate. Even with certainty about future climate conditions, the investment required for ex-ante adaptation may not yield an adequate return if a discount rate of 5% or higher is applied.
- **Risk aversion is an important consideration in developing adaptation strategies because of the variability in adaptation costs and outcomes across climate scenarios.** Risk neutrality is a reasonable assumption for large, diversified economies for which the relative costs of adaptation are modest. Hence, the PRC, Japan, and the Republic of Korea should choose options that minimize the net cost of adaptation across climate scenarios. Mongolia is less diversified and it is affected more by climate uncertainty so it may wish to give more weight to the worst climate outcomes when developing its adaptation strategy.
- **The increase in economic losses due to cyclones may be significant in Japan and the Republic of Korea, but the costs of adaptation are modest.** Averaged over all climate scenarios, 9.3% of Japan's population and 3.8% of the Republic of Korea's population are expected to suffer an increase in average cyclone damages equivalent of more than 1% of local GDP. However, the costs of increasing design standards to maintain the current 1-in-100-year level of protection is only $2.5 billion per year for Japan over the period to 2050.
- **The level of protection against cyclones in the PRC seems to be too low.** The increase in economic losses due to cyclones is small for the PRC, but the average level of damages under the current climate is much higher than the cost of adopting design standards that would protect against 1-in-100-year storms. The cost of addressing this "adaptation deficit" for coastal areas would be about $21 billion per year. The additional cost of adaptation to climate change would be about $4 billion per year.
- **The increase in average losses caused by short-term flooding due to climate change in the PRC by 2050 is modest, but there are large variations across climate scenarios.** In the southeast region, 8% of the population may suffer an increase in economic losses from short-term flooding exceeding 0.5% of local gross domestic product (GDP) in the worst climate scenario, but the average over all climate scenarios is 2%. The impact of climate change would be very small if a consistent level of protection against 1-in-50-year floods were adopted.
- **The risks associated with cumulative flooding in the PRC, especially in the Yangtze River basin, may increase substantially under a small number of climate scenarios.** There are two climate scenarios under which more than 80% of the population of the eastern and southeastern regions would suffer an increase in economic losses caused by cumulative flooding of more than 1% of local GDP, and under two other climate scenarios the impacts are slightly less severe. Increasing protection to a 1-in-50-year flood standard would reduce the impact of climate change but a higher level of protection may be justified in the provinces which are most at risk—Anhui, Henan, Hubei and Hunan.

Introduction

This chapter examines the costs of adaptation to climate change in the infrastructure sector in East Asia during 2011–2050. Infrastructure has been given a rather broad definition: transport (especially roads, rail, and ports), electricity, water and sanitation, and communications, but also urban and social infrastructure such as urban drainage, urban housing, health and educational facilities (both rural and urban), and public buildings. The study builds upon the analysis of infrastructure that was undertaken as part of the World Bank study of the Economics of Adaptation to Climate Change (EACC),[1] but extends it in several important ways.

First, the analysis was conducted at the subnational scale (see Appendix). For the PRC, this includes calculating the costs of adaptation for each of the 31 geographical units. For Japan, the 47 prefectures or equivalent have been aggregated into 8 regions, while the 16 provinces or equivalent for the Republic of Korea have been aggregated into 3 regions. Mongolia is treated as a single geographical unit because of the paucity of data on infrastructure assets at the *aimag* (provincial) level. As it is impractical to report the results for 43 separate provinces and/or regions, the tables show the costs of adaptation for 6 regions in the PRC plus 3 countries.

Second, the study incorporates a more detailed treatment of temperature and humidity stresses on roads and buildings.

Third, the analysis has been carried out using climate scenarios generated by 17 separate General Circulation Models (GCMs) at the resolution of 1° grid squares, which have then been aggregated at the province or region level. This analysis examines whether the benefits of investing in adaptation outweigh the costs for each climate scenario for 5-year time periods—2011–2015 up to 2046–2050—and for a range of discount rates.

Fourth, the study explores climate change uncertainty in more depth than previous work. The GCMs differ considerably in their projections for patterns of precipitation as well as maximum and minimum temperatures. Thus, there is substantial uncertainty about the impacts of climate change and, consequently, the costs of adaptation. The study examines how this uncertainty may be taken into account when planning for adaptation and how attitudes to risk determine the timing of adaptation. In some sectors the appropriate response to uncertainty may be to postpone significant investments in adaptation so as to collect better information on what type of adaptation is likely to be most suitable. This is an application of "real options" modeling developed by economists for investment decisions that involve substantial uncertainty, such as spending on research and development or exploration for hydrocarbons or minerals.

Lastly, the study extends previous work on the analysis of future extreme events, e.g., cyclones and floods,[2] and how they may influence adaptation strategies.[3] It is possible that climate change will lead to an increase in either the frequency or intensity of extreme weather events. These impacts can be described in terms of shifts in the probability distributions of specific extreme events, e.g., cyclones with a sustained wind speed in excess of 180 kilometers per hour (km/hr) or floods with a peak height more than 5 meters (m) above mean river level. If nothing were to be done about the shift in the probability distributions of such events, the expected future damage would increase sharply. Adaptation here is

1 World Bank. (see Introduction, footnote 4); Hughes, G. A, P. Chinowsky, and K. Strzepek. 2010. The Costs of Adapting to Climate Change for Infrastructure. *Economics of Adaptation to Climate Change Discussion Paper* No. 2, Washington, DC: World Bank; Hughes, G. A, P. Chinowsky and K. Strzepek 2010. The Costs of Adaptation to Climate Change for Water Infrastructure in OECD Countries. *Utilities Policy* Vol. 18: 142–53.

2 Coastal flooding due to sea-level rise and storm surge is not explicitly considered. This is addressed in Chapter 3.

3 World Bank. 2011. *Economics of Adaptation to Climate Change: Samoa*. Washington, DC.

assumed to take the form of adjustments in engineering and other design standards so that buildings and other infrastructure assets can withstand 1-in-50-year or 1-in-100-year storms or floods. An important consideration is that current standards may be too low—the so-called "adaptation deficit"—in the sense that investments designed to protect against stronger storms or more severe flooding may be justified even in the absence of climate change. In such cases, it is important to distinguish between the costs and benefits associated with (i) adjustments in levels of protection against extreme events holding climate constant, and (ii) adjustments in design standards to maintain levels of protection as a consequence of climate change. As in all later chapters, the costs of adaptation are in constant 2005 dollar values.

Methodology

The analysis starts from the notion that demand for infrastructure of any type (e.g., electricity generation, roads, sewer and water connections) can be understood as a function of socioeconomic variables, such as GDP per capita and population, and a range of geophysical and climate variables. The "normal" level of infrastructure reflects the decisions made in middle- or high-income countries around the world about the amount of infrastructure which they require given GDP per capita, population, plus a range of physical and climatic variables. The appendix provides details of the socioeconomic projections used for East Asia.

There are two ways that climate change can affect infrastructure. Firstly, it can change the unit costs for building and maintaining infrastructure. More intense precipitation or higher temperatures may degrade roads more quickly, for example. This is referred to as the Delta-C cost of adaptation, or the cost of climate proofing. The analysis of Delta-C costs starts from the basis that design standards should be adjusted so as to deliver the same level of performance as would have applied if climate change had not occurred. If roads or buildings are currently constructed to withstand a 1-in-50-year or 1-in-100-year flood or wind storm, then the same design standard should apply but under the circumstances of a changed frequency or severity of those events.

The changes in unit costs are calculated from a set of dose-response relationships, which quantify the increase in unit cost due to a change in a particular climate variable that is required to hold constant the level of service provided by a specific type of infrastructure. For example, a dose-response relationship for paved roads states that the standardized cost of constructing road pavements will increase by 3% for each 6° C increase in pavement temperature, which is an indicator based on average and maximum temperatures plus latitude. This cost is incurred because more expensive pavement binders must be used as the pavement temperature increases in order to ensure that the pavement can withstand the traffic stresses over its design life.

Secondly, climate change may alter the demand for infrastructure required to maintain levels of comfort and well-being. For example, changes in precipitation will alter the design and/or capacity of storm water and sewer networks, while higher temperatures will increase the demand for cooling and thus for electricity generation. The cost of responding to changes in the demand for infrastructure is referred to as the Delta-Q cost of adaptation.

The analysis incorporates detailed analysis of two classes of buildings: wooden and nonwooden (brick and/or concrete). For wooden buildings, the climate-induced decay rate is determined by value of the Scheffer Index.[4] This index is based on the product of monthly average temperature and the

4 Scheffer, T. C. 1971. A Climate Index for Estimating Potential for Decay in Wood Structures Above Ground. *Forest Product Journal* Vol. 21: 25–31; Morris, P. I. and J. Wang. 2011. Scheffer Index as Preferred Method to Define Decay Risk Zones for Above Ground Wood in Building Codes. *International Wood Products Journal* Vol. 2: 67–70.

average number of days in the month with significant precipitation (> 0.25 millimeters) summed over all months; the higher the value, the shorter expected lives for wood structures constructed with untreated timber. Nonwooden buildings have exterior cladding that are more resistant to climate stresses, so the main issue concerns the heating, ventilation, and air-conditioning (HVAC) system, specifically in relation to changes in humidity. The cost is determined by a moisture (MEWS) index, which is a function of precipitation and relative humidity.[5] Higher values of the MEWS index due to climate change mean that ventilation and cooling systems must be upgraded to protect buildings and the health of their occupants.

For roads, the analysis takes account of higher capital and maintenance costs because of the effects of changes in temperatures and precipitation on pavement life and vulnerability to flooding.

The background report provides full details of the Delta-C and Delta-Q costs, the types of infrastructure considered, and the dose-response relationships used in the analysis.

The steps in the analysis can be summarized as follows:

1. **Construct baseline projections of infrastructure investment in the future for 5-year periods from 2011 to 2050, assuming no climate change.** The value of new investment required for infrastructure for a given country in a defined period is obtained by multiplying the unit cost of infrastructure at 2005 prices. The unit costs have been compiled from a large variety of World Bank and other sources. It is assumed that assets depreciate linearly over time.
2. **Add alternative climate scenarios.** The data used for the baseline projections is supplemented with projections of the climate variables taken from GCMs. These are constructed as "deltas" at different dates with respect to the no-climate-change baseline of monthly average, maximum, and minimum temperatures and precipitation. The variables for each period (e.g., 2050) are 10-year averages centered on 2050 (2046–2055). These are computed for 2030, 2050, and 2090 and then interpolated to give the projections for the 5-year periods.
3. **Project infrastructure quantities under the alternative climate scenarios.** This is similar to the projection of baseline infrastructure quantities in step 1, but uses the climate variables for the alternative climate scenarios.
4. **Apply the dose-response relationship to estimate changes in unit costs for alternative climate scenarios.**[6] The changes in unit costs for infrastructure types in a given country for a given period are calculated using the climate change deltas for the alternative climate scenarios and the dose-response relationships discussed previously. These dose-response relationships underlie the design standards for infrastructure. It is assumed that the design standards are forward-looking and include climate change for 40 years into the future, i.e., infrastructure built in 2050 will consider the climate up to 2090.
5. **Estimate the change in total investment costs for the baseline projections (following step 4).** This yields the total investment cost of adaptation estimates for each climate scenario (Delta-C).

[5] Beaulieu, P. et al. 2002. Hygrothermal Response of Exterior Wall Systems to Climate Loading: Methodology and Interpretation of Results for Stucco, EIFS, Masonry and Sidingclad Wood-frame Walls. Final Report from Task 8 of MEWS Project (T8-03). *Research Report 118*. National Research Council Canada.

[6] There are some special factors that are not included in the dose-response equations that need to be taken into account in the cost calculations: (i) the decreased operating efficiency of existing thermal power plants as the ambient temperature increases; (ii) the decreased efficiency and feasibility of water cooling thermal power plants as temperature increases; and (iii) the increased operating costs of water treatment plants with climate change due to increased turbidity in source water and increased water quality standards for outflows.

6. **Estimate the change in investment costs due to the difference between the baseline infrastructure quantities (step 1) and the alternative climate scenario quantities (step 3).** This yields the cost variation of adaptation estimates for each climate scenario (Delta-Q).

Climate scenarios

As noted above, 17 GCM scenarios are used for the analysis in this chapter in combinations with historical data from the Climate Research Unit (monthly and annual variables) and the Princeton daily datasets (Appendix Chapter 1).[7] The "delta method" is employed to derive projections of precipitation and temperature variables. To calculate the projected value of a climate variable for 2030, the first step is to calculate the difference between the average of projected values for 2026–2035 generated by the GCM and the average of the predicted values for 1970–1999 generated by the same GCM (the "delta"). At the second step, this delta is added to the average for the actual climate data using 1980 as the notional base year.

This method is straightforward for changes in monthly and annual averages or totals but not for daily and extreme values. GCMs are incapable of producing reliable estimates of daily climate variables, such as maximum or minimum temperatures, precipitation, or wind speed. Instead, the analysis relies upon a combination of two approaches. The first approach draws upon the historic distributions of monthly values for temperature and precipitation from the Climate Research Unit dataset. For example, the difference between the 99th percentile and the mean value of the maximum monthly average of daily maximum temperature can be expressed as a proportion of the mean value. This proportion is then assumed to remain constant in future, so changes in the 99th percentile can be calculated from projected changes in the maximum monthly average of the daily maximum temperature.

The second approach makes use of the daily data from the Princeton dataset to generate Gumbel distributions, which are commonly used to model the distribution of maximum (or minimum) values. For example, the Princeton dataset provides daily precipitation for 1948–2008 for each grid square. A Gumbel distribution is fitted to maximum 3-day precipitation in each year with the parameters of the distribution expressed as functions of variables such as climate variables, latitude, longitude, mean elevation, and the percentage of the grid cell covered by water. The estimated relationship is used to calculate the deltas for the 98th and 99th percentiles (corresponding to 1-in-50-year or 1-in-100-year events) and these deltas are added to the historical values to generate projected values for 2030, etc.[8]

The economic impacts of extreme events

This chapter also explores the projected economic costs due to cyclones and floods in East Asia in 2050. Climate models in general cannot provide reliable estimates of extreme events, so the approach here assesses how climate change could alter historical patterns of vulnerability to cyclones and floods. The estimates of economic losses are based on a global historical dataset for 1980–1999 compiled by the Center for Hazards and Risk Research (CHRR) at Columbia University at a very high spatial resolution (2.5 arc-minute grid cell size).[9] The dataset includes estimates of average economic losses per year from cyclones and floods, expressed as a proportion of local GDP. The focus is on how climate change may alter the average economic losses over a similar period, not losses from specific events. For cyclones, the analysis is solely concerned with wind damage, while the damage caused by extreme rainfall associated with cyclones is covered by the analysis of short-term flooding.

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7 Historical values of humidity were also calculated using the Integrated Surface Database maintained by the National Oceanic and Atmospheric Administration's National Climate Data Center.

8 This approach is also used to project the future values of all the climate indexes that are based on daily weather variables, e.g., pavement temperature plus the Scheffer and MEWS indexes.

9 Center for Hazards and Risk Research. 2005. *Global Cyclone Hazard Frequency and Distribution – Version 1.0*. New York: CIESIN, Columbia University.

Cyclones. There is a lot of uncertainty about how climate change will alter the distribution and magnitude of cyclones.[10] However, there is fairly good agreement that climate change will increase the intensity of cyclones: for every 1° Celsius (C) rise in average sea surface temperatures, the intensity of cyclones could increase by 3%–5%.[11] A simple regression over the 30-year period suggests that ocean temperature anomalies are only about one-third of land temperature anomalies for the whole globe. For this study, the change in peak wind speeds due to climate change were computed for each GCM assuming (i) that sea surface temperature increases in the northwest Pacific are 50% of the increase in the mean land temperature for July–October (the main cyclone season), and (ii) a sensitivity of a 5% increase in cyclone intensity (i.e., wind speed) per 1° C increase in temperature. This first assumption is likely to overstate the potential increase in cyclone damage over the next 40 years. The results were linked to separate spatial estimates of the distribution of population by grid square.

Storm damage tends to increase as a power of the difference between the peak wind speed and the design standard for buildings and other structures. The calculations for the PRC presented here assume that wind damage is zero or minimal for storms with peak wind speeds up to 30 meters per second (m/s) (108 km/hr), while the equivalent zero-damage threshold for Japan is 40 m/s (144 km/hr) and for the Republic of Korea 35 m/s (126 km/hr). For each country the amount of damage caused by a storm with a peak wind speed greater than the design standard is assumed to be proportional to the fifth power of the excess wind speed. This corresponds to the damage relationship used in a recent global analysis of the damage caused by tropical cyclones.[12]

The estimates of the potential impact of climate change by grid cell were generated by adjusting the historic estimates of economic losses due to cyclones by the increase in peak wind speeds due to climate change and the associated increase in wind damage for both current design standards. The deciles of economic losses have been normalized by assuming that the top decile is equivalent to an average economic loss of 2% of GDP annually averaged over 50–100 years, which is broadly consistent with the estimates for current losses. In addition, the effect of adopting more stringent standards designed to protect against increases of 5 m/s (18 km/hr) and 10 m/s (36 km/hr) in 1-in-100-year peak wind speeds were examined. The increases in economic losses by grid square were aggregated to give the increase in economic losses for Japan, the Republic of Korea, and two regions in the PRC (east and southeast) as the impact of cyclones is minimal in other parts of the PRC.

Floods. Two distinct flood types are included in this analysis: (i) short-term flooding, including flash floods, in which extreme amounts of rain in a 24- or 72-hour period cause flooding within a relatively short distance of the original precipitation; and (ii) longer term or cumulative flooding, based on the accumulation of precipitation along a river basin. Short-term flooding is likely to be most important in Japan and the Republic of Korea, as well as in coastal areas of the PRC. All of these areas are affected by major tropical storms, while many of their river basins are relatively short in length. On the other hand, inland areas in the PRC are more likely to be affected by changes in the frequency and severity of cumulative flooding caused by climate change, although floods caused by peak 72-hour rainfall may be important in some provinces. These analyses are also based on the historical CHRR database of the economic impacts of floods. However, the database does not distinguish between the two types of floods, so a simplifying assumption is made: flood damage in the PRC coastal areas—especially Fujian, Guangdong, Guangxi Zhuang Autonomous Region, Hainan, and Zhejiang—is primarily due to short-term flooding, while flood damage in inland provinces—including Anhui, Guizhou, Hubei, Hunan, and Jiangxi—is primarily due to cumulative flooding.

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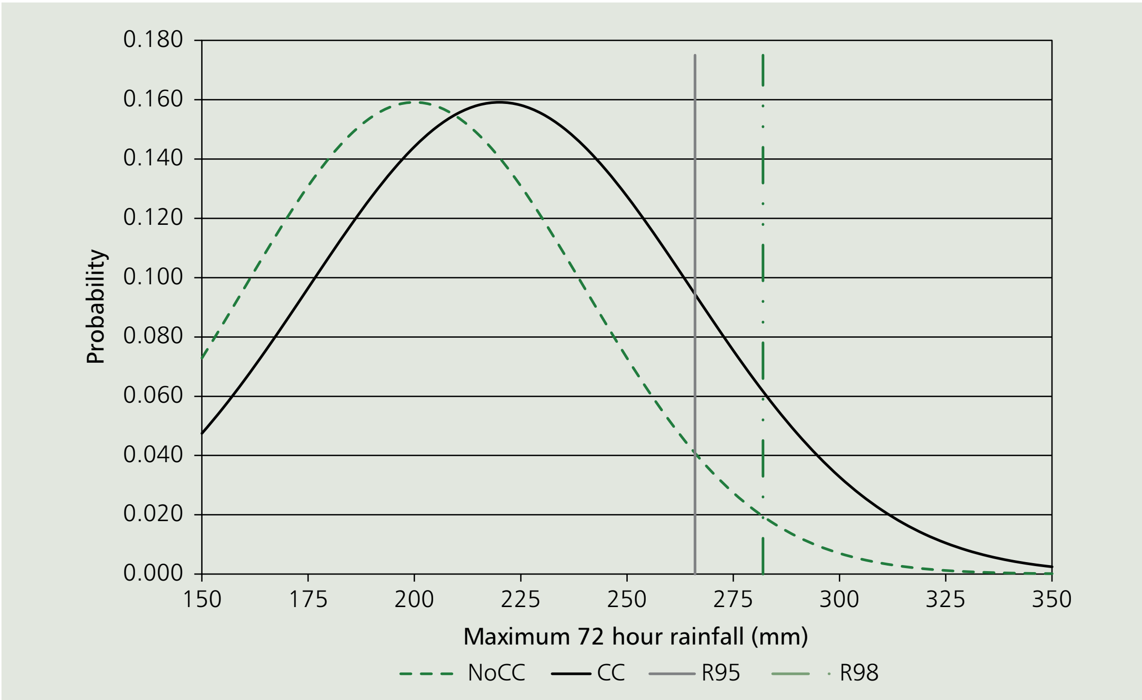
[10] Following normal terminology for the northwest Pacific, in this study the term "cyclone" is used to refer to all tropical storms with a peak wind speed of at least 63 kilometers per hour, or about 18 meters per second.

[11] Emanuel, K. 2000. A Statistical Analysis of Tropical Cyclone Intensity. *Monthly Weather Review* Vol. 128: 1,139–52.

[12] Mendelsohn, R., K. Emanuel, and S. Chonabayashi. 2011. The Impact of Climate Change on Global Tropical Storm Damages. *Policy Research Working Paper* No. 5562. Washington, DC: World Bank.

Figure 1 Impact of Climate Change on Short-Term Flooding



CC = with climate change, mm = millimeters, NoCC = without climate change.

Note: R95 refers to the rainfall level corresponding to a 1-in-20-year flood; R98 refers to the rainfall level corresponding to a 1-in-50-year flood.

Source: Asian Development Bank project team.

It is assumed that short-term flooding is in direct relation to the maximum 72-hour rainfall, and no hydrological model was employed. The key idea underlying the analysis of short-term flooding is illustrated in Figure 1, which shows a hypothetical distribution of maximum 72-hour rainfall under a situation of no climate change. The rainfall level R95 includes 95% of the observations of 72-hour rainfall. Because 72-hour rainfall is a proxy for flooding, design standards for 1-in-20-year floods are effective up to the R95 rainfall amount. Now, suppose climate change shifts the distribution of extreme rainfall to the right (the "CC" scenario in Figure 1). If no additional investment is made in flood prevention, the probability that there will be flooding will be higher than 5%, and the average severity of the floods that do occur will also increase.

For this analysis, the distribution of the maximum 72-hour rainfall is assumed to be normal with a mean and standard deviation without climate change equal to their values over the 20th century. The mean and standard deviation in 2050 for each climate scenario are taken from the climate projections for each GCM, assuming that the ratio of the standard deviation to the mean remains constant. There is very little general evidence about the relationship between the magnitude of floods and the amount of damage which they cause, because this depends greatly upon local conditions—including topography and the type of assets. Thus, it is assumed that the damage function is linear with increase in the volume of flood water. This is applied to the historical relationship between the average economic losses from the CHRR dataset and flood volume to project economic losses in 2050.

Cumulative flooding is largely an issue in the PRC. The analysis of the impacts of climate change on cumulative flooding relies upon estimates of the 90th percentile (i.e., the value that is exceeded in 10% of years) of annual flows at the downstream point of each river segment in the PRC, which

Box 1 Could Appropriate Investments in Infrastructure Help Avert the Health Impacts of Climate Change?

Human health in a country closely tracks the quality of infrastructure, which is correlated with income (see table). However, most studies indicate that climate change may have an adverse impact on health outcomes, though from a much lower base once the influence of higher incomes is taken into account.[a] The question then is whether additional investments in infrastructure investments can offset the health impacts of climate change.

Human Development Index and Infrastructure Quality for Selected East Asian Countries

Country	Human Development Index 2011	World Ranking in Overall Quality of Infrastructure
People's Republic of China	0.687	69
Japan	0.901	13
Republic of Korea	0.897	18
Mongolia	0.653	136

Sources: United Nations Development Programme. 2011. Sustainability and Equity: A better future for all. *Human Development Report 2011*. New York; World Economic Forum. 2011. *Global Competitiveness Report 2011–2012*. Geneva.

Infrastructure can play a role in mitigating the urban heat effects of a warmer climate. This includes changes in building design and operation – ventilation and air-conditioning – plus city-wide measures to reduce the "heat island effect," such as "green" infrastructure (increasing tree and vegetative cover and installing rooftop gardens), reflective roofs, and cool pavements.[b] However, reliance on air-conditioning alone is not a viable strategy except for those at acute risk of heat disorders.[c] Public health action measures to prevent heat disorders and deaths, including some modifications of the physical environment, have proven highly effective when applied consistently and based on inter-sector coordination.[d]

Adequate infrastructure can reduce the opportunities for vectors of climate-related diseases to breed and expand, but it must be combined with surveillance, integrated vector management, outbreak control, and sound public health practices. The proximate cause of waterborne disease is unsafe water and inadequate sanitation. Again, investment in infrastructure reduces the risks but behavioral changes are also critical. Even without adequate infrastructure, great strides can be made in reducing the risks of diarrheal disease and death by employing simple, fast, and low-cost interventions at the household and community level.[f] As discussed in Chapter 3, coastal defenses can significantly reduce the number of people displaced by flooding, as well as immediate deaths and injuries due to extreme storm events. Other measures—including robust planning, effective institutions, early warning systems, and adequate emergency response—are of course also required.

Overall, investments in infrastructure must be accompanied by effective public health measures and related institutional changes to minimize the impact of climate change on human health.

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[a] Ebi, K. L. 2008. Adaptation Costs for Climate Change-Related Cases of Diarrhoeal Disease, Malnutrition, and Malaria in 2030. *Global Health 2008* 4: 9; Asian Development Bank. 2009. *The Economics of Climate Change in Southeast Asia: A Regional Review.* Manila; Parry, M. et al. 2009. *Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates.* London: International Institute for Environment and Development and Grantham Institute for Climate Change; Chiabai, A. et al. 2010. Human Health. In *Costing Adaptation: Preparing for Climate Change in India.* Edited by Markandya, A. and A. Mishra. New Delhi: TERI Press.

[b] United States Environmental Protection Agency. 2008. *Reducing Urban Heat Islands: Compendium of Strategies.* Washington, DC.

[c] United States Center for Disease Control website on extreme heat. http://www.bt.cdc.gov/disasters/extremeheat/

[d] World Health Organization (WHO) Regional Office for Europe. 2008. Heat-Health Action Plans: Guidance. Copenhagen.

[e] WHO website on health and environment linkages initiative. http://www.who.int/heli/risks/vectors/vector/en/index.html

[f] WHO. 2007. *Combating Waterborne Disease at the Household Level.* Geneva.

were estimated using the CLIRUN2 model (Chapter 1, Appendix, footnote 47). It was necessary to use annual flow data because monthly flows depend upon the exact timing of precipitation with all of the upstream basins that contribute to the flow in a particular river segment; this goes beyond the capability of GCMs. Since a substantial proportion of the flow in the river segments that are most vulnerable to cumulative flooding is due to precipitation during the main rainy season, it seems reasonable to use annual flows as a proxy for potential flooding.[13] It is difficult to ascertain the flood defense standards in the PRC, but it is assumed that, for the middle and lower segments of the Yangtze River, the (population-weighted) average level of protection after the completion of the Three Gorges Dam is 1-in-50 years, while for the rest of the country it is 1-in-10 years.

Results

The results reported in this chapter focus on the costs of climate proofing infrastructure (Delta-C costs) as well as the economic impacts of extreme events. For each country averaged over all climate scenarios, the changes in total investment and maintenance costs due to the changes in the demand for infrastructure as a consequence of climate change (Delta-Q costs) are negative. The averages of the Delta-Q costs tend to be significantly lower than the costs of climate proofing, which means that the aggregate Delta-C costs tend to overstate the costs of adapting to climate change but they are of the right order of magnitude.

Since the countries and regions start from very different levels of infrastructure provision and development, absolute dollar values are of limited use in making comparisons. Instead, the primary comparisons are based on the costs of adaptation expressed as a percentage of baseline expenditures on infrastructure, either in aggregate or by category of infrastructure. Baseline expenditures are calculated as the sum of investment and maintenance costs for new and replacement infrastructure that would have been incurred over the time period—mainly 2011–2050—without climate change. Thus, the cost of adaptation is expressed as a percentage increase in the cost of providing a fixed level of infrastructure services. This is referred to as the relative cost of climate proofing.

Japan and Mongolia face the highest relative costs of climate proofing

The total cost of climate proofing infrastructure during 2011–2050 in East Asia is estimated to be $23 billion per year averaged over all climate scenarios, and ranges from $150 million per year in Mongolia to $11 billion per year in the PRC (Table 1). There is considerable variation across climate scenarios with the total cost for the region as a whole varying from $8 billion to $63 billion.

The countries with the highest costs of adaptation expressed as an average percentage of baseline expenditure across climate scenarios are Japan (2.3%) and Mongolia (2.2%), while the PRC has the lowest (0.6%). Thus, the average costs of climate proofing infrastructure are relatively modest compared to the total costs of infrastructure in the region.

[13] During 1980–2000 the mean maximum flow on the Yangtze River in Hubei province was about 14 times the mean minimum flow and about 3.5 times the mean average flow. Xiong, L. and S. Guo. 2004. Trend Test and Change Point Detection for the Annual Discharge Series of the Yangtze River at the Yichang Hydrological Station. *Hydrological Sciences Journal* Vol. 49: 99–112.Total discharges during and following the rainy season account for up to 80% of total annual flows.

Table 1 Average Costs of Adaptation for Climate Proofing by Country and/or Region and Climate Scenario, 2011–2050 ($ billion per year)

	PRC by Region									
Climate scenario	North	Northeast	East	Southeast	Southwest	West	Total	Japan	Korea, Rep. of	Mongolia
BCCR_BCM20	1.2	0.6	8.5	0.4	0.9	1.0	12.7	14.2	1.9	0.1
CCCMA_CGM3	5.2	1.1	25.5	5.7	4.3	2.4	44.2	13.2	5.4	0.1
CNRM_CM3	1.2	0.4	1.0	0.2	0.8	1.2	4.7	12.1	1.4	0.1
CSIRO_MK30	1.0	0.6	1.1	0.5	0.8	0.8	4.7	6.8	1.2	0.1
CSIRO_MK35	1.5	1.0	1.4	0.5	1.0	1.0	6.5	7.4	2.1	0.1
GFDL_CM20	0.8	0.2	1.0	0.4	1.9	0.6	5.0	14.3	1.4	0.1
GFDL_CM21	1.0	0.2	0.8	0.5	1.0	0.7	4.1	3.8	0.7	0.1
GISS_ER	2.7	1.0	8.8	4.2	3.8	0.9	21.4	6.0	1.4	0.1
INM_CM30	1.2	0.4	1.2	0.6	0.8	0.8	5.1	5.2	2.2	0.1
IPSL_CM4	1.3	0.6	2.3	0.7	1.1	1.5	7.5	7.3	3.5	0.2
MIROC32	0.8	1.4	1.1	0.3	1.0	1.3	5.8	12.9	2.8	0.6
MPI_ECHAM5	0.8	0.2	1.2	0.3	0.9	0.6	3.9	4.3	0.9	0.1
MRI_CGCM232A	0.6	0.2	0.9	0.1	0.8	0.7	3.3	3.6	1.3	0.1
NCAR_CCSM30	3.5	2.3	5.5	1.5	1.7	1.2	15.6	7.2	2.6	0.2
NCAR_PCM1	1.5	0.4	3.0	0.3	0.8	1.3	7.2	3.2	3.2	0.3
UKMO_HADCM3	4.5	1.3	7.8	11.8	1.7	1.2	28.3	18.1	3.5	0.1
UKMO_HADGEM1	2.9	0.5	1.2	0.6	1.3	1.1	7.6	22.2	1.7	0.2
Average over GCMs	1.9	0.7	4.3	1.7	1.4	1.1	11.0	9.5	2.2	0.2
Standard deviation	1.4	0.6	6.2	3.0	1.0	0.4	11.0	5.6	1.2	0.1
Average as % of baseline	0.6	0.7	0.6	0.4	0.9	1.0	0.6	2.3	1.8	2.2
Median as % of baseline	0.4	0.5	0.2	0.1	0.6	1.0	0.4	1.7	1.6	1.5
Max as % of baseline	1.7	2.2	3.8	2.7	2.7	2.3	2.5	5.3	4.5	8.5

Notes: Figures are at 2005 prices. See Appendix Chapter 1 for the climate scenarios. For the definition of regions in the PRC, see Appendix.

Source: Asian Development Bank project team.

The variation in the costs of adaptation across climate scenarios is large for some countries

The minimum and maximum costs of adaptation across climate scenarios span a range from $3 billion to $44 billion per year for the PRC, and from $50 million to $560 million per year for Mongolia. Mongolia has the highest maximum relative cost of adaptation (8.5% of baseline expenditure).

Two points should be emphasized. There is no simple link between income and the impacts of climate change—geography is the main determinant of the relative costs of adaptation. In addition, there is no particular climate scenario that consistently leads to the highest or lowest costs across all four countries. The results are most closely linked to mean annual precipitation: the climate scenarios with the highest adaptation costs tend to be ranked in among the wettest scenarios.

Roads have the highest relative costs of climate proofing

Infrastructure assets have been assigned to seven categories: power and communications, water and sewers, roads, other transport, health and schools, urban and housing. Urban includes storm water drainage and municipal buildings, of which the first component is the most important for adaptation. In terms of absolute sums, housing has the highest costs of climate-proofing—an average of $10 billion per year during 2011–2050. However, roads have the highest relative costs of climate proofing—7.8% of baseline expenditure averaged across climate scenarios, or an average of $7 billion per year, with a maximum value of 12.2% of baseline costs (Table 2). Of the other infrastructure classes, only urban infrastructure (2.1%) has relative costs of climate proofing greater than 1.0% on average.

The adaptation costs for roads are influenced by both precipitation and temperature because of (i) the cost of resurfacing paved roads and/or using more expensive pavement binders to cope with higher pavement temperatures, and (ii) the additional costs of building and maintaining all roads because of changes in the risk of flooding because of changes in patterns of precipitation. For urban infrastructure, the main driver of adaptation costs is the increase in maximum 3-day precipitation, which determines the required level of investment in storm water drainage.

Countries will adapt to climate change. The economic issue is whether they should do this via initial investment in climate proofing (ex-ante adaptation), which requires them to make assumptions about what the future climate will be, or by spending money after the actual climate outcome is known (ex-post adaptation)

The decision on whether and when to climate proof infrastructure is determined by the trade-off between the initial capital costs of climate proofing (ex-ante adaptation[14]) versus the higher costs of operating, maintaining, and/or replacing infrastructure that is not designed to cope with future climate conditions. Climate proofing infrastructure (i.e., the additional construction costs because of changes in climate) results in lower operations and maintenance (O&M) costs later. But, there are opportunity costs associated with climate proofing infrastructure, and in some cases it may make sense to simply deal with increased O&M and replacement costs in the future (ex-post adaptation). This decision must include a consideration of discount rates and uncertainty about climate scenarios. The higher the discount rate, the less likely it is that there will be positive economic benefits from climate proofing.[15]

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[14] Throughout this chapter, "climate proofing," "ex-ante adaptation," and "advance adaptation" are used synonymously.

[15] The discount rate is the opportunity cost of capital, or the return from alternative investments of equal risk. When the discount rate is high, the benefits and costs of future investments are valued less than those in the present. The discount rate is based on two concepts: (i) The "rate of time preference," i.e., most people prefer consumption undertaken now rather than later. Thus, a dollar available now is more highly valued than one received later. (ii) Uncertainty or risk. There is necessarily some degree of uncertainty as to whether a future dollar will actually be received, lessening its value in proportion to the expected size of the risk. Its value is lessened in proportion to the expected size of this uncertainty or risk factor.

Table 2 Average Costs of Climate Proofing by Infrastructure Category and Climate Scenario, 2011–2050 ($ billion per year)

Climate scenario	Power and communications	Water and sewers	Roads	Other transport	Health and schools	Urban	Housing	Total
BCCR_BCM20	0.8	0.3	6.9	0.2	1.5	3.4	15.8	28.8
CCCMA_CGM3	2.2	0.8	9.0	0.4	4.3	5.9	40.5	63.0
CNRM_CM3	0.7	0.2	6.3	0.1	1.2	3.2	6.6	18.3
CSIRO_MK30	0.5	0.2	5.3	0.1	0.8	2.4	3.6	12.8
CSIRO_MK35	0.7	0.2	7.6	0.1	1.1	3.1	3.3	16.1
GFDL_CM20	0.7	0.2	6.8	0.1	1.1	3.4	8.4	20.8
GFDL_CM21	0.5	0.1	4.7	0.0	0.7	2.2	0.4	8.7
GISS_ER	1.2	0.5	5.9	0.2	2.0	3.9	15.1	28.8
INM_CM30	0.7	0.2	6.7	0.1	1.0	2.9	1.0	12.6
IPSL_CM4	0.8	0.2	7.4	0.2	1.2	3.1	5.6	18.4
MIROC32	0.9	0.2	6.3	0.1	1.6	4.2	8.8	22.1
MPI_ECHAM5	0.5	0.1	4.6	0.1	0.6	1.5	1.9	9.2
MRI_CGCM232A	0.4	0.1	4.2	0.0	0.6	1.4	1.5	8.2
NCAR_CCSM30	0.9	0.4	7.3	0.2	1.7	4.1	11.1	25.7
NCAR_PCM1	0.6	0.3	4.7	0.1	1.0	2.7	4.5	13.9
UKMO_HADCM3	1.4	0.6	10.5	0.3	3.0	6.4	27.8	50.0
UKMO_HADGEM1	0.9	0.3	9.4	0.2	1.7	5.7	13.5	31.6
Average over climate scenarios	0.8	0.3	6.7	0.1	1.5	3.5	10.0	22.9
Standard deviation	0.4	0.2	1.8	0.1	1.0	1.4	10.6	14.7
Average as % of baseline	0.2	0.2	7.8	0.7	1.1	2.1	0.7	1.0
Median as % of baseline	0.2	0.2	7.8	0.6	0.9	1.9	0.5	0.8
Maximum as % of baseline	0.6	0.6	12.2	1.8	3.2	3.9	2.8	2.7

Notes: Figures are at 2005 prices. See Appendix Chapter 1 for the climate scenarios.

Source: Asian Development Bank project team.

The net benefits of ex-ante adaptation across all infrastructure types in each country, averaged over all climate scenarios and using a range of discount rates, are shown in Figures 2A to 2D. To reiterate, the costs of ex-ante adaptation are the initial capital costs and future O&M costs during the lifetime of the infrastructure asset, while the benefits are the avoided costs, or savings, from not having to spend money on replacement and/or higher O&M because of damage due to the infrastructure being less suited to the future climate. The net benefits are positive when these savings are larger than the costs of climate proofing. With a larger discount rate, climate proofing is less advantageous because much of the costs are borne when the infrastructure is constructed (investment costs), while the benefits accrue in the future. The cost of ex-ante adaptation reflects the cost of designing assets to cope with changes in weather risks up to 40 years ahead from the time period concerned. For example, with ex-ante adaptation, roads built in 2016–2020 are designed to cope with changes in the severity of 1-in-100-year floods up to 2056–2060 under the relevant climate scenario. Similarly, changes in O&M costs are assessed over the typical economic life of the relevant assets up to a maximum of 40 years.

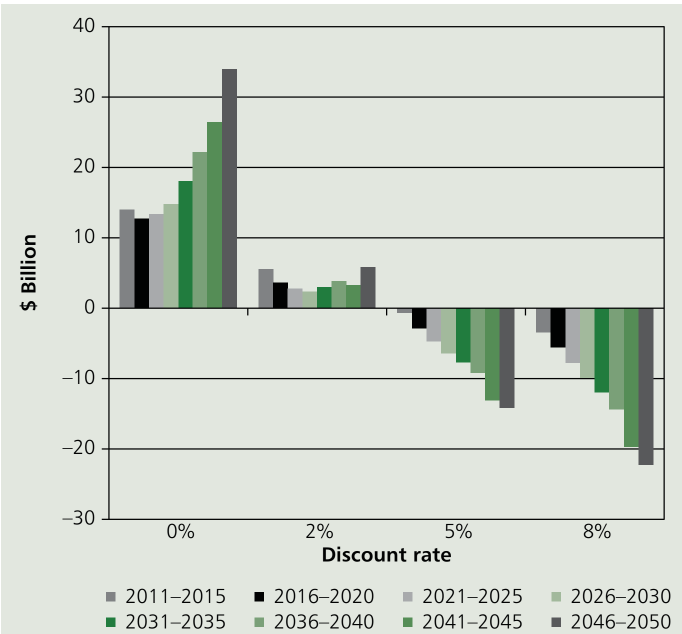
Assuming that the future climate is known, Japan and the Republic of Korea should generally climate proof all infrastructure that is built now, while in the People's Republic of China and Mongolia the cost-effectiveness of climate proofing depends on the type of infrastructure

When a discount rate of 0% is considered, the net benefits of climate proofing infrastructure are positive for all countries and time periods, including the present (2011–2015), meaning climate proofing is justified on economic grounds. For Japan and the Republic of Korea, ex-ante adaptation has positive economic benefits for all time periods and discount rates up to 8% (with one minor exception). In the PRC, however, the net benefit becomes quite small at a discount rate of 2% and is negative for higher discount rates, even in 2050. Similarly, the net benefit of adaptation in Mongolia is negative or very small for a discount rate of 5% and negative for higher discount rates, regardless of the time period. Both of these countries have high economic growth rates, so consideration of a discount rate of less than 5% is difficult to justify. The difference is due to large O&M costs in Japan and the Republic of Korea under some climate scenarios without ex-ante adaptation, particularly those which imply significant increases in precipitation. As discussed in Chapter 1, Japan and the Republic of Korea are expected to experience greater increases in precipitation than the other countries in East Asia.

The results above are averaged across all infrastructure types. The net benefits of adaptation for each infrastructure category at a discount rate of 5%, averaged across all GCMs, are shown in Figures 3A to 3D. With one minor exception, ex-ante adaptation has positive economic benefits for all infrastructure types and time periods in Japan and the Republic of Korea. Japan would probably receive the greatest economic benefits from climate proofing roads, housing, and urban infrastructure, while in the Republic of Korea the greatest economic benefits would result from adapting social infrastructure (health and schools), urban infrastructure, housing, and roads to climate change. In the PRC and Mongolia the picture is more complex, with some infrastructure types having high costs and others large benefits. For the PRC, the net benefits of adaptation are negative for all categories of infrastructure except roads, and the net cost of adaptation is particularly large for housing. In Mongolia, however, the benefits of adaptation are negative for roads but positive for social and urban infrastructure. This analysis indicates priority categories for policy makers when considering what infrastructure types to climate proof now.

Larger increases in annual precipitation leading to higher O&M costs in future in Japan and the Republic of Korea explain some of these results, but this is not the complete story. Specific dose-response relationships for individual infrastructure assets interact with the projected changes in the seasonal distribution of precipitation and precipitation extreme events. As an illustration, for health, schools, and housing it is not the annual level of precipitation that matters but rather the distribution of precipitation over the year which determines humidity, the main driver of costs related to ventilation and cooling.

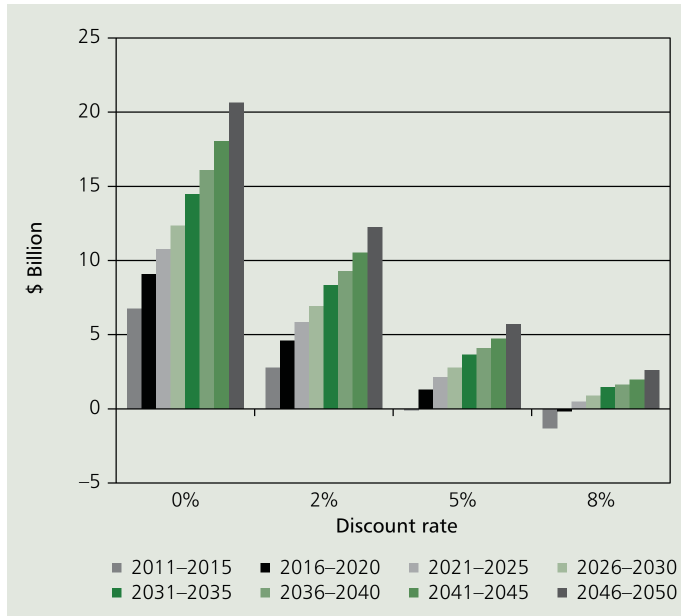
Figure 2A Net Benefits of Climate Proofing for All Infrastructure in the People's Republic of China ($ billion)



Note: At 2005 prices, average over all climate scenarios.

Source: Asian Development Bank project team.

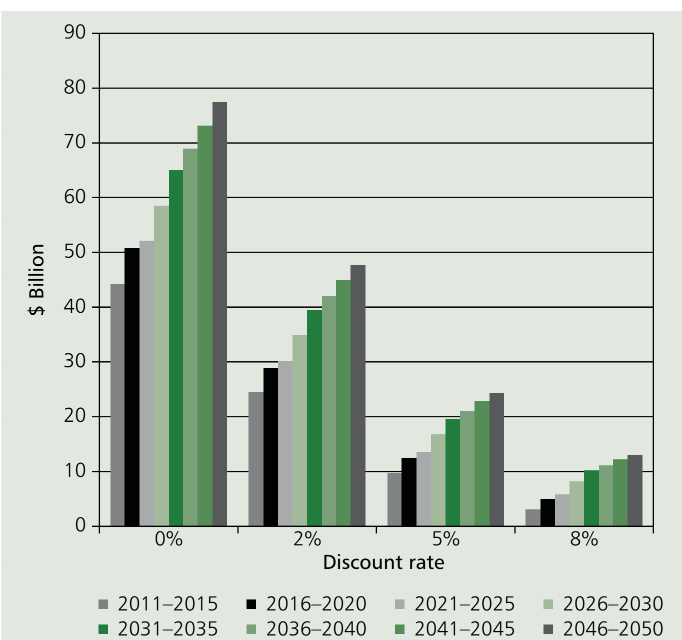
Figure 2B Net Benefits of Climate Proofing for All Infrastructure in Japan ($ billion)



Note: At 2005 prices, average over all climate scenarios.

Source: Asian Development Bank project team.

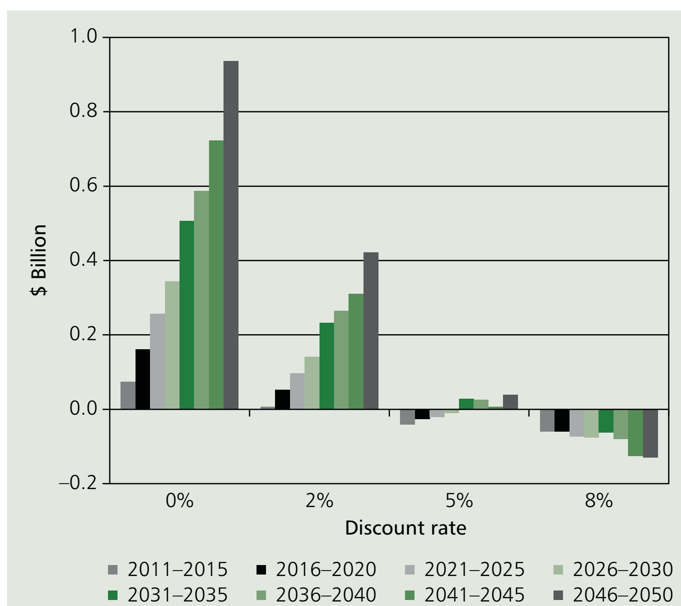
Figure 2C Net Benefits of Climate Proofing for All Infrastructure in the Republic of Korea ($ billion)



Note: At 2005 prices, average over all climate scenarios.

Source: Asian Development Bank project team.

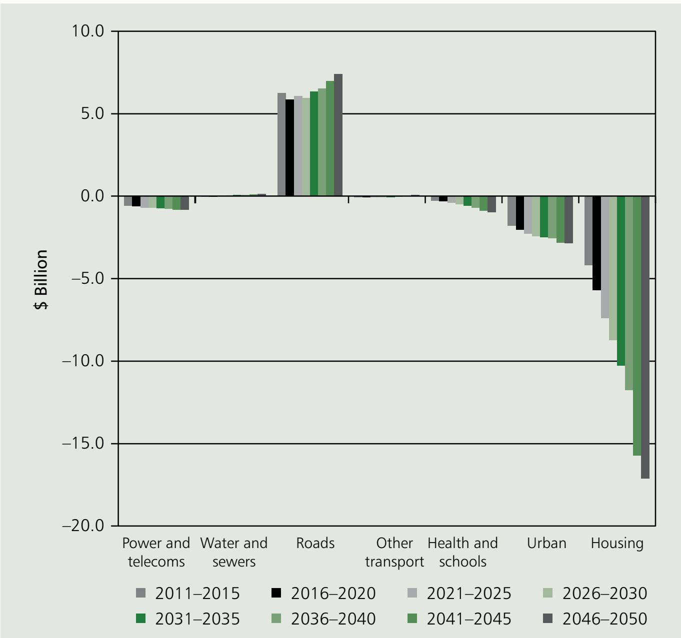
Figure 2D Net Benefits of Climate Proofing for All Infrastructure in Mongolia ($ billion)



Note: At 2005 prices, average over all climate scenarios.

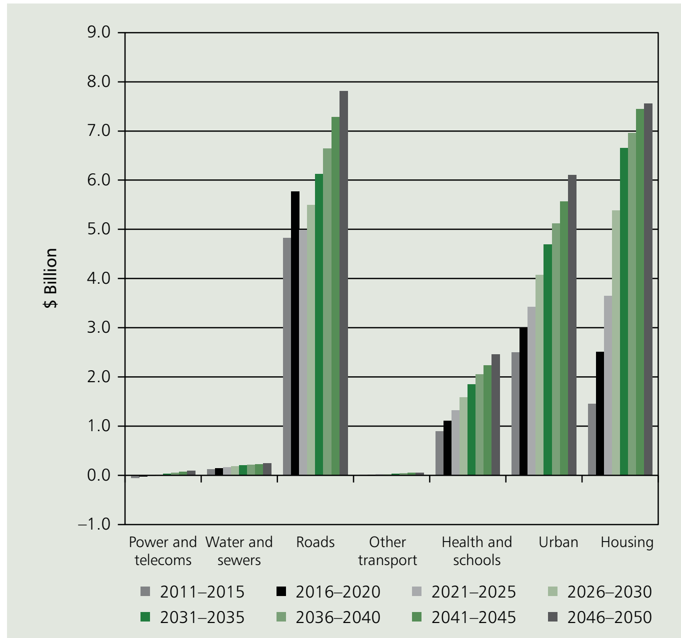
Source: Asian Development Bank project team.

Figure 3A Net Benefits of Climate Proofing by Infrastructure Category in the People's Republic of China ($ billion, discount rate = 5%)



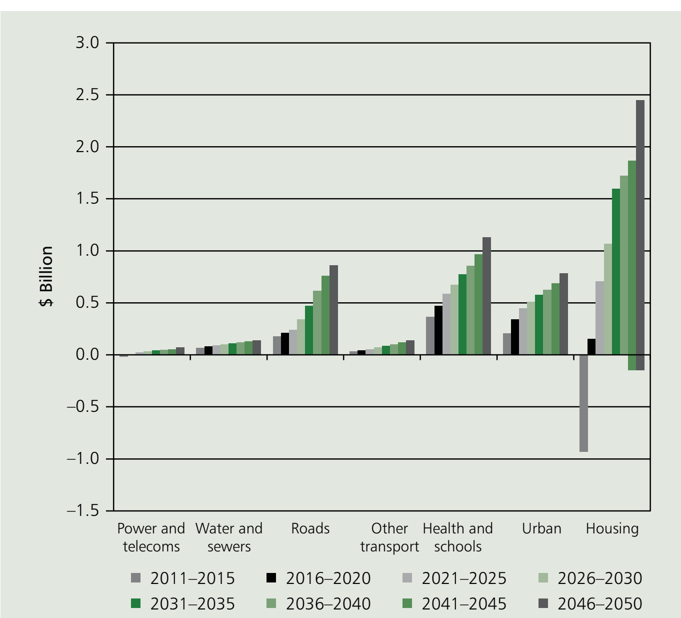
Note: At 2005 prices with 5% discount rate average over all climate scenarios.
Source: Asian Development Bank project team.

Figure 3B Net Benefits of Climate Proofing by Infrastructure Category in Japan ($ billion, discount rate = 5%)



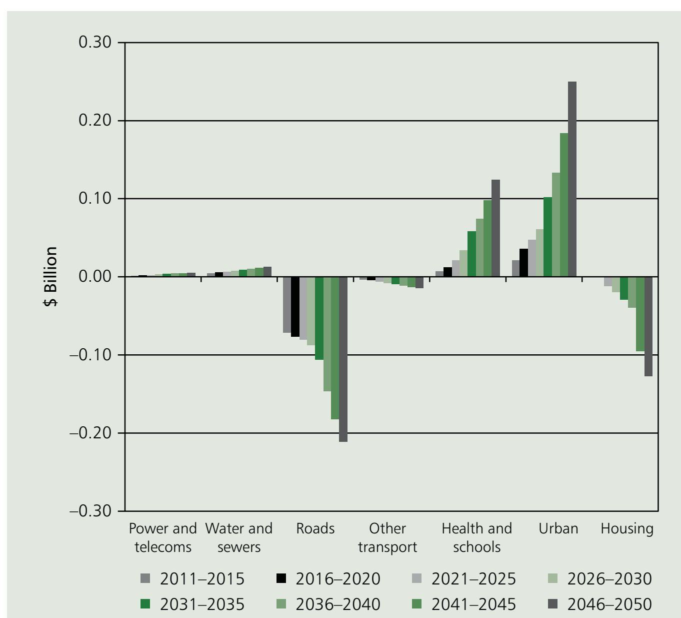
Note: At 2005 prices with 5% discount rate average over all climate scenarios.
Source: Asian Development Bank project team.

Figure 3C Net Benefits of Climate Proofing by Infrastructure Category in the Republic of Korea ($ billion, discount rate = 5%)



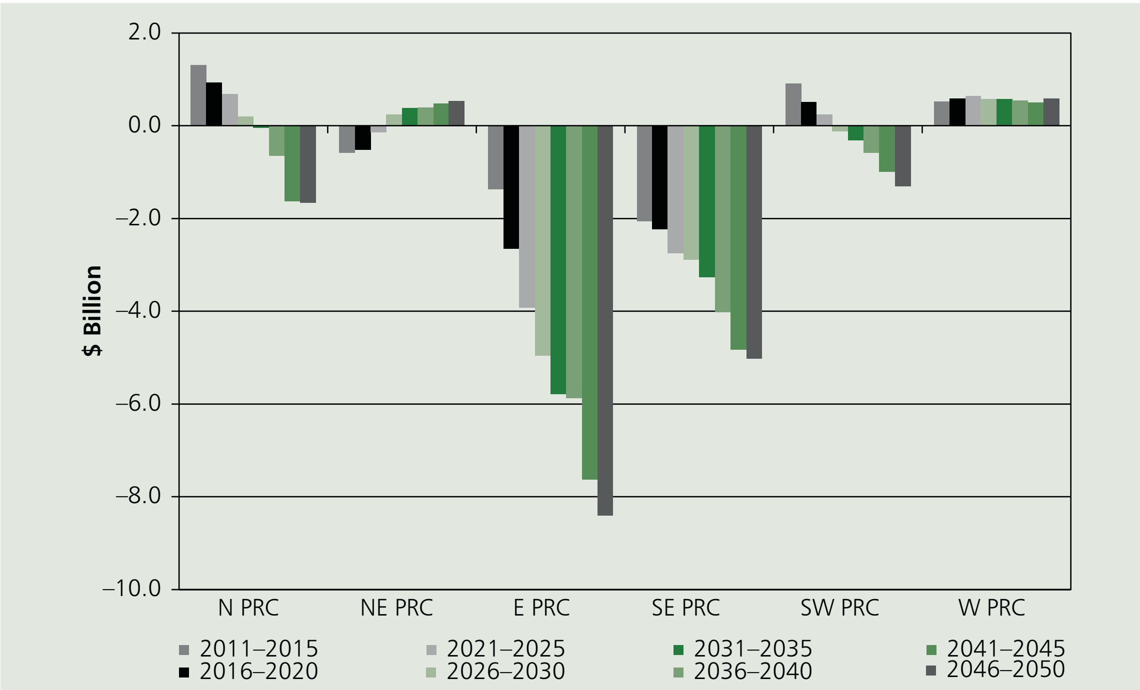
Note: At 2005 prices with 5% discount rate average over all climate scenarios.
Source: Asian Development Bank project team.

Figure 3D Net Benefits of Climate Proofing by Infrastructure Category in Mongolia ($ billion, discount rate = 5%)



Note: At 2005 prices with 5% discount rate average over all climate scenarios.
Source: Asian Development Bank project team.

Figure 4 Net Benefits of Climate Proofing for All Infrastructure by Regions in the People's Republic of China ($ billion, discount rate = 5%)



N = North, NE = Northeast, E = East, SE = Southeast, SW = Southwest, W = West.

Note: At 2005 prices with 5% discount rate, average over all climate scenarios.
For the definitions of regions in the PRC see Appendix.

Source: Asian Development Bank project team.

The above analyses on the net economic benefits of climate proofing infrastructure are averaged across all climate scenarios and for each country as a whole. But climate uncertainty and the spatial scale of analysis matter. For instance, the results for the net benefits of adaptation across all infrastructure types in the PRC are largely determined by three climate scenarios that result in very high costs. Among specific types of infrastructure there is great variation. All scenarios show positive economic benefits for roads, but for housing there are a few outlier climate scenarios that lead to very high costs. Lastly, the aggregated results for the PRC are largely determined by the large costs for the eastern and southeastern regions, although some other regions do have net positive benefits (Figure 4).

Attitudes to risk matter when making decisions under uncertainty. Technically, these may be summarized by a parameter that reflects the decision maker's degree of risk aversion. A country would be risk neutral or have zero risk aversion if it is willing to choose the option which yields the highest average value over all climate scenarios. Hence, the comparisons discussed above are appropriate if countries are risk neutral.

On the other hand, the distribution of outcomes across climate scenarios may be skewed with a small number of outcomes with large positive or negative net benefits. If decision makers are risk averse they will give more weight to the worst outcomes rather just examining the average outcome. Under extreme risk aversion, the decision will be made on the basis of what option will minimize the maximum loss that might be incurred.

The background technical paper explains how the degree of risk aversion can be formally incorporated into the analysis and presents results on the best options by country under different degrees of risk aversion. It is worth noting that many economists argue that large diversified economies—certainly the PRC, Japan, and the Republic of Korea—should be risk neutral when making decisions that will not have a substantial impact on economic welfare in future. For Mongolia, the risks of climate change are larger and the economy is less diversified, so some degree of risk aversion may be reasonable.

Incorporating risk aversion in climate uncertainty complicates the picture, but Japan and the Republic of Korea should adapt earlier and climate proof more infrastructure types than the People's Republic of China and Mongolia

For the PRC, adaptation seems to be clearly justified now for water and sewers and for roads but not for other types of infrastructure, except for housing when the degree of risk aversion is very high, and even then only after 2025. In contrast, adaptation seems to be broadly justified in Japan except for power and communications, and other transport. The pattern is more mixed for the Republic of Korea and Mongolia. Generally, the Republic of Korea is similar to Japan but adaptation can be postponed in many sectors until after 2020 or even 2030 unless there is a very high degree of risk aversion. Mongolia is similar to the PRC but with adaptation being justified for housing now, and health and schools and urban infrastructure after 2040. The most important conclusion that can be drawn from this analysis is that uncertainty about future climate outcomes strengthens the case for caution before embarking on significant investments in adaptation.

As explained earlier, the analysis of the impact of climate change on extreme events such as cyclones and flooding focuses on the increase in the average economic loss caused by cyclones or floods over a period of years expressed as a proportion of local GDP. The threshold for a major impact is an increase in the average economic loss of more than 1% of local GDP, while any increase in the average economic loss of less than 0.1% of local GDP is treated as not being significantly different from zero.

The actual impact of any climate scenario will depend upon the level of protection provided by the design standards for defenses against cyclones and floods, usually expressed as the maximum severity of the storm or level of rainfall that the defense is designed to withstand, e.g., a flood defense may be designed to provide protection against a 1-in-50-year rainfall event. Viewed in economic terms, the efficient level of protection is that at which the marginal cost of increasing protection, i.e., building more flood defenses, is just equal to the marginal benefits of reducing the average economic loss due to flooding. The design standards in operation in rich countries will generally provide more protection than those in poorer countries, since the demand for and the net economic benefits of protection tend to increase with GDP.

An adaptation deficit is said to exist when the current level of protection is less than the efficient level of protection, meaning that the costs of providing better defenses is lower than the benefits of more protection in the form of the reduction in the average economic loss. This seems to be the situation in areas of the PRC which are most exposed to storm and flood damage. The cost of adaptation to climate change on its own is the cost of maintaining the efficient level of protection, e.g., against a 1-in-50-year flood, when the distribution of extreme events has shifted.[16]

The increase in the economic losses due to cyclones is projected to be minor in the People's Republic of China in 2050 but substantial in Japan and the Republic of Korea

In 2050 more than 99% of the population of the coastal areas of the PRC will live in areas where the increase in the average economic loss due to cyclones will be less than 0.1% of local GDP. In contrast, in Japan 9.3% of the total population and 18.1% of the rural population will live in areas where the

[16] It is possible that climate change will alter the *shape* of the distribution of extreme events in addition to their *location*. In that case, the trade-off between costs and benefits involved in choosing an efficient level of protection may change. This is a second-order effect that is very difficult to identify in less than 50 or 100 years, and so it has not been considered in the analysis.

increase in the average economic loss due to cyclones are projected to be more than 1.0% of local GDP. In the Republic of Korea, the equivalent figures are 3.8% of the total population and 4.6% of the rural population, which are still significant.

But, the costs of cyclone proofing buildings in terms of wind damage are modest

The impact of climate change on the average level of economic losses due to cyclones in Japan and the Republic of Korea can be largely offset if building design standards are adjusted by increasing the threshold of protection by 5 m/s in peak wind speeds. In this case, the proportion of the population at risk of an increase in average economic losses greater than 0.1% of GDP in 2050 is close to zero. An increase in the design standard by 10 m/s should ensure that the impact of climate change on economic losses due to cyclones up to 2100 should be minimal. Based on detailed analysis of amendments to building codes in Florida, it is estimated that one code amendment of 5 m/s will increase average building costs by 0.8%, totaling about $2.5 billion per year over 2010–2050 for Japan, which is equivalent to about 0.6% of total expenditure on infrastructure. The results are similar for the Republic of Korea.

Recent experience suggests that current design standards for coastal areas in eastern and southeastern PRC are too low. A design standard of 30 m/s (108 km/hr) is equivalent to a 1-in-10-year storm for these areas. In contrast, a 1-in-100-year design standard for Fujian and Zhejiang would imply that buildings and other structures should be capable of withstanding a cyclone such as Typhoon Saomai, which made landfall in August 2006 with a peak wind speed over land of 185 km/hr.[17] Adopting a standard ensuring that buildings can withstand peak wind speeds of 50–55 m/s (180–198 km/hr) might increase the overall cost of constructing infrastructure by 3.5%–4.0%, or an average of $25 billion per year at 2005 prices, for the coastal areas of the two regions. This is a large sum, but about 85% of the additional cost is addressing the current adaptation deficit—adopting building codes designed to withstand the peak wind speeds associated with a current 1-in-100-year storm (the current standard in Japan and the Republic of Korea). The remaining 15% of the additional cost (about $4 billion per year) represents the cost of ensuring that structures built up to 2050 are capable of coping with the higher peak wind speeds associated with more intense typhoons as a consequence of climate change.

Projected changes in economic losses from short-term flooding are small in Japan and the Republic of Korea but significant in the coastal areas of the People's Republic of China

If there is no change in design standards for infrastructure, the impact of climate change on the average economic loss due to short-term flooding in Japan and the Republic of Korea will be small. Less than 0.1% of the total population in Japan and 0.5% in the Republic of Korea will live in areas where the increase in economic losses may be greater than 0.5% of local GDP in 2050, and none where the increase may be greater than 1%. However, the impact of climate change on short-term flooding in the coastal areas of the PRC may be moderate, although there is high variation across climate scenarios. In the southeastern region of the PRC, between 0.1% and 8.4% of the total population may suffer an increase in economic losses exceeding 0.5% of local GDP under different climate scenarios, while the equivalent range is 0.2%–4.4% for the eastern region. In both regions the proportion of the population exposed to an increase in economic losses of greater than 1% of local GDP is less than 1%, even in the worst climate scenarios.

The impact of climate change on short-term flooding in the PRC can be largely eliminated by increasing the level of protection provided by flood defenses. On average, it seems that the typical defenses in place today offer protection against the effects of 1-in-20-year 3-day rainfall. If the design standards for all flood defenses were adjusted to provide a minimum threshold of protection against 1-in-50-year 3-day

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17 Carpenter, G. 2006. *Typhoon Saomai: Impact and Historical Comparison.* London: Guy Carpenter and Company.

rainfall, the proportions of the population that might be exposed to an average loss due to climate change greater than 0.1% of total income would be reduced to less than 1.0% in each region. As with cyclones, most of the cost involved is that associated with addressing the existing adaptation deficit, i.e., increasing the current standard of protection provided by flood defenses without consideration of future climate change. Since the costs of constructing flood defenses to provide a minimum standard of protection depend on local circumstances, it was not possible to estimate the total cost of adaptation for short-term flooding.

Projected average changes in economic losses from cumulative flooding in the People's Republic of China are dramatic but highly variable across climate scenarios

The impact of climate change on average economic losses in 2050 due to cumulative flooding in the eastern, southeastern, and southwestern regions of the PRC may be very large if the current design standards for flood defenses are not improved. Averaged over all climate scenarios, between 18% and 22% of the populations of these regions will suffer an increase in the expected annual loss due to flooding of at least 1% of local GDP. There is great variation across climate scenarios and the averages are the consequence of major losses under a small number of scenarios. For example, in the eastern region, the proportion of the population at risk of an increase in economic losses of at least 1% of local GDP in 2050 varies from less than 1% in the best eight climate scenarios to 78%–84% in the worst three scenarios. The analysis suggests that adopting a consistent 1-in-50-year standard for flood defenses would greatly reduce the impact of climate change in each region in all but three or four climate scenarios.

These results further underscore the importance of risk aversion when considering adaptation to climate change. If the authorities are risk neutral, then the adoption of a 1-in-50-year standard for flood defenses may be efficient for the average climate scenario. On the other hand, if they are highly risk averse, then flood defenses that would protect against the potential flooding in the climate scenarios associated with the worst climate scenarios will be required and the costs of adaptation will be much higher.

The detailed analysis provides more guidance. It is no surprise that the key issue concerns flooding in the Yangtze River basin. The provinces of Anhui and Hunan are at particular risk, while the provinces of Hubei and Henan may be affected less severely. The critical climate scenarios are BCCR_BCM20, followed by GISS_ER and CCCMA_CGM3. With detailed local information it would be possible to assess the cost of implementing local adaptation strategies on top of a minimum 1-in-50-year standard for all flood defenses.

Conclusions

The analysis of the costs of adaptation to climate change for infrastructure in this chapter highlights a high degree of variation across infrastructure categories, countries, and climate scenarios. Even so, the average cost of adaptation for all infrastructure across all climate scenarios is less than 2.5% of baseline expenditures in all countries, and is less than 1.0% of baseline expenditures for the PRC. Again, in aggregate and over all climate scenarios, allowing for changes in the demand for infrastructure services seems more likely to reduce rather than increase the cost of adaptation.

Of the infrastructure categories examined, it is roads (paved and unpaved) which have the greatest relative cost of adaptation, with an average of 7% of baseline expenditures and a maximum of 12% in the worst climate scenario. Adaptation costs for roads are linked to changes in annual precipitation as well as changes in episodes of peak rainfall that cause flooding. Similar factors influence the costs for urban infrastructure, in particular storm water drainage, which has the second-highest relative cost of adaptation.

The costs of climate proofing infrastructure are a complex function of local geography and climate outcomes. Space matters and the results can vary, particularly in a country such as the PRC, based on the spatial scale or level of aggregation. It is critical to understand the local details of weather and climate and their impacts on infrastructure, and that detailed, local, on-the-ground knowledge is important.

In addition, uncertainty about climate scenarios is important. There are large variations in the costs of adaptation across climate scenarios. In planning for adaptation it is necessary to take account of the consequences of spending either too little or too much by choosing one climate scenario over alternatives. For discount rates of 5% or higher, the best strategy may be to opt for ex-post adaptation, i.e., incurring higher costs to operate or replace infrastructure but at a later time, rather than ex-ante adaptation where the initial costs involve the risk of making mistakes by investing in the wrong level or type of adaptation.

The degree of risk aversion is important as in any decision that has to be made under uncertainty. Many commentators on climate change focus on the worst outcomes. This implies a very high degree of risk aversion. For large countries in East Asia, the risks associated with adaptation for infrastructure may not warrant a high level of risk aversion, in which case it is sufficient to focus on the average costs of adaptation over all climate scenarios. On the other hand, Mongolia is small and less diversified, so it may wish to give more weight to the worst outcomes.

The most serious impacts of climate change on the average losses due to extreme events concern cyclones in Japan and the Republic of Korea and flooding—both short term and cumulative—in the PRC. In these cases, adaptation will involve changes in design standards to maintain or increase the level of protection when the distribution of extreme events has shifted. The relative cost of adaptation will be small in Japan and the Republic of Korea.

However, existing levels of protection against natural hazards in the PRC appear to be well below their efficient level, so that damage caused by storms or floods could be substantially reduced by adopting 1-in-50-year or 1-in-100-year design standards, even without consideration of climate change. If such policies were adopted, the additional costs of adaptation for storms and flooding would be modest under most climate scenarios. The exception is that cumulative flooding may give rise to large losses in the Yangtze River basin under a small number of climate scenarios. In this case, the costs of ensuring greater protection may be much larger.

Appendix: Socioeconomic Projections

People's Republic of China

The models which are used to establish the baseline without climate change (NoCC) and to assess the impact of climate change rely upon projections of economic and demographic variables by province at 5-year intervals from 2010 to 2050. The starting point that was used for this study is a set of demographic projections prepared by the International Institute for Applied Systems Analysis (IIASA) which were used as inputs into their PRCGRO model.[18] The IIASA projections take account of rural–urban and interprovincial migration rates. The central scenario projections have been adjusted to reflect the most recent estimates of population and urbanization in the 2010 census. The projections of growth rates and population composition have been adjusted to be consistent with the growth rates, age composition, and urbanization rates in the aggregate population projections for the People's Republic of China (PRC) in the United Nations (UN) Population Division's 2010 medium fertility scenario and the 2009 World Urbanization Prospects.[19]

The total population for the 31 provinces, autonomous regions, and municipalities of the PRC that are the focus of attention in this study is projected to be 1.4 billion in 2030 and 1.3 billion in 2050, with an urbanization rate of 61.8% in 2030 and 73.2% in 2050. The percentage of the total population aged over 65 will increase rapidly to 16.5% in 2030 and 25.6% in 2050. The corresponding figures for 2010 were 1.34 billion with an urbanization rate of 47.0% and 8.2% of the population aged over 65. Thus, the major demographic changes from 2010 to 2050 are (i) the continuation of the rapid growth in the urban population, up from about 630 million in 2010 to nearly 950 million in 2050; and (ii) the increase in the elderly population from about 110 million in 2010 to 330 million in 2050. These changes will have significant consequences for the nature of the additional economic and social infrastructure that must be provided between 2010 and 2050 and, as a result, on the manner in which climate change may affect the costs of providing such infrastructure.

Almost all projections of economic growth in the PRC over the next two decades focus on the country as a whole with little or no geographical breakdown. The projections for this study are based upon a regional analysis prepared as part of IIASA's PRCGRO model. This is a variant of a regional general equilibrium model focusing on the supply and demand for agricultural products. Value-added in sectors other than agriculture, food processing, and related activities is treated as exogenous. The model incorporates eight regions with a slightly different classification from the standard six regions used for the PRC's statistical data. The main differences are the inclusion of (i) a central region comprising Jiangxi, Hubei, and Hunan; and (ii) a plateau region comprising Tibet Autonomous Region and Qinghai.

The gross domestic product (GDP) projections by province used for this study have been constructed as follows:

(i) Data on GDP—in aggregate and per person—at current prices for 2010 was converted to 2005 constant prices and adjusted to reflect population estimates by province from the 2010 census.

(ii) An initial set of projected growth rates for GDP at constant prices per person by region and for 5-year periods from 2010–2015 to 2025–2030 was derived from the PRCGRO model and then applied to all provinces in each region. These projections were combined with the relevant

[18] Toth, F. L., G-Y. Cao, and Hizsnyik. 2003. Regional Population Projections for [the PRC]. *Report I*R-03-42. Laxenburg, Austria: IIASA; Cao, G-Y. et al. 2006. Metropolitan trends and challenges in [the PRC]: the demographic dimension. *Report I*R-06-0*5*1. Laxenburg, Austria: IIASA.

[19] UN Population Division. 2010. *World Urbanization Prospects: The 2009 Revision.* New York; UN Population Division. 2011. *World Population Prospects: The 2010 Revision*. New York.

population projections to generate projections of total provincial GDP at constant prices for 2015 to 2030.

(iii) For 2030–2050, the initial growth rates in GDP per person by province from 2030 to 2050 were derived by extrapolating growth rates over 2010–2030 on the assumption that average growth in each 5-year period is 90% of growth in the previous 5-year period. This reflects the pattern of declining growth in GDP per person from 2010 to 2030 and is consistent with the historical experience of rapidly growing economies in East Asia.

(iv) The initial growth rates in provincial GDP at constant prices were scaled to match the projections for the PRC's GDP based upon results generated by the aggregate general equilibrium model used by the Development Research Centre of the State Council combined with the UN aggregate population projections.

Two further adjustments to the estimates of GDP per person at the provincial level are required. First, the infrastructure equations are estimated using GDP per person at purchasing power parity (PPP) expressed in constant 2005 international prices in US dollar terms. Conversion from yuan at constant 2005 prices to dollars at PPP raises a problem that cannot be easily resolved. The simplest procedure is to use the national PPP conversion rate from domestic prices to dollars for GDP in 2005, which was $1 = CNY3.45. However, the ratio of PPP conversion rates to market exchange rates are systematically correlated with GDP per person. In the case of the PRC, the projected rate of growth in GDP per person from 2010 to 2050 might be expected to change the ratio of the market exchange rate to the PPP conversion factor from 1.937 in 2010 to 1.579 in 2030 and 1.323 in 2050.

In practice, this means that, looking backwards from 2050, growth in GDP per person measured at constant local prices will tend to be higher than growth in GDP per person at PPP measured at constant international prices. This is a characteristic feature of past international data for countries that have experienced rapid growth in GDP per person. The reason lies in systematic changes in the relative prices of traded and nontraded goods and services which occur as countries develop. What happens is that expenditure on nontraded services (such as education, health, and business and personal services) tends to increases as countries get richer and their relative prices increase at the same time; this is often called the "Baumol effect." As a consequence, base-weighted indices of prices tend to understate the extent to which prices are increasing and this leads to an overstatement of volume growth when this is derived from nominal GDP.

The issue is whether a correction of this kind—i.e., looking back from 2050—should be applied when making projections looking forward. There is no correct answer, because it depends upon how the initial projections are made. If these are generated from a model that takes account of the sector differences in productivity growth that underpin the Baumol effect, it may be reasonable to adopt the single conversion factor approach. However, that appears not to be the case for the Development Research Centre of the State Council's model and so, on balance, it appears to be appropriate to allow for the change in the ratio between the market exchange rate and the PPP conversion factor associated with economic growth.

A better approach is to adjust GDP per person in local prices by a provincial cost of living index. Two notable attempts have been made to estimate spatial price indices for the PRC's provinces: by Brandt and Holz (2006)[20] using a consumption basket approach, and by Gong and Meng (2008)[21] using an Engel curve approach for urban PRC. The Brandt and Holz analysis covers years up to

[20] Brandt, L. and C. A. Holz. 2006. Spatial Price Differences in [the PRC]: Estimates and Implications. *Economic Development and Cultural Change* Vol. 55 (1): 43–86.

[21] Gong, C. H. and X. Meng. 2008. Regional Price Differences in Urban [PRC] 1986–2001: Estimates and Implication. *Working Paper*. Canberra: Research School of Social Sciences, Australian National University.

2004 and includes estimates for provincial price differences that encompass both rural and urban households. For this reason, GDP per person at constant 2005 prices has been adjusted for provincial price differences using the Brandt and Holz provincial price indices. This is the best that can be done with the data available, but it should be noted that the price indices are based on differences in the cost of household consumption. Ideally, the price indices used to adjust GDP per person should take account of differences in the costs of other components of final expenditure, in particular government consumption and investment.

In this report, the PRC is divided into six regions:

(i) **North:** Beijing, Tianjin, Hebei, and Shanxi;

(ii) **Northeast:** Liaoning, Jilin, and Heilongjiang;

(iii) **East:** Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, and Shandong;

(iv) **Southeast:** Henan, Hubei, Hunan, Guangdong, Guangxi Zhuang Autonomous Region, and Hainan;

(v) **Southwest:** Chongqing, Sichuan, Guizhou, Yunnan, and Tibet Autonomous Region; and

(vi) **West:** Shaanxi, Gansu, Qinghai, Ningxia Hui Autonomous Region, and Xinxiang.

Japan, Republic of Korea, and Mongolia

The demographic projections for Japan, the Republic of Korea, and Mongolia are based on the national projections from the UN's 2010 medium fertility scenario and the 2009 World Urbanization Prospects, supplemented with national information for Japan and the Republic of Korea.

Japan. Japan has 47 prefectures that are aggregated into eight regions—Hokkaido, Tohoku, Kanto, Chubu, Kansai, Chugoku, Shikoku, and Kyushu—conventionally used by the government for statistical purposes. The regions differ greatly in size and population with a population range in 2010 of 5.5 million for Hokkaido to 45.0 million for Kanto, which includes the metropolitan area of Tokyo. However, the smaller regions are distinct geographical units with specific climatic conditions varying from cool summers and cold winters in Hokkaido to the subtropical climate of Kyushu and Ryukyu Islands. For this reason, the analysis for Japan is based upon the eight regional units with data constructed by aggregating data for the prefectures in each region.

The National Institute of Population and Security Research has published population projections for total population and age structure by prefecture at 5-year intervals up to 2035.[22] These were adjusted pro rata to be consistent with the UN's projections up to 2035. The ratios between the values for each prefecture and the national averages were kept constant at their 2035 values in order to extend the projections by prefecture for the remaining periods to 2050. The data on urbanization rates by prefecture are only available up to 2010, so the urbanization rates by prefecture were projected by keeping the relative urbanization rates across prefectures constant but ensuring consistency with the projected growth in urbanization in the UN projections. One point to note is that the UN has adopted a different definition of urbanization from that standard in Japanese official data, yielding much lower values for reported urbanization. The projections have followed the Japanese definition while maintaining the growth rates in urbanization from the UN data, since it is not possible to generate estimates by prefecture on the UN basis.

[22] Nishioka, H. et al. 2011. Population Projections by Prefecture in Japan 2005-35. *Japanese Journal of Population.* Vol. 9 (1).

The national projections for GDP per person at 2005 PPP prices are based on the projections used in the World Bank's Economics of Adaptation to Climate Change (EACC) study[23] but using actual figures for Japan in 2010 (as published by the Organisation for Economic Co-operation and Development [OECD]) as the base values. The EACC growth rates were applied from 2010 onwards. Prefecture projections were generated by assuming that the ratios of prefecture values to the national averages for the base year(s) remain unchanged over time. The base ratios of GDP per person by prefecture to GDP per person for the whole country were calculated from GDP per person at factor cost for 2007 adjusted by the regional cost of living index (with all Japan = 100) for 2007.

Republic of Korea. The Republic of Korea has a population and land area that is similar to several provinces in the eastern half of the PRC. On the other hand, treating the country as a single geographical unit would mask potential differences in the impact of climate change between the northern and southern parts of the country as well as between areas that border the Yellow Sea. Hence, the 16 provinces and cities have been combined into three regions for the analysis. As for Japan, the regional estimates are constructed by aggregating separate statistics and projections for each province and city. The regions are defined as covering the following provinces and cities:

- **North:** Seoul, Incheon, Gangwon, and Gyeonggi;
- **Southeast:** Busan, Daegu, Ulsan, Gyeongsangbuk, and Gyeonsangnam; and
- **Southwest:** Daejeon, Gwangju, Chuncheongbuk, Chuncheongnam, Jeollabuk, Jeollanam, and Jeju.

In 2007, Statistics Korea published demographic projections by province based on the 2005 census, but the report is only available in Korean. The summary in English does not suggest that there will be major changes in the provincial composition of population and population structure. Hence, information on population and other variables by province in 2010 have been adjusted to match the UN projections, maintaining the relationship between the values for different provinces. As for Japan, there is a difference between the definitions used to calculate urbanization rates in the Korean and UN statistics, though in this case the reported urbanization rate is considerably lower in national statistics than in the UN statistics. The projections follow the national definition for the same reason as for Japan.

The national projections for GDP per person at 2005 PPP prices are based on the projections used in the EACC study but using actual figures for the Republic of Korea in 2010 (as published by the OECD) as the base values. The EACC growth rates were applied from 2010 onwards. Prefecture or provincial projections were generated by assuming that the ratios of prefecture and/or province values to the national averages for the base year(s) remain unchanged over time. The base ratios of GDP per person by province to GDP per person for the whole country were calculated from GDP per person for 2010 without any adjustment for regional price differences.

Mongolia. While the geographical extent of Mongolia is large, its population is small when compared with provinces in the PRC or the regional units used for Japan and the Republic of Korea. Large investments in mining projects and their impact on the rest of the economy have led to a concentration of the population, with about 60% living in Ulaanbaatar and neighboring *aimags* (provinces). As a consequence, population-weighted averages reflect conditions in the north–central section of the country. With limited data on incomes and the stock of infrastructure at the provincial level, it is neither feasible nor essential to examine the impacts of climate change at subnational level. Hence, the country is treated as a single geographical unit in this analysis.

[23] World Bank. 2009. *The Costs to Developing Countries of Adapting to Climate Change: New Methods and Estimates.* Washington, DC; World Bank. 2010. *Economics of Adaptation to Climate Change: Synthesis Report.* Washington, DC.

Mining investment has meant that growth in GDP has accelerated since 2009 and is expected to peak at an annual rate of more than 20% when the huge Oyu Tolgoi mine development opens in 2013–2014, with other large mining projects following in the second half of the decade. Mongolia is a small, landlocked, and resource-based economy which is extremely dependent upon markets in the PRC. Hence, any projections of the country's future economic growth must rely heavily upon assumptions about prospects for the mining sector and economic growth in neighboring countries.

For this study, the projections of economic growth for 2010–2015 are based on estimates prepared by the Asian Development Bank (*Asian Development Outlook*) and the International Monetary Fund (*Global Economic Prospects*). From 2015 onwards, it has been assumed that the rate of economic growth gradually converges to match that for the Inner Mongolia Autonomous Region of the PRC, which has a larger population with similar economic and physical characteristics. The rate of convergence has been set so that the projected values of real GDP per person at PPP in 2050 are almost equal in Mongolia and Inner Mongolia Autonomous Region.

The socioeconomic projections for Mongolia shown in the Tables A1–A5 are used throughout the report, with the exception of the analysis in Chapter 6. In that case only, the GDP projections are based on earlier pre-mining-boom estimates. While the revised GDP estimate and projections would alter the total abatement potential presented in Chapter 6 for Mongolia, it would not change the marginal abatement cost of the technologies presented, nor the qualitative results for the country.

Table A1 Projections of Total Population, 2010–2050 (million)

Country	Geographical Unit	Estimate 2010	Projections 2020	2030	2040	2050
PRC	Beijing	19.7	25.5	29.9	34.0	37.7
	Tianjin	13.0	15.7	17.5	19.0	20.0
	Hebei	72.2	74.2	74.1	71.8	67.5
	Shanxi	35.9	38.4	39.9	40.2	39.3
	Inner Mongolia Autonomous Region	24.8	25.5	25.5	24.7	23.3
	Liaoning	44.0	43.3	41.5	38.5	34.7
	Jilin	27.6	28.2	27.9	26.9	25.1
	Heilongjiang	38.5	36.9	34.4	31.0	27.2
	Shanghai	23.1	29.3	33.7	37.7	40.8
	Jiangsu	79.1	80.1	78.9	75.3	69.8
	Zhejiang	54.7	57.7	59.2	58.9	56.9
	Anhui	59.8	57.7	54.0	49.1	43.3
	Fujian	37.1	39.8	41.6	42.1	41.4
	Jiangxi	44.8	45.2	44.3	42.2	38.9
	Shandong	96.3	98.6	98.1	94.6	88.7
	Henan	94.5	94.3	91.5	86.0	78.6
	Hubei	57.5	58.8	58.4	56.3	52.7
	Hunan	66.0	64.1	60.4	55.2	49.0
	Guangdong	104.8	121.7	131.9	138.7	141.7
	Guangxi Zhuang Autonomous Region	46.3	45.3	43.1	39.7	35.5
	Hainan	8.7	9.6	10.3	10.8	10.9
	Chongqing	29.0	29.4	28.9	27.6	25.6
	Sichuan	80.8	77.3	71.9	64.8	56.7
	Guizhou	34.9	35.2	34.5	32.8	30.2
	Yunnan	46.2	49.5	51.6	52.1	51.1
	Tibet Autonomous Region	3.0	3.5	3.9	4.3	4.5
	Shaanxi	37.5	37.3	36.1	33.8	30.7
	Gansu	25.7	27.1	27.8	27.6	26.7
	Qinghai	5.7	6.0	6.3	6.3	6.2
	Ningxia Hui Autonomous Region	6.3	7.1	7.8	8.3	8.5
	Xinjiang Uyghur Autonomous Region	21.9	25.3	28.3	30.8	32.6
Japan	Hokkaido	5.5	5.2	4.7	4.3	4.1
	Tohoku	11.7	10.9	9.9	9.1	8.6
	Kanto	45.0	44.5	42.7	40.3	38.3
	Chubu	18.1	17.6	16.7	15.7	14.9
	Kansai	20.7	19.8	18.5	17.2	16.3
	Chugoku	7.5	7.1	6.5	6.1	5.8
	Shikoku	4.0	3.7	3.3	3.1	2.9
	Kyushu	14.5	13.9	13.0	12.2	11.5
Republic of Korea	North	24.9	25.9	26.1	25.6	24.4
	Southeast	12.6	13.1	13.2	12.9	12.3
	Southwest	10.5	10.9	11.0	10.8	10.3
Mongolia	Mongolia	2.8	3.2	3.5	3.8	4.1

Source: Asian Development Bank project team.

Table A2 Projections of Population Aged 0–14 Years, 2010–2050 (% of total population)

Country	Geographical Unit	Estimate 2010	Projections			
			2020	2030	2040	2050
PRC	Beijing	12.3	11.3	10.0	9.5	9.7
	Tianjin	15.1	13.9	12.4	11.9	12.2
	Hebei	19.0	16.1	13.9	12.9	12.8
	Shanxi	21.6	18.3	15.9	14.8	14.7
	Inner Mongolia Autonomous Region	19.4	17.5	15.1	14.1	13.9
	Liaoning	15.8	14.2	12.7	12.2	12.5
	Jilin	16.4	14.5	12.6	11.8	11.8
	Heilongjiang	16.9	15.2	13.1	12.2	12.0
	Shanghai	11.6	11.1	10.0	9.8	10.2
	Jiangsu	16.6	14.4	12.6	11.9	12.0
	Zhejiang	15.9	14.0	12.3	11.7	11.8
	Anhui	21.5	18.5	16.3	15.5	15.7
	Fujian	19.2	16.2	13.8	12.5	12.0
	Jiangxi	22.8	19.7	16.8	15.3	14.7
	Shandong	17.6	15.3	13.6	12.9	13.2
	Henan	20.9	17.3	15.1	14.1	14.0
	Hubei	19.1	16.4	14.1	13.0	12.7
	Hunan	18.9	16.3	14.1	13.1	13.0
	Guangdong	20.3	17.4	15.2	14.2	14.1
	Guangxi Zhuang Autonomous Region	22.3	18.9	16.0	14.4	13.6
	Hainan	23.1	19.5	16.4	14.7	13.8
	Chongqing	18.0	15.1	13.5	13.0	13.5
	Sichuan	20.4	18.0	15.6	14.4	14.2
	Guizhou	26.6	23.0	19.9	18.4	18.2
	Yunnan	23.7	20.9	18.1	16.8	16.6
	Tibet Autonomous Region	29.4	26.6	23.5	22.5	23.0
	Shaanxi	20.4	17.1	14.6	13.4	12.9
	Gansu	21.7	17.9	15.7	14.8	14.9
	Qinghai	24.2	21.2	18.3	16.9	16.5
	Ningxia Hui Autonomous Region	23.8	19.9	17.0	15.5	14.9
	Xinjiang Uyghur Autonomous Region	23.5	20.2	17.2	15.7	15.2
Japan	Hokkaido	11.7	9.6	8.5	8.4	8.8
	Tohoku	12.7	10.8	10.0	9.8	10.3
	Kanto	12.5	10.3	9.0	9.0	9.5
	Chubu	13.7	11.3	10.3	10.3	10.8
	Kansai	13.2	10.8	9.8	9.8	10.3
	Chugoku	13.1	11.0	10.0	10.0	10.5
	Shikoku	12.6	10.5	9.6	9.6	10.0
	Kyushu	13.7	11.8	10.8	10.7	11.2
Republic of Korea	North	16.3	14.2	14.0	13.3	13.1
	Southeast	15.6	13.6	13.4	12.8	12.6
	Southwest	16.9	14.7	14.5	13.8	13.6
Mongolia	Mongolia	27.6	28.8	24.8	22.1	22.4

Source: Asian Development Bank project team.

Table A3 Projections of Population Aged Over 65 Years, 2010–2050 (% of total population)

Country	Geographical Unit	Estimate 2010	Projections 2020	2030	2040	2050
PRC	Beijing	8.7	12.1	16.7	23.8	26.3
	Tianjin	9.4	14.1	20.0	29.0	32.4
	Hebei	8.3	12.6	17.9	25.8	28.8
	Shanxi	7.2	10.7	15.1	21.6	24.1
	Inner Mongolia Autonomous Region	7.2	11.9	18.0	26.7	30.4
	Liaoning	9.6	15.5	23.4	34.8	39.6
	Jilin	8.0	13.5	20.5	30.5	34.8
	Heilongjiang	8.2	14.9	23.6	35.9	41.4
	Shanghai	10.4	13.3	17.8	24.9	27.2
	Jiangsu	10.0	14.3	19.3	27.0	29.6
	Zhejiang	9.3	13.2	18.5	26.4	29.4
	Anhui	8.9	12.7	16.8	23.2	25.3
	Fujian	6.9	9.9	14.2	20.5	22.9
	Jiangxi	7.1	10.7	15.0	21.5	24.0
	Shandong	9.2	13.6	18.9	27.0	29.9
	Henan	8.2	12.1	16.7	23.8	26.4
	Hubei	7.9	12.1	17.2	24.8	27.7
	Hunan	9.0	13.6	18.8	26.8	29.7
	Guangdong	5.7	7.4	9.9	13.9	15.2
	Guangxi Zhuang Autonomous Region	8.1	11.6	15.8	22.1	24.3
	Hainan	6.5	8.9	12.1	17.2	18.9
	Chongqing	9.8	13.9	18.0	24.5	26.4
	Sichuan	9.6	14.1	18.6	25.8	28.0
	Guizhou	7.2	10.0	12.4	16.6	17.6
	Yunnan	6.5	9.0	11.7	16.1	17.4
	Tibet Autonomous Region	5.1	6.8	8.5	11.3	12.0
	Shaanxi	8.0	12.5	17.6	25.3	28.2
	Gansu	7.2	10.7	13.8	18.8	20.2
	Qinghai	6.0	8.9	11.6	16.0	17.3
	Ningxia Hui Autonomous Region	5.6	8.3	11.1	15.5	17.0
	Xinjiang Uyghur Autonomous Region	5.7	7.9	10.0	13.4	14.3
Japan	Hokkaido	24.6	32.2	35.6	40.0	42.1
	Tohoku	25.5	32.0	35.2	39.0	41.1
	Kanto	21.5	27.5	30.3	35.0	36.8
	Chubu	22.6	28.4	30.6	34.6	36.4
	Kansai	23.1	29.4	31.7	36.0	37.9
	Chugoku	25.7	31.9	33.9	37.4	39.4
	Shikoku	26.7	33.3	35.7	39.3	41.4
	Kyushu	23.8	30.0	32.7	36.2	38.1
Republic of Korea	North	9.6	13.5	20.1	25.5	28.3
	Southeast	12.3	17.4	25.8	32.7	36.3
	Southwest	14.3	20.2	29.9	38.0	42.1
Mongolia	Mongolia	4.1	4.7	7.8	11.1	14.1

Source: Asian Development Bank project team.

Table A4 Projections of Population Living in Urban Areas, 2010–2050 (% of total population)

Country	Geographical Unit	Estimate 2010	Projections			
			2020	2030	2040	2050
PRC	Beijing	88.9	94.3	97.9	99.9	99.9
	Tianjin	81.5	86.3	89.9	92.5	94.5
	Hebei	35.7	43.9	51.3	58.0	64.2
	Shanxi	43.9	51.5	58.4	64.5	70.1
	Inner Mongolia Autonomous Region	51.7	58.6	64.6	69.8	74.5
	Liaoning	63.5	69.0	73.7	77.5	80.7
	Jilin	58.9	65.2	70.5	74.9	78.9
	Heilongjiang	60.3	65.9	70.6	74.3	77.6
	Shanghai	99.9	99.9	99.9	99.9	99.9
	Jiangsu	52.5	60.2	66.9	72.7	78.0
	Zhejiang	58.6	65.8	71.9	77.1	81.8
	Anhui	35.8	43.7	50.9	57.3	63.3
	Fujian	51.2	58.4	64.9	70.4	75.5
	Jiangxi	36.1	43.8	50.9	57.3	63.2
	Shandong	48.6	56.5	63.3	69.2	74.6
	Henan	32.8	41.1	48.7	55.6	61.9
	Hubei	50.4	58.0	64.5	70.2	75.3
	Hunan	36.6	44.4	51.3	57.5	63.3
	Guangdong	65.4	72.0	77.2	81.4	85.1
	Guangxi Zhuang Autonomous Region	37.2	45.2	52.4	58.9	64.8
	Hainan	50.1	57.7	64.2	69.8	74.9
	Chongqing	41.3	48.5	55.3	61.4	67.0
	Sichuan	35.3	42.7	49.7	56.0	61.7
	Guizhou	31.8	39.6	47.4	54.4	60.9
	Yunnan	32.0	40.2	48.1	55.2	61.7
	Tibet Autonomous Region	27.1	34.8	42.4	49.2	55.6
	Shaanxi	40.9	48.3	55.1	61.2	66.7
	Gansu	32.2	39.9	47.3	54.0	60.2
	Qinghai	39.8	46.6	53.1	58.8	64.0
	Ningxia Hui Autonomous Region	40.4	47.7	54.5	60.6	66.1
	Xinjiang Uyghur Autonomous Region	42.0	49.2	55.9	61.8	67.2
Japan	Hokkaido	80.8	82.4	84.0	85.7	87.3
	Tohoku	83.6	84.2	84.7	85.3	85.9
	Kanto	94.1	94.6	95.0	95.4	95.7
	Chubu	90.6	90.7	90.8	90.8	90.8
	Kansai	94.3	94.7	95.1	95.4	95.7
	Chugoku	91.5	92.0	92.5	93.0	93.5
	Shikoku	83.9	84.6	85.3	86.0	86.7
	Kyushu	85.7	85.9	86.1	86.3	86.5
Republic of Korea	North	58.4	59.0	59.5	59.9	60.2
	Southeast	54.5	56.3	57.6	58.2	58.7
	Southwest	34.6	35.7	36.4	36.9	37.2
Mongolia	Mongolia	62.0	67.0	71.6	75.8	79.5

Source: Asian Development Bank project team.

Table A5 Projection of Gross Domestic Product per Person, 2010–2050 ($ at 2005 international prices)

Country	Geographical Unit	Estimate 2010	Projections 2020	2030	2040	2050
PRC	Beijing	11,423	19,915	31,661	46,606	64,561
	Tianjin	12,718	22,172	35,250	51,889	71,879
	Hebei	6,349	11,068	17,597	25,903	35,883
	Shanxi	4,772	8,319	13,226	19,469	26,970
	Inner Mongolia Autonomous Region	9,482	15,263	23,314	33,434	45,287
	Liaoning	8,138	13,229	20,640	30,177	41,559
	Jilin	6,329	10,288	16,052	23,468	32,319
	Heilongjiang	5,253	8,539	13,323	19,478	26,825
	Shanghai	13,041	23,917	39,848	61,247	88,051
	Jiangsu	9,907	18,169	30,271	46,527	66,889
	Zhejiang	9,956	18,259	30,422	46,759	67,223
	Anhui	4,028	7,387	12,307	18,916	27,195
	Fujian	7,616	12,590	19,254	27,505	37,133
	Jiangxi	4,163	7,195	11,415	16,861	23,424
	Shandong	8,529	14,869	23,640	34,799	48,205
	Henan	5,329	9,290	14,769	21,741	30,117
	Hubei	5,246	9,065	14,383	21,244	29,514
	Hunan	4,350	7,518	11,928	17,619	24,477
	Guangdong	7,609	12,578	19,236	27,480	37,098
	Guangxi Zhuang Autonomous Region	3,712	6,135	9,383	13,404	18,096
	Hainan	3,634	6,007	9,186	13,123	17,717
	Chongqing	6,189	9,994	15,447	22,392	30,612
	Sichuan	4,210	6,798	10,508	15,233	20,825
	Guizhou	2,229	3,599	5,563	8,064	11,024
	Yunnan	2,782	4,492	6,944	10,066	13,761
	Tibet Autonomous Region	3,116	4,973	7,327	10,167	13,386
	Shaanxi	4,645	7,476	11,420	16,377	22,183
	Gansu	2,915	4,693	7,168	10,279	13,923
	Qinghai	4,210	6,719	9,900	13,735	18,084
	Ningxia Hui Autonomous Region	5,048	8,126	12,412	17,799	24,109
	Xinjiang Uyghur Autonomous Region	4,480	7,211	11,015	15,796	21,396
Japan	Hokkaido	24,982	27,843	31,364	35,586	40,095
	Tohoku	26,632	29,694	33,467	37,982	42,795
	Kanto	33,857	37,842	42,752	48,584	54,740
	Chubu	33,625	37,533	42,338	48,070	54,161
	Kansai	29,349	32,728	36,888	41,866	47,171
	Chugoku	28,797	32,102	36,164	41,028	46,227
	Shikoku	26,372	29,403	33,133	37,599	42,364
	Kyushu	25,296	28,203	31,774	36,051	40,619
Republic of Korea	North	23,629	28,303	33,253	39,892	48,635
	Southeast	24,649	29,524	34,688	41,613	50,733
	Southwest	24,068	28,828	33,870	40,632	49,537
Mongolia	Mongolia	3,613	8,870	18,129	31,406	45,491

Source: Asian Development Bank project team.

Chapter 3

The Economics of Adaptation in the Coastal Sector

Key Messages

- **Without adaptation, and under the medium scenario for sea-level rise:**
  - the People's Republic of China (PRC) will lose an average of 27 square kilometers (km^2) of dryland per year during 2010–2050 because of submergence;
  - Japan will lose an average of 3.3 km^2 per year because of erosion;
  - Japan will lose about 28% of its coastal wetlands by 2050 while the losses in the PRC and the Republic of Korea will be 19%–22%;
  - 500,000 people will be forced to migrate in the PRC and 54,000 in Japan causing cumulative economic losses of $86 billion in the PRC and nearly $7 billion in Japan; and
  - the major part of these losses is caused by climate change, though this is exacerbated by coastal subsidence and erosion.
- **Coastal adaptation, including beach nourishment and the construction of sea dikes, can reduce the economic losses due to sea-level rise by 99%.** Even under the worst-case high sea-level rise scenario with cyclones, the residual damage after adaptation would be only $247 million per year from 2010 to 2050.
- **The cost of coastal adaptation costs, including port upgrades, is $4.1 billion per year under the medium scenario from 2010 to 2050.** The PRC accounts for $2.1 billion per year of this total and Japan for $1.2 billion per year.
- **Adaptation costs are dominated by the capital costs of building sea dikes, though the cost of maintaining sea dikes increases over time.**
- **The cost of upgrading ports in East Asia is about $400 million per year under the medium scenario with 77% required for ports in the PRC.**
- **Most of the costs of coastal adaptation in East Asia are associated with climate change.** Without climate change the cost of coastal adaptation as a result of subsidence would be about $1 billion per year.
- **The incremental cost of adapting to climate change in East Asia is $2.7 billion per year for 2010–2050 under the medium scenario with a range from $1.2 billion to $6.8 billion per year over all of the scenarios examined.**
- **Coastal adaptation to climate change is highly cost effective.** The ratio of the damage avoided by adaptation to climate change to the incremental cost of adaptation is 5.0 for the medium scenario and at least 4.6 over all scenarios.

Introduction

East Asia is very vulnerable to the impacts of sea-level rise in terms of both exposed population and assets. The PRC, Japan, and the Republic of Korea are estimated to account for 28% of the global population in the low-elevation coastal zone (LECZ) (Figure 1).[1] In Japan, for example, 24% of the population lives in the LECZ (Table 1). With large export-based economies, ports and other infrastructure assets in coastal areas are vital for current and future economic prosperity. Overall, the region contains 23 coastal cities with a population greater than 1 million people that are associated with ports—14 in the PRC, 6 in Japan, and 3 in the Republic of Korea.[2] In these 23 cities a total of 12 million people and $864 billion in assets are exposed to a 1-in-100-year flood.

Figure 1 East Asian Deltas

Source: Asian Development Bank project team.

1 LECZs are areas below 10 meters elevation. CIESIN. 2012. Low Elevation Coastal Zone Urban–Rural Estimates, Global Rural-Urban Mapping Project (GRUMP), Alpha Version. New York: Socioeconomic Data and Applications Center (SEDAC), Columbia University.

2 Nicholls, R. J. et al. 2008. Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates. *OECD Environment Working Papers No. 1.* Paris: OECD Publishing. http://dx.doi.org/10.1787/011766488208

Table 1 Population in the Low-Elevation Coastal Zone in East Asia

Country	Total		Low-Elevation Coastal Zone		
	Population (2000)	Total area (km^2) (ca. 1995)	Population (2000)	Number of urban areas greater than 1 million people	Area (km^2) (ca. 1995)
PRC	1,262,333,728	9,198,069	143,879,600	26	182,041
Japan	126,578,071	372,634	30,477,106	11	26,802
Republic of Korea	46,739,744	98,977	2,878,453	4	4,959

km^2 = square kilometer, PRC = People's Republic of China.

Source: Center for International Earth Science Information Network (CIESIN), Columbia University, 2012.

Climate change impacts on the coast

The impacts of increased atmospheric carbon dioxide (CO_2) concentration and resulting climate change on the coast include ocean acidification; increased sea surface temperature; sea-level rise; increased storm frequency and intensity in some locations; altered wave conditions, affecting erosion and accretion; and changes in runoff and nutrient and sediment supply to coastal areas, leading to altered water quality and salinity (Table 2). Sea-level rise has received most attention to date. In the 20th century, the global mean sea level rose an estimate 17–19 centimeters (cm),[3] primarily because of thermal expansion and the melting of small land-based glaciers. The potential magnitude of future sea-level rise up to 2100 is very uncertain, because of different views about the impact of climate change on the large ice sheets of Greenland and Antarctica. The range produced for the IPCC Fourth Assessment Report extends to 59 cm.[4] Some studies have emphasized a range of sea-level rise with the upper limit exceeding that of the Fourth Assessment Report.[5]

Local sea-level rise is a function of climate-change-induced changes in sea level, combined with vertical land movement due to geologic uplift and subsidence and human-induced processes such as subsidence due to fluid withdrawal and drainage of coastal soils susceptible to subsidence and oxidation. Hence, relative sea-level rise varies from place to place. It will be higher than the global mean in areas that are subsiding, which includes many populated deltas and coastal cities.[6] Subsidence can greatly exacerbate sea-level rise and could be as important as climate change in some Asian cities.[7]

3 Church, J. A. and N. J. White. 2011. Sea-Level Rise from the Late 19th to the Early 21st Century. *Surveys in Geophysics* 32, (4–5): 585–602. http://dx.doi.org/10.1007/s10712-011-9119-1; Evrejeva, S. et al. 2008. Recent Global Sea Level Acceleration Started Over 200 Years Ago? *Geophysical Research Letters* 35 (8). http://dx.doi.org/L08715 10.1029/2008gl033611; Bindoff, N. et al. 2007. Observations: Oceanic Climate Change and Sea Level. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by S. Solomon, D. Qin, and M. Manning. Cambridge, UK: Cambridge University Press. 385–431.

4 The figure is 76 centimeters if observed increases in ice sheet discharge are scaled up by temperature rise is included.

5 Nicholls, R. J. et al. 2011. Sea-Level Rise and Its Possible Impacts Given a 'Beyond 4 Degrees C World' in the Twenty-First Century. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences* 369 (1934): 161–81. http://dx.doi.org/10.1098/rsta.2010.0291; Grinsted, A., J. C. Moore, and S. Jevrejeva. 2010. Reconstructing Sea Level from Paleo and Projected Temperatures 200 to 2100 AD. *Climate Dynamics* 34 (4): 461–72. http://dx.doi.org/10.1007/s00382-008-0507-2; Vermeer, M. and S. Rahmstorf. 2009. Global Sea Level Linked to Global Temperature. *Proceedings of the National Academy of Sciences* 106 (51): 21,527–32. http://dx.doi.org/10.1073/pnas.0907765106; Rahmstorf, S. 2007. A Semi-empirical Approach to Projecting Future Sea-Level Rise. *Science* 315: 368–70.

6 Syvitski, J. P. M. et al. 2009. Sinking Deltas Due to Human Activities. *Nature Geoscience* 2 (10): 681–86. http://dx.doi.org/10.1038/ngeo629; Ericson, J. P. et al. 2006. Effective Sea-Level Rise and Deltas: Causes of Change and Human Dimension Implications. *Global and Planetary Change* 50: 63–82.

7 Hanson, S. et al. 2011. A Global Ranking of Port Cities With High Exposure to Climate Extremes. *Climatic Change* 104 (1): 89–111. http://dx.doi.org/10.1007/s10584-010-9977-4; Fuchs, R. J. 2010. Cities at Risk: Asia's Coastal Cities in an Age of Climate Change. *AsiaPacific Issues* No. 96. Honolulu: East-West Center. http://www.eastwestcenter.org/fileadmin/stored/pdfs/api096.pdf; Nicholls, R. J. et al. 2010. Economics of Coastal Zone Adaptation to Climate Change. *World Bank Discussion Papers* 10. Washington, DC: International Bank for Reconstruction and Development–World Bank.

Table 2 Main Physical and Ecosystem Effects of Increased Carbon Dioxide and Climate Change in Coastal Areas

Driver (trend)	Main Physical and Ecosystem Effects on Coastal Systems
CO_2 concentration (↑)	Increased CO_2 fertilization; decreased seawater pH (or ocean acidification) negatively impacting coral reefs and other pH-sensitive organisms
Sea surface temperature (↑, R)	Increased stratification and/or changed circulation, reduced incidence of sea ice at higher latitudes, increased coral bleaching and mortality, poleward species migration, increased algal blooms
Sea level (↑, R)	Inundation, flood, and storm damage; erosion; saltwater intrusion; rising water tables and impeded drainage; and wetland loss (and change)
Storm intensity (↑, R)	Increased extreme water levels and wave heights; increased episodic erosion, storm damage, inundation, and defense failure
Storm frequency (?, R) and track (?,R)	Altered surges and storm waves and risk of storm damage and flooding
Wave climate (?, R)	Altered wave conditions, including swell; altered patterns of erosion and accretion; and reorientation of beaches
Runoff (R)	Altered flood risk in coastal lowlands, altered water quality and/or salinity, altered fluvial sediment supply, and altered circulation and nutrient supply

CO_2 = carbon dioxide.

Note: Trend: ↑ = increase; ? = uncertain; R = regional variability.

Source: Nicholls, R. J. et al. 2007. Coastal Systems and Low-Lying Areas. In Climate Change 2007: Impacts, Adaptation and Vulnerability. Edited by M. L. Parry et al. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press, 315–56.

In contrast, uplift counters sea-level rise to some degree but has a much smaller effect over the long term within East Asia.

Coastal adaptation measures

There are three generic approaches to coastal adaptation:[8]

(i) **Planned retreat:** The impacts of sea-level rise are allowed to occur and human impacts are minimized by measures such as reducing human use of the coastal zone via land use planning, development control, and setback zones.

(ii) **Accommodation:** The impacts of sea-level rise are allowed to occur and human impacts are minimized by measures such as adapting human use of the coastal zone to the hazard via increasing flood resilience (e.g., raising homes on pilings or flood proofing) and risk-based hazard insurance.

[8] Linham, M. and R. J. Nicholls. 2010. Technologies for Climate Change Adaptation: Coastal Erosion and Flooding. *TNA Guidebook Series*. Roskilde, Denmark; United Nations Environment Programme Risø Centre on Energy, Climate and Sustainable Development. http://tech-action.org/Guidebooks/TNAhandbook_CoastalErosionFlooding.pdf; Klein, R. J. T. et al. 2001. Technological Options for Adaptation to Climate Change in Coastal Zones. *Journal of Coastal Research* 17 (3): 531–43; Bijlsma, L. et al. 1996. Coastal Zones and Small Islands. In Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Edited by R. T. Watson, M. C. Zinyowera, and R. H. Moss. The Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Working Group II. Cambridge, UK: Cambridge University Press 289–324; IPCC Coastal Zone Management Subgroup. 1990. Sea-Level Rise: A World-Wide Cost Estimate of Coastal Defence Measures. Appendix D in Report of the Coastal Zone Management Subgroup, Response Strategies Working Group of the IPCC. The Hague: Netherlands Ministry of Transport, Public Works and Water Management.

(iii) **Protection.** The impacts of sea-level rise are controlled by "soft" or "hard" engineering (e.g., nourished beaches and dunes or seawalls), reducing human impacts in the zone that would be impacted without protection.

These approaches can be combined into a portfolio of adaptation measures. Regardless of the measure, a residual risk always remains—there is always a small risk that a defense standard for a seawall can be exceeded, for example. Thus, managing risk should be a core consideration of coastal adaptation. Policy analyses typically include a choice of protection versus planned retreat, while accommodation has not yet been extensively considered.[9] Consideration of protection on the global scale has employed two distinct approaches:

(i) Protection of all developed areas, using a criterion such as population density exceeding 10 persons per square kilometer.[10]

(ii) A cost–benefit approach, where areas of protection are selected by comparing the avoided damages with the costs of protection.[11]

In both cases, the costs of the required protection and the residual impacts in areas that are not protected can be determined.

It should be noted that the feasibility of protection is a matter of dispute. Different views concerning this issue explain much of the difference between estimates of actual, as opposed to potential, impacts of sea-level rise.[12] One view is that protection is either infeasible or at best partial, so that a part or all of the potential impacts translate into actual impacts. In this case, the world could face tens of millions of environmental refugees due to sea-level rise alone.[13] An alternative view is that effective protection can ensure that the actual impacts will be much less than potential impacts.

This is not simply a matter of physical investment, since much of the damage due to sea-level rise is associated with storm surges, so that social institutions to maintain as well as build protective infrastructure, and implement effective disaster management are critical. *One important conclusion is the importance of economic growth and institutional development in supporting investment in adaptation*.[14] Coastal adaptation must be linked to the wider set of development goals.

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9 Accommodation is currently observed at lower population densities in areas that are not economic to protect, such as much of the United States, and Bangladesh where flood warnings and shelters have greatly reduced the death toll during the landfall of major tropical cyclones.

10 IPCC Coastal Zone Management Subgroup (footnote 8); Hoozemans, F. M. J., M. Marchand, and H. A. Pennekamp. 1993. Sea Level Rise. A Global Vulnerability Analysis. Vulnerability Assessments for Population, Coastal Wetlands and Rice Production on a Global Scale. Delft and the Hague: Delft Hydraulics and Rijkswaterstaat; Nicholls, R. J. 2004. Coastal Flooding and Wetland Loss in the 21st Century: Changes Under the SRES Climate and Socio-economic Scenarios. *Global Environmental Change-Human and Policy Dimensions* 14 (1): 69–86. http://dx.doi.org/10.1016/j.gloenvcha.2003.10.007

11 Fankhauser, S. 1995. Valuing Climate Change-the Economics of the Greenhouse. London: Earthscan Publications; Tol, R. S. J. 2007. The Double Trade-off Between Adaptation and Mitigation for Sea Level Rise: An Application of FUND. *Mitigation and Adaptation Strategies for Global Change* 12: 741–53; Sugiyama, M., R. J. Nicholls, and A. Vafeidis. 2008. Estimating the Economic Cost of Sea-Level Rise. *Report 156*. Boston: MIT Joint Program on the Science and Policy of Global Change. http://dspace.mit.edu/handle/1721.1/41522; Anthoff, D., R. J. Nicholls, and R. S. J. Tol. 2010. The Economic Impact of Substantial Sea-Level Rise. *Mitigation and Adaptation Strategies for Global Change* 15 (4): 321–35. http://dx.doi.org/10.1007/s11027-010-9220-7

12 Nicholls, R. J. and R. S. J. Tol. 2006. Impacts and Responses to Sea-Level Rise: A Global Analysis of the SRES Scenarios Over the Twenty-First Century. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences* 364 (1,841): 1,073–95. http://dx.doi.org/10.1098/rsta-2006.1754

13 Dasgupta, S. et al. 2009. The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis. *Climatic Change* 93 (3): 379–88. http://dx.doi.org/10.1007/s10584-008-9499-5; Myers, N. 2002. Environmental Refugees: A Growing Phenomenon of the 21st Century. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* 357 (1,420): 609–13. http://dx.doi.org/10.1098/rstb.2001.0953

14 Anthoff, D., R. J. Nicholls, and R. S. J. Tol. (see footnote 12).

Previous estimates of the costs of coastal adaptation

The global costs of protecting coasts were first estimated by Delft Hydraulics for the Intergovernmental Panel on Climate Change (IPCC),[15] and were later improved upon by a number of early assessments.[16] The United Nations Framework Convention on Climate Change (UNFCCC) conducted an assessment of the adaptation costs for sea-level rise up to 2030 and estimated that the costs would be $4 billion–$11 billion annually at the end of the period.[17] Parry considers these costs to be a minimum estimate, noting that (i) the range of sea-level scenarios considered was limited; (ii) the protection costs could increase if the impacts on coastal ecosystems were considered; and (iii) other aspects of climate change, such as more intense storms, were not considered.[18]

The World Bank's Economics of Adaptation to Climate Change (EACC) report[19] addressed many of the limitations of the UNFCCC study. It took account of costs up to 2050 and post-2007 literature on sea-level-rise scenarios, encompassing a rise of 40–126 centimeters by 2100. Projections up to 2100 are relevant because investments made in 2050 are designed to provide protection against the impacts of sea-level rise over a 50-year planning horizon. Moreover, the EACC study allowed for the possibility of more intense tropical storms and it included maintenance costs and port upgrades in the adaptation costs. Hence, the cost estimates in the report are significantly higher than the UNFCCC costs, and range from $26 billion to $89 billion per year in the 2040s, depending upon the sea-level-rise scenario being considered. Excluding high-income countries, the annual costs were $13 billion–$45 billion per year in the 2040s. The largest component of the costs relate to the construction, upgrade, and maintenance of sea dikes. Beach nourishment costs are also significant and would also increase with time.

Methodology

The Dynamic Interactive Vulnerability Assessment model

For this study, an integrated model of coastal systems—the Dynamic Interactive Vulnerability Assessment (DIVA version 3.4.0) model—has been used to assess the biophysical and socioeconomic impacts of sea-level rise and socioeconomic development in East Asia (Figure 2).[20] Supporting the DIVA model is a database (STRM DIVA database 19)[21] that divides the world into 12,148 linear segments of varying length (with an average of 70 kilometers); about 100 different physical, ecological, and socioeconomic attribute data are associated with each segment.[22]

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[15] IPCC Coastal Zone Management Subgroup (see footnote 8).

[16] Hoozemans, F. M. J., M. Marchand, and H. A. Pennekamp (see footnote 9); Fankhauser, S (see footnote 10). Sugiyama, M., R. J. Nicholls, and A. Vafeidis (see footnote 11).

[17] Nicholls, R. J. 2007. Adaptation Options for Coastal Areas and Infrastructure: An Analysis for 2030. Report to the United Nations Framework Convention on Climate Change. Bonn.

[18] Parry, M. L. et al. 2009. Assessing the Costs of Adaptation to Climate Change: A Review of the United Nations Framework Convention on Climate Change and Other Recent Estimates. London; International Institute for Environment and Development and Grantham Institute for Climate Change. 111.

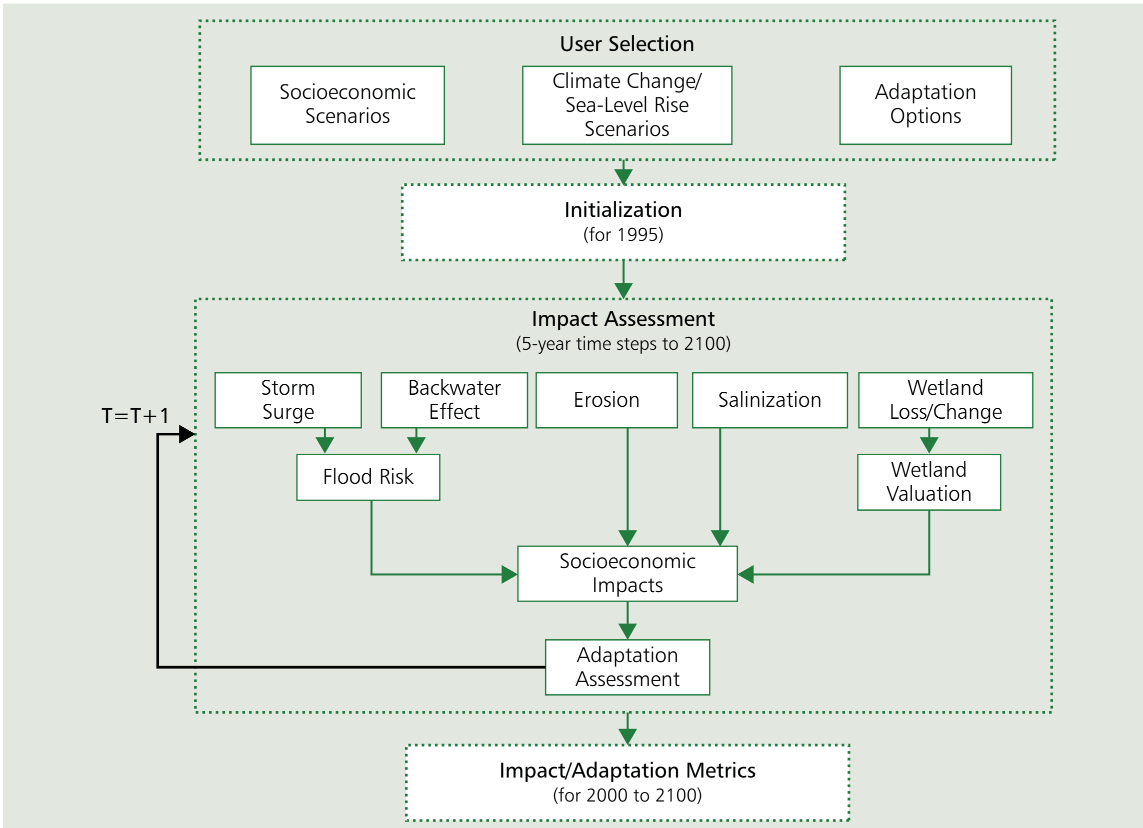
[19] World Bank (see Introduction, footnote 4); Hughes, G. A, P. Chinowsky, and K. Strzepek. 2010. The Costs of Adapting to Climate Change for Infrastructure. *Economics of Adaptation to Climate Change Discussion Paper* No 2. Washington, DC: World Bank; Hughes, G. A, P. Chinowsky, and K. Strzepek. 2010. The Costs of Adaptation to Climate Change for Water Infrastructure in OECD Countries. *Utilities Policy* Vol. 18: 142–53.

[20] Hinkel, J. and R. J. T. Klein, 2009. The DINAS-COAST Project: Developing a Tool for the Dynamic and Interactive Assessment of Coastal Vulnerability. *Global Environmental Change* 19 (3): 384–95; Vafeidis, A. T. et al. 2008. A New Global Coastal Database for Impact and Vulnerability Analysis to Sea-Level Rise. *Journal of Coastal Research* 24 (4): 917–24.

[21] Vafeidis, A. T. et al. (see footnote 19); McFadden, L. et al. 2007. A Methodology for Modeling Coastal Space for Global Assessment. *Journal of Coastal Research* 23 (4): 911–20. http://dx.doi.org/10.2112/04-0365.1

[22] The data includes population, elevation and bathymetry, geomorphic type, landform type, tidal range, wetland characteristics, administrative boundaries, world heritage sites, extreme sea levels, uplift or subsidence, land use, GDP per capita, tourist arrivals and departures, rivers, tidal basins, and wave climate.

Figure 2 Schematic of the DIVA Model Process



DIVA = Dynamic Interactive Vulnerability Assessment.
Source: Hinkel, J. and R. J. T. Klein. 2009. Integrating Knowledge to Assess Coastal Vulnerability to Sea-Level Rise: The Development of the DIVA Tool. *Global Environmental Change-Human and Policy Dimensions* 19 (3): 384–95. http://dx.doi.org/10.1016/j.gloenvcha.2009.03.002; Nicholls, R. J. 2007. Adaptation Options for Coastal Areas and Infrastructure: An Analysis for 2030. *Report to the UNFCCC*. Bonn.

DIVA is driven by scenarios (i.e., plausible futures) of climate and socioeconomic change. The climate scenarios describe temperature and consequent sea-level change, while the socioeconomic scenarios describe land use, coastal population change, and gross domestic product (GDP) growth. Self-consistent scenarios, which evolve over time to 2050, are utilized in this study. DIVA first downscales to relative sea-level rise by combining the sea-level-rise scenarios due to global warming with vertical land movement. Rates of vertical land movement are a combination of glacial-isostatic adjustment according to the geophysical model of Peltier[23] and, where appropriate, deltaic subsidence.

Three indicators of the impact of sea-level rise are considered: (i) coastal wetland loss (square kilometers [km^2] per year), (ii) dryland loss due to erosion or submergence (km^2/year), and (iii) forced migration due to erosion or submergence (thousands/year). DIVA explicitly includes two adaptation options whose costs can be examined: (i) beach nourishment in response to beach erosion, and (ii) dike upgrade and maintenance in response to coastal flooding. Actual impacts are a function not only of the selected climatic and socioeconomic scenarios but also of the selected adaptation strategy. There can be residual damage if the adaptation measures do not eliminate the risk of coastal impacts.

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[23] Peltier, W. R. 2000. Global Glacial Isostatic Adjustment and Modern Instrumental Records of Relative Sea Level History; and ICE4G (VM2) Glacial Isostatic Adjustment Corrections. Both in *Sea Level Rise: History and Consequences*. Edited by Douglas, B. C., M. S. Kearney, and S. P. Leatherman. San Diego: Academic Press.

For this study, the base year in the DIVA model is 1995, with potential impacts and costs calculated in 5-year intervals until 2100. All results are in constant 2005 dollars. The adaptation actions operate on different time scales: beach nourishment is based on the actual sea-level change, while dike upgrade and maintenance anticipates sea-level change up to 50 years in the future. This reflects current engineering practice. Beach nourishment is essentially a reactive approach to observed erosion with instantaneous benefits. Flood defenses offer longer-term benefits and are designed to provide an appropriate standard of service over a lifetime of 50 years or more.

Relative sea-level-rise scenarios

The sea-level-rise scenarios of the IPCC Fourth Assessment Report have been criticized as too conservative. Indeed, many papers have indicated the potential for larger rises than those included in the Fourth Assessment Report range.[24] To acknowledge this debate, this study considers four sea-level rise scenarios:

- **No climate change:** Changes in relative sea levels result only from vertical land movements only (a reference case).
- **Low sea-level rise scenario:** Based on the midpoint of the IPCC Fourth Assessment Report A2 emissions scenario range in 2090–2099.
- **Medium sea-level rise scenario:** Based on the work on the Rahmstorf A2 emissions scenario trajectory.[25]
- **High sea-level rise scenario:** Based on the "maximum" trajectory of Rahmstorf (footnote 25).

These sea-level rise scenarios imply global mean rise in sea level of 16–38 cm by 2050 and 40–126 cm by the end of the planning horizon in 2100 (Table 3). These scenarios allow for a significant acceleration in the rate of sea-level rise after 2050.

Table 3 Sea-Level Rise Scenarios Considered, 2010–2100
(rise, in centimeters above 1990 levels)

	Scenario			
Year	No climate change	Low	Medium	High
2010	0.0	4.0	6.6	7.1
2020	0.0	6.5	10.7	12.3
2030	0.0	9.2	15.5	18.9
2040	0.0	12.2	21.4	27.1
2050	0.0	15.6	28.5	37.8
2100	0.0	40.2	87.2	126.3

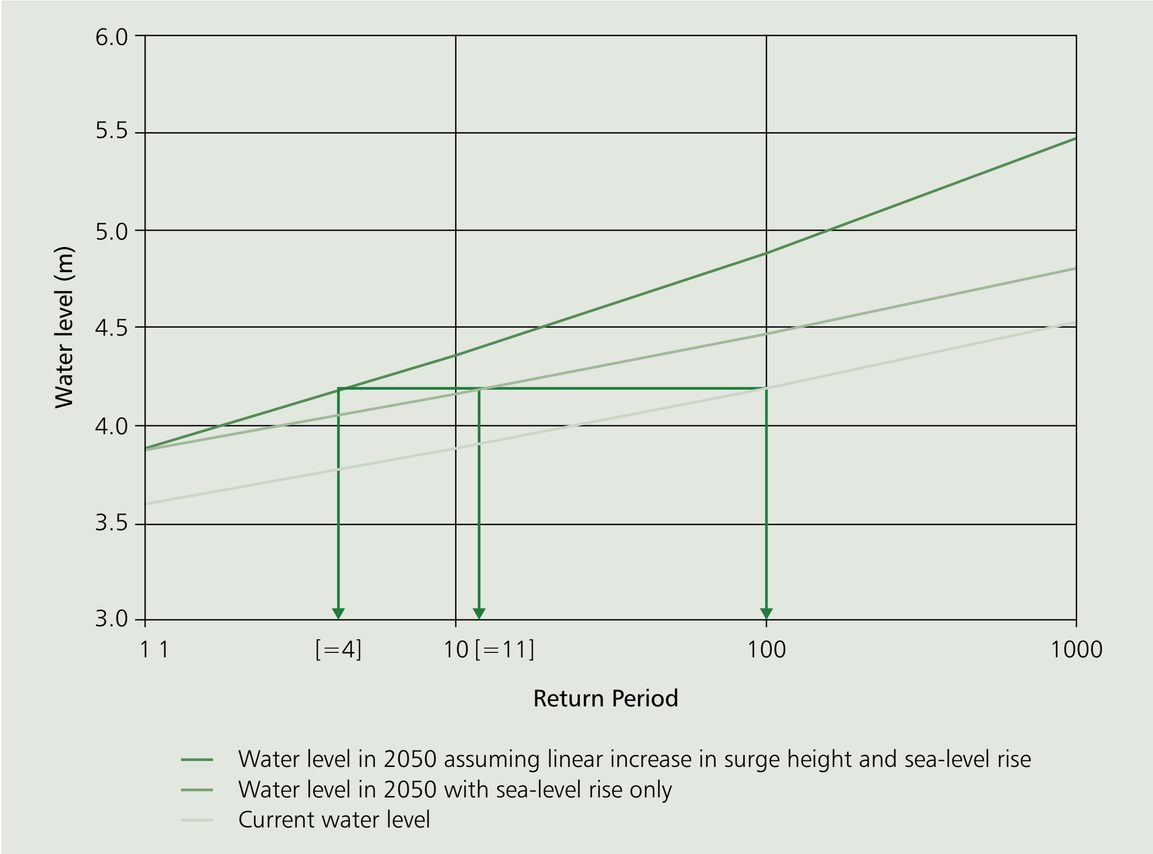
Source: Asian Development Bank project team.

[24] Nicholls, R. J. et al. (see footnote 5).
[25] Rahmstorf, S. 2007. A Semi-Empirical Approach to Projecting Future Sea-Level Rise. *Science* 315: 368–70.

Tropical cyclone intensity

The possibility that climate change will lead to an intensification of tropical cyclones is a major concern in those areas of the world that currently experience such storms.[26] However, there is no scientific consensus as to whether storms will or will not intensify in any region. To model the possible increase in "storminess," the maximum storm surge level is assumed to be a uniform increase above the mean sea-level rise, with the largest changes for the most extreme events. Therefore, return periods of extreme water levels of the 1-in-10 year, the 1-in-100 year, and the 1-in-1,000-year extreme water level event increase linearly by 5% (1-in-10 year), 10% (1-in-100 year), and 15% (1-in-1,000 year) by 2050 compared to 2000 (see Figure 3 for Shanghai). This method means that the lower the probability of the event, the greater the increase in extreme water level. In effect, this is a guided sensitivity analysis, which gives an indication of how much influence an increase in tropical storm intensity can have on dike costs and residual flood damage. It should be noted that the analysis in this chapter only takes account of higher water levels. The impacts of increased wind speeds are considered in Chapter 2.

Figure 3 Assumed Change in the Distribution of Extreme Water Levels in Shanghai, People's Republic China, Taking into Account an Increase in Mean Sea Level (High Scenario) with an Increase in Tropical Storm Intensity



Source: Asian Development Bank project team.

26 Nicholls, R. J. et al. 2007. Coastal Systems and Low-Lying Areas. In Climate Change 2007: Impacts, Adaptation and Vulnerability. Edited by M. L. Parry et al. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge, UK: Cambridge University Press, 315–56.

Population and gross domestic product scenarios

The economic impact of sea-level rise and storm surge on coastal areas is not only a function of the *hazard* (the physical increase in water levels) but also the *exposure* (the number of people and assets exposed to the event) and the *vulnerability* (the capacity to cope and recover from the hazard).[27] Indeed, the projections of GDP and population for East Asia are likely to be large drivers of the costs of adaptation.

The projections used for this study use the best available data in 2011; projections of growth rates and population composition are consistent with the growth rates, age composition, and urbanization rates in the United Nations Population Division's 2010 medium fertility scenario and the 2009 World Urbanization Prospects.[28] Population is projected to decline in all three countries considered (Table 4). Therefore, the total number of people exposed to sea-level rise declines over time, but there are exceptions, such as Guangdong province where population is projected to increase as a result of migration. On the other hand, GDP per capita grows substantially over the same period, especially in the PRC. By 2050, Shanghai's GDP per capita is the highest in the region, overtaking both the Republic of Korea and Japan. The GDP and population scenarios are described in detail in the appendix to Chapter 2.

Table 4 National Population and Gross Domestic Product for the People's Republic of China, Japan, and Republic of Korea, 2010 and 2050

	Population (million)		**GDP** ($ billion)	
Country	**2010**	**2050**	**2010**	**2050**
People's Republic of China	1,388.7	1,296.5	8,382.6	47,722.2
Japan	127.2	102.4	3,877.0	5,062.9
Republic of Korea	48.0	47.0	1,151.7	2,320.9

GDP = gross domestic product.

Source: Chapter 2, Appendix.

Scenario combinations

The scenario combinations that are considered are summarized in Table 5. The no-change scenario includes vertical land movement and socioeconomic change only. It is important to note that these scenarios are not an attempt to represent the most likely outcomes. Rather, they represent reasonable, plausible, and useful futures to explore in order to understand coastal adaptation planning and investment for East Asia under uncertainty.

[27] United Nations Economic and Social Commission for Asia and the Pacific and the United Nations International Strategy for Disaster Reduction. 2010. Protecting Development Gains: Reducing Disaster Vulnerability and Building Resilience in Asia and the Pacific. *The Asia-Pacific Disaster Report 2010*. Bangkok.

[28] United Nations Population Division of the Department of Economic and Social Affairs. 2010. *World Urbanization Prospects: The 2009 revision*. New York: United Nations Development Programme (UNDP). http://esa.un.org/unpd/wup/index.htm; United Nations Population Division of the Department of Economic and Social Affairs. 2011. *World Urbanization Prospects: The 2010 revision*. New York: UNDP. http://esa.un.org/wpp/Documentation/publications.htm

Table 5 Scenario Combinations Used in this Study

Scenario Name	Sea-Level Scenario	Vertical Land Movement	Increased Storminess of Cyclones	Population and GDP Growth
No change	No change	Yes	No	Yes
Low	Low	Yes	No	Yes
Medium	Medium	Yes	No	Yes
High	High	Yes	No	Yes
High (with cyclones)	High	Yes	Yes	Yes

GDP = gross domestic product:

Source: Asian Development Bank project team.

Impact calculations

The following impacts are considered in this study:[29]

- Coastal wetland loss (km^2/year).
- Dryland loss due to erosion or submergence (km^2/year).
- Forced migration due to erosion or submergence (thousands/year).

DIVA calculates coastal wetland loss by considering the effect of three interacting drivers: (i) sea-level rise (scaled by tidal range), (ii) sediment supply, and (iii) accommodation space (i.e., room for the wetland to migrate onshore).[30] For the wetlands in each segment, a series of scores are estimated for each driver as a function of the different scenarios. This includes the presence or absence of dikes which hinder the onshore migration of wetlands, where they exist, leading to "coastal squeeze." The scores for each wetland type are then calibrated against available results from the landscape modeling literature,[31] leading to an estimate of wetland loss.

Coastal erosion is only calculated for sandy coasts. The impacts of both direct and indirect effects are assessed.[32] The direct effect of sea-level rise on coastal erosion is estimated using the Bruun Rule, which relates shoreline retreat to local sea-level rise.[33] The Bruun Rule states that a typical concave-upward beach profile erodes sand from the beach face and deposits it offshore to maintain constant water depth. While the Bruun Rule ignores processes such as long-shore drift, it is considered appropriate here as the average retreat for a coastal segment.

The standard DIVA database on the length of sandy beaches has been augmented for Japan and the Republic of Korea.[34] Sea-level rise also affects coastal erosion indirectly as tidal basins become sediment sinks under rising sea levels, trapping sediments from the nearby open coast into tidal basins.[35] This

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29 For the full description of the methodology used in this study see Nicolls, R., S. Hanson and J. Hickel. 2013. *Cost of Adaptation to Rising Coastal Water Levels for the People's Republic of China, Japan, and the Republic of Korea* (TA 7465 report). Manila.

30 McFadden, L. et al. In preparation. Broad-Scale Coastal Wetland Change Under Sea-Level Rise and Related Stresses: The DIVA Wetland Change Model.

31 McFadden, L. et al. (see footnote 30).

32 Nicholls, R. J. et al. 2011. A Global Analysis of Coastal Erosion of Beaches Due to Sea-Level Rise: An Application of DIVA. Proceedings of Coastal Sediments 2011. Miami, Singapore: World Scientific.

33 Zhang, K. Q., B. C. Douglas, and S. P. Leatherman. 2004. Global Warming and Coastal Erosion. *Climatic Change* 64 (1–2): 41–58. http://dx.doi.org/10.1023/b:clim.0000024690.32682.48

34 For Japan: Uda, T. 2010. Japan's Beach Erosion: Reality and Future Measures. *Advanced Series on Ocean Engineering* Vol 31. Singapore: World Scientific. For Korea, the data improvements are based on expert judgment.

35 Stive, M. J. F. et al. 1998. Morphodynamics of a Tidal Lagoon and the Adjacent Coast. In *Physics of Estuaries and Coastal Seas*. Edited by Dronkers, J. and M. Scheffers. Rotterdam: Balkema, 397–407.

indirect erosion is also calculated where appropriate using a simplified version of the Aggregated Scale Morphological Interaction between a Tidal Inlet and the Adjacent Coast (ASMITA) model.[36] This analysis considers five tidal basins in Japan and three tidal basins in the PRC.[37]

Inundation of the coastal zone caused by mean sea-level rise and associated storm surges are assessed in DIVA. Because of the difficulties of reconciling projected changes in storm surge characteristics due to climate change[38] with 20th century observations,[39] extreme sea-level events produced by a combination of storm surges and astronomical tides are raised uniformly across all return periods by mean sea-level rise over the 20th century. In addition, as mentioned previously, because of the possibility of more intense tropical cyclones, the high sea-level rise scenario (with cyclones) assumes that water levels of rare events increase more than those of frequent events.

DIVA treats the construction and upgrade of dikes as the primary adaptation option for inundation and flooding, using 1995 as the base year. Since there are no empirical data on actual dike heights available at a global level, a demand for safety is computed, and the required safety level is assumed to be provided by dikes in the starting year.[40] The demand for safety is a function that relates per capita income and population density to dike heights. This function was derived econometrically based on observed protection levels in Europe. Hence, the scenarios examine the additional investment required to adapt to climate change on the assumption that the countries start from an "efficient" level of investment in dikes given their initial population density, income per capita, etc. In the terminology used by some analysts, this is equivalent to assuming that there is no adaptation deficit. It mirrors the basis used in examining adaptation for infrastructure in Chapter 2.

The methodology followed in assessing the need for additional investment in dikes under the various sea-level rise scenarios is as follows:

- Where there is very low population density (less than 1 person/km^2) there are no dikes.
- Above this population threshold, an increasing proportion of the demand for safety is provided:
  - 50% of the demand for safety (i.e. optimal protection level) is applied at a population density of 20 persons/km^2, and
  - 90% of the demand for safety is applied at a population density of 200 persons/km^2.

In essence, this approach is akin to providing isolated dikes around individual settlements at low population densities, while more continuous dikes exist at higher population densities. Based on the selected dikes, land elevations, and relative sea level (including more extreme sea levels if appropriate), a flood model is used to estimate the frequency of flooding over time.[41] It must be emphasized that flood damage still occurs where dikes are in place, as no dike is completely secure, and this is referred to as *residual (flood) damage*. Lastly, if sandy beaches and a flood plain both exist in the same coastal segment, then both erosion and flood impacts can occur. Thus, beach nourishment and dike construction and/or upgrade adaptation measures can both be applied in the same segment.

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36 Van Goor, M. A. et al. 2003. Impact of Sea-Level Rise on the Morphological Equilibrium State of Tidal Inlets. *Marine Geology* 202 (3–4): 211–27. http://dx.doi.org/10.1016/s0025-3227(03)00262-7; Stive, M. J. F. et al. (see footnote 35).

37 For a more detailed account of the erosion impact methods see Nicholls, R. J. et al. (footnote 32).

38 Von Storch, H. and K. Woth. 2008. Storm Surges: Perspectives and Options. *Sustainability Science* 3 (1): 33–43. http://dx.doi.org/10.1007/s11625-008-0044-2

39 Menendez, M. and P. L. Woodworth. 2010. Changes in Extreme High Water Levels Based on a Quasi-global Tide-Gauge Data Set. *Journal of Geophysical Research-Oceans* 115. http://dx.doi.org/C10011 10.1029/2009jc005997

40 Tol, R. S. J. 2006. The DIVA Model: Socio-economic Scenarios, Impacts and Adaptation and World Heritage (CD-ROM). Potsdam. DIVA 1.5.5 Potsdam Institute for Climate Impact Research. Tol, R. S. J. and G. W. Yohe. 2007. The Weakest Link Hypothesis for Adaptive Capacity: An Empirical Test. *Global Environmental Change-Human and Policy Dimensions* 17 (2): 218–27. http://dx.doi.org/10.1016/j.gloenvcha.2006.08.001

41 For more details on the flood model, see Tol, R. S. J. (footnote 40).

DIVA translates all these physical damages into social and economic impacts, based on the detailed spatially explicit data on GDP, population density, and land use. The "forced migration" indicator gives the number of people that have to migrate from the dry land that is permanently lost due to erosion and/or is submerged by sea-level rise. To determine people displaced by flooding, a flood frequency threshold is required. In this analysis, it is assumed that people abandon all land areas that are subject to flooding more often than once per year.

The economic consequences are expressed in terms of damage and adaptation costs. The cost of dryland loss is estimated based on the land-use scenarios, with the assumption that only agricultural land is lost. Agricultural land has the lowest value and it is assumed that if land used for other purposes (e.g., industry or housing) is lost then in turn those land uses would move and displace agricultural land. The value of agricultural land is a function of income density. If the available agricultural land is less than the estimated area of dryland loss, then the losses are being underestimated and should be considered minimum estimates. The cost of extreme flood events is calculated as the expected value of damage to assets (buildings and infrastructure) based on a damage function that is logistic (i.e., "s-shaped") with regard to flood depth. The costs of migration are calculated on the basis of an estimate of the loss of GDP per capita.[42]

Adaptation cost calculations

Without adaptation, existing dikes (as estimated by DIVA for 1995) are maintained, but not raised, so flood risk rises with mean sea-level rise. With adaptation, dikes are progressively raised, based on the demand function for safety described above. It is assumed that any increase in demand for safety is provided by a raised dike,[43] and the incremental costs of dike construction are calculated. Both sea-level rise and increasing wealth lead to investment in higher dikes, because it is assumed that higher GDP translates into a lower risk tolerance for flooding. All of the calculations assume that existing dikes can be raised incrementally.

The unit costs for dikes used in this study are $3 million per km per meter of raised height for the PRC, $2.7 million for Japan, and $8.4 million for the Republic of Korea.[44] These estimates are based on the best available information but they may be too low for urban areas where land values can be very high and the limited space is a major constraint on how defenses can be built. A recent review found that unit dike costs for some projects in Louisiana (United States), the Netherlands, and Viet Nam are significantly higher than earlier estimates.[45]

The estimates of damages and adaptation costs do not consider the backwater effect on rivers.[46] These may be significant, especially in the extensive PRC coastal lowlands.[47] Good data on the number and length of rivers were not available, so an in-depth analysis is not possible. Considering just three large rivers in the PRC in this study,[48] dike upgrade costs associated with the potential backwater effect were estimated to be $34 million per year in the no-climate-change scenario to $160 million per year for high sea-level rise (with cyclones) scenario during 2010–2050.

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42 For a more detailed account of the valuation of impacts see Tol, R. S. J. (see footnote 40).

43 In East Asia, raising dikes is the only option as all flood-prone coasts are assumed to be defended today due to their high population density.

44 Hoozemans, F. M. J., M. Marchand, and H. A. Pennekamp (see footnote 10).

45 Jonkman, S. N. et al. 2012. Costs of Adapting Coastal Defenses to Sea-Level Rise – New Estimates and Their Implications. In review.

46 The backwater effect refers to the effect of relative sea-level rise on water levels in the coastal reaches of rivers. The distance inland that this extends can be large in coastal lowlands.

47 Li, C. X. et al. 2004. The Coasts of [the PRC] and Issues of Sea Level Rise. *Journal of Coastal Research* SI 43: 36–49; Han, M., J. Hou, and L. Wu. 1995. Potential Impacts of Sea-Level Rise on [the PRC]'s Coastal Environment and Cities: A National Assessment. *Journal of Coastal Research* SI 14: 79–95.

48 The Pearl, Yangtze, and Yellow Rivers.

The demand function for safety has also been modified to include the design life of dike and flood defenses, reflecting that it is prudent for society to anticipate future sea-level rise such that the desired level of protection is realized over the lifetime of the defense.[49] A 50-year design life is assumed in the analysis, meaning that for each segment and in each 5-year time step, sea-level rise is anticipated 50 years ahead based on linearly extrapolating the rate of local sea-level rise into the future. That is, the observations available from 2045–2050, for example, drive the decision in 2050 to upgrade dikes to a level that would satisfy society's demand for safety in 2100. The analysis also includes the cost of dike maintenance and operation. These costs have been calculated to be approximately 1% per year of the capital costs for sea dikes.[50] As the stock of dikes grows over time, these maintenance and operation costs grow in importance. Only dikes built since 2010 have been included in the analysis.

The DIVA model includes the cost of both beach and shore nourishment. In beach nourishment, the sand is placed directly on the intertidal beach, while in shore nourishment the sand is placed below low tide in the active zone where the sand will progressively feed onshore because of wave action, following current Dutch practice.[51] Shore nourishment is less expensive than beach nourishment but the benefits are not felt immediately. The maximum costs of beach nourishment are $14.9 per cubic meter ($m^3$), while for shore nourishment they are $11.6/$m^3$. Nourishment follows a cost–benefit analysis that balances the costs and benefits of protection (in terms of avoided damage to land, residents, and tourism).[52] Beach nourishment is the preferred adaptation option, but only if the tourism revenue is sufficient to justify the additional costs. Otherwise, shore nourishment or no nourishment is followed. Tourism revenues are derived from the Hamburg Tourism Model (HTM Version 1), an econometric model of tourism flows which includes the effects of changes in population, GDP, and climate.[53] All costs presented are in 2005 dollars, with no discounting.

Port upgrade costs. To maintain the future role of ports in the global supply chain, port infrastructure needs to be adapted to changes in sea levels. In this study, adaptation is assumed to take the form of raising existing port ground level in response to sea-level rise projected to 2050 in order to maintain relative elevation to mean sea level. This maintains the port operational areas at an appropriate elevation relative to the local tidal regime. The estimated costs do not consider port expansion, nor include explicit cost–benefit considerations—it is assumed that these strategic and valuable areas will need to be maintained to 2050 (and beyond). As with dikes and storm surges, the analysis in this chapter covers adaptation to the impact of higher water levels on ports, while the analysis in Chapter 2 covers adaptation to other impacts of climate change on ports, including buildings and onshore infrastructure.

The ports included are those from Lloyds List's Ports of the World,[54] where tidal data exist. A methodology based on statistics of the tonnage moved is used to estimate the area of the port that would require raising. The unit cost estimates (in US dollars) are based on those used in an IPCC Coastal Zone Management Subgroup report[55] and are resolved at the country level and updated to 2005. These costs represent a one-off raising of the port and are annualized over the 40-year duration of the assessment. The costs of damage to port areas without upgrade are not evaluated.

49 Nicholls, R. J. et al. (see footnote 5).
50 See Appendix 2 of Nicolls, R., S. Hanson and J. Hickel. 2013. *Cost of Adaptation to Risky Coastal Water Levels for the People's Republic of China, Japan, and the Republic of Korea*. Manila.
51 Van Koningsveld, M. et al. 2008. Living with Sea-Level Rise and Climate Change: A Case Study of the Netherlands. *Journal of Coastal Research* 24 (2): 367. http://dx.doi.org/10.2112/07a-0010.1
52 Nicholls, R. J. et al (see footnote 32).
53 Hamilton, J., D. J. Maddison, and R. S. J. Tol. 2005. Climate Change and International Tourism: A Simulation Study. *Global Environmental Change* 15 (3): 253–66; Hamilton, J., D. J. Maddison, and R. S. J. Tol. 2005. The Effects of Climate Change on International Tourism. *Climate Research* 29, 255–68. For a more detailed account of the adaptation methods for erosion, see Nicholls, R. J. et al (see footnote 32).
54 Lloyds List. 2009. *Ports of the World 2009.* London: Informa Maritime and Professional.
55 IPCC Coastal Zone Management Subgroup (see footnote 8).

Results

The People's Republic of China is projected to have the largest dryland losses without adaptation measures, and Japan is projected to have the largest dryland losses with adaptation measures

The PRC, Japan, and the Republic of Korea all experience dryland loss because of a combination of submergence and erosion, and wetland loss under all scenarios, with and without adaptation (Tables 6–7). In absolute terms, dryland loss is greatest in the PRC and smallest in the Republic of Korea, assuming no adaptation. This reflects the fact that the Republic of Korea lacks sandy beaches and submergence is not expected to be significant as low-lying areas are limited. With adaptation, Japan has the largest land losses, as nourishment is not economic in many eroding areas. Within the PRC, the highest rates of land loss due to erosion are found in Guangxi Zhuang Autonomous Region under all scenarios. Adaptation (representing beach and/or shore nourishment) reduces the average annual rate of erosion, and the largest effect can be found in Guangdong province and Guangxi Zhuang Autonomous Region.

The People's Republic of China and Japan are projected to have the greatest absolute and relative wetland losses

For wetlands, no adaptation is considered and losses are essentially independent of adaptation choices. All three countries show a decline in wetland area under all the scenarios, with the PRC having the highest rates of loss over the 40-year period under all scenarios, largely reflecting the fact that it has the largest stock of wetlands, which are often located in large subsiding deltas. In relative terms, the largest losses are in Japan, except for the no-change scenario (Table 8). For example, under the high

Table 6 Average Annual Rates of Dryland Loss Due to Submergence and Erosion for the Medium Sea-Level Rise Scenario, 2010–2050 (km^2/year)

Country	Land Loss with Adaptation		Land Loss without Adaptation	
	Submergence	Erosion	Submergence	Erosion
PRC	0.01	0.92	26.84	2.23
Japan	0.08	2.79	0.08	3.32
Republic of Korea	0.00	0.15	0.00	0.15
PRC Province/municipality/autonomous region				
Fujian	0.00	0.00	0.00	0.00
Guangdong	0.00	0.22	1.84	0.67
Guangxi Zhuang Autonomous Region	0.00	0.36	0.00	0.86
Hainan	0.00	0.00	0.00	0.00
Hebei	0.00	0.15	0.00	0.21
Jiangsu	0.00	0.01	0.00	0.04
Liaoning	0.00	0.03	24.99	0.04
Shandong	0.00	0.13	0.00	0.22
Shanghai	0.01	0.01	0.01	0.09
Tianjin	0.00	0.00	0.00	0.06
Zhejiang	0.00	0.01	0.00	0.04

km^2 = square kilometer, PRC = People's Republic of China.

Source: Asian Development Bank project team.

Table 7 Average Annual Rates of Dryland and Wetland Loss for the People's Republic of China Under All Sea-Level Rise Scenarios, 2010–2050 (km^2/year)

	With Adaptation			Without Adaptation		
	Dryland			Dryland		
Scenario	Erosion	Submergence	Wetland	Erosion	Submergence	Wetland
High (with cyclones)	1.13	0.01	36.32	2.54	63.10	36.32
High	1.13	0.01	36.32	2.54	63.10	36.32
Medium	0.92	0.01	30.79	2.23	26.84	30.79
Low	0.74	0.00	25.91	1.82	0.00	25.91
No change	0.53	0.00	5.48	1.33	0.00	5.48

km^2 = square kilometer.

Source: Asian Development Bank project team.

Table 8 Coastal Wetland Area Over Time for All Scenarios, 2010–2050 (km^2)

Scenario	Country	2010	2020	2030	2040	2050
High (with cyclones)	PRC	5,806	5,521	5,192	4,797	4,309
	Japan	1,640	1,532	1,376	1,228	1,073
	Republic of Korea	827	786	741	695	648
High	PRC	5,806	5,521	5,192	4,797	4,309
	Japan	1,640	1,532	1,376	1,228	1,073
	Republic of Korea	827	786	741	695	648
Medium	PRC	5,807	5,522	5,222	4,898	4,556
	Japan	1,641	1,540	1,432	1,309	1,176
	Republic of Korea	827	811	766	718	669
Low	PRC	5,915	5,668	5,404	5,130	4,843
	Japan	1,675	1,572	1,470	1,373	1,283
	Republic of Korea	827	812	793	773	750
No change	PRC	6,127	6,082	6,029	5,968	5,900
	Japan	1,789	1,788	1,787	1,786	1,785
	Republic of Korea	847	847	847	847	847

km^2 = square kilometer, PRC = People's Republic of China.

Source: Asian Development Bank project team.

sea-level rise scenario with cyclones, the PRC is projected to lose 26% of its wetlands from 2010 to 2050, Japan 35%, and the Republic of Korea 22%; under the medium sea-level rise scenario, the losses are 22% for the PRC, 28% for Japan, and 19% for the Republic of Korea.

Within the PRC, Shandong, Jiangsu, and Guangdong provinces have the highest average annual rates of wetland decline across the scenarios, including the no-change scenario, as these provinces are subject to subsidence. While the cost of losing wetlands is not estimated in this study, these losses matter because of the loss of ecosystem services. Wetlands can play an important role in coastal zone management as they can buffer flood waters and waves and reduce the need for engineered management. There are also reasons for coastal wetland loss other than sea-level rise, and land reclamation has been significant in all three countries. This might be expected to continue in the next few decades but there is a growing realization in all three countries of the importance of wetland conservation that may influence coastal management approaches over the next 40 years.[56]

Without adaptation, sea-level rise could result in the forced migration of 1 million people from 2010–2050 in the People's Republic of China, with associated costs of $150 billion

Assuming no adaptation, the highest number of people forced to move is in the PRC, where it is estimated that up to 1 million people could be displaced by 2050 for the high sea-level rise scenario, largely because of submergence (Table 9). The cumulative cost of this forced migration could be about $150 billion. Under the medium sea-level rise scenario, the impacts are still significant: 500,000 people displaced and associated costs of around $86 billion. Erosion is a smaller contributor to forced migration than submergence: up to 80,000 people displaced in the PRC, 62,000 in Japan, and 4,000 in the Republic of Korea by 2050 for the high sea-level rise scenario and assuming no adaptation.

Adaptation—building dikes to prevent submergence and using beach nourishment to limit erosion—reduces these impacts. The initial levels of protection in Japan and the Republic of Korea mean that submergence is not a major issue in these countries, but adaptation reduces the level of migration due to erosion by 40%–45% and the costs by almost 50%. For the PRC, adaptation means that forced

Table 9 Cumulative Forced Migration and Associated Costs, 2010–2050

		With Adaptation				Without Adaptation			
		Number of People ('000)		Cost ($ million)		Number of People ('000)		Cost ($ million)	
Scenario	Country	E	S	E	S	E	S	E	S
High (with cyclones)	PRC	26	0	2,137	0	80	974	14,207	138,554
	Japan	36	0	4,071	0	62	2	7,625	219
	Republic of Korea	3	0	286	0	4	0	496	58
High	PRC	26	0	2,137	0	80	974	14,207	138,554
	Japan	36	0	4,071	0	62	2	7,625	219
	Republic of Korea	3	0	286	0	4	0	496	58
Medium	PRC	21	0	1,503	0	69	424	10,936	75,157
	Japan	30	0	3,438	0	54	0	6,651	0
	Republic of Korea	2	0	195	0	3	0	347	0
Low	PRC	17	0	881	0	55	0	7,185	0
	Japan	23	0	2,644	0	43	0	5,369	0
	Republic of Korea	1	0	85	0	2	0	166	0
No change	PRC	14	0	536	0	40	0	3,583	0
	Japan	16	0	1,930	0	32	0	4,066	0
	Republic of Korea	0	0	0	0	0	0	0	0

E = due to erosion, PRC = People's Republic of China, S = due to submergence.

Note: In 2005 dollars.

Source: Asian Development Bank project team.

[56] Nicholls, R. J. et al. 2011. Scenarios for Coastal Vulnerability Assessment. In *Treatise on Estuarine and Coastal Science.* Edited by Wolanski, E. and D. S. McLusky. Waltham: Academic Press, 289–03; Nicholls, R. J. et al. 2008. Climate Change and Coastal Vulnerability Assessment: Scenarios for Integrated Assessment. *Sustainability Science* 3 (1): 89–102. http://dx.doi.org/10.1007/s11625-008-0050-4

migration because of submergence can be avoided entirely, while migration because of erosion declines by 66%. Note that tropical cyclones have no effect on forced migration, as inundation associated with these storms is temporary and populations are able to return to impacted areas.

Without adaptation, economic damage in the coastal zone in East Asia could be $55 billion per year during 2010–2050

Under the high sea-level rise scenario with cyclones, the total economic damage from land loss (erosion), forced migration, and flooding is projected to be $55 billion per year without adaptation during 2010–2050 in East Asia—96% of which is in the PRC (Table 10). Even under the medium sea-level rise scenario, the projected costs are $37 billion per year for the region. Flooding is responsible for over 90% of the damage in East Asia generally and in the PRC in particular. The inclusion of tropical cyclones greatly increases the estimates of flood damage, particularly in the PRC. Under the high sea-level rise scenario, tropical cyclone impacts are responsible for 30% of the flood damage. Considering provinces in the PRC, Guangdong, Tianjin, and especially Shanghai and Jiangsu are most affected under the medium sea-level rise scenario with no adaptation.

Projected economic damage in East Asia is reduced 99% when adaptation measures are included

Economic damages are reduced dramatically by adaptation. The residual damage under the high sea-level rise scenario with cyclones is projected to be $247 million per year during 2010–2050 in the region; under the medium sea-level rise scenario the figure is $148 million (Table 10). Flood damage is especially reduced; in Japan, the Republic of Korea, and many provinces in the PRC, it declines to zero (Figure 4).

Table 10 Average Annual National Damage Costs with and without Adaptation, 2010–2050 ($ million per year)

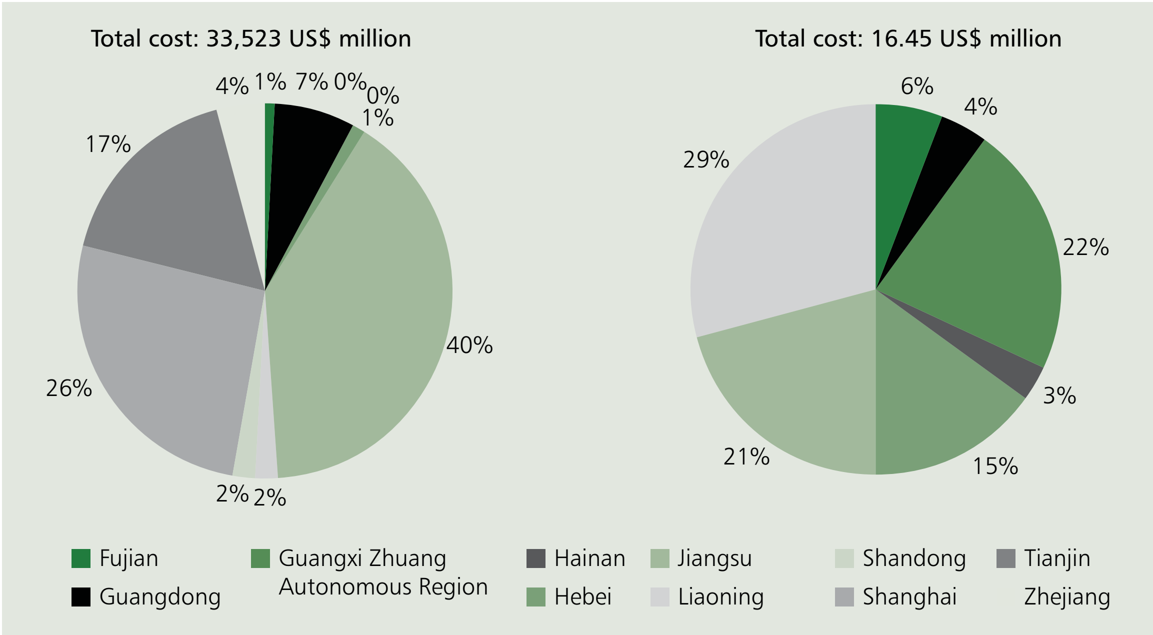
		With Adaptation			Without Adaptation		
Scenario	Country	Land Loss	Forced Migration	Flood damage	Land Loss	Forced Migration	Flood damage
High (with cyclones)	PRC	1	53	83	4	3,819	48,944
	Japan	2	102	0	3	196	922
	Republic of Korea	0	7	26	0	14	1,091
High	PRC	1	53	14	4	3,819	37,769
	Japan	2	102	0	3	196	601
	Republic of Korea	0	7	0	0	14	681
Medium	PRC	1	38	16	3	2,152	33,523
	Japan	2	86	0	2	166	489
	Republic of Korea	0	5	0	0	9	610
Low	PRC	0	22	109	2	180	29,151
	Japan	1	66	0	2	134	310
	Republic of Korea	0	2	4	0	4	495
No change	PRC	0	13	480	1	90	23,245
	Japan	1	48	12	1	102	31
	Republic of Korea	0	0	141	0	0	440

PRC = People's Republic of China.

Note: In 2005 dollars. Land loss costs apply to erosion only.

Source: Asian Development Bank project team.

Figure 4 Distribution of Average Annual Sea-Flood Costs for the Coastal Areas of the People's Republic of China under the Medium Sea-Level Rise Scenario, 2010–2050



(a) = without adaptation, (b) = with adaptation.

Note: Some provinces/municipalities/autonomous regions are expected to have minimal sea-flood costs with the levels of protection projected and therefore do not appear in (b).

Source: Asian Development Bank project team.

Total adaptation costs in East Asia excluding port upgrades range from $2.2 billion to $7.3 billion per year during 2010–2050

Total adaptation costs for the region are a fraction of the damage costs without adaptation, ranging from $2.2 billion per year for the low sea-level rise scenario to $7.8 billion per year for the high sea-level rise scenario with cyclones (Table 11). The PRC accounts for 43%– 57% of the total regional costs. For the coastal areas of the PRC, adaptation costs under the medium scenario are highest for Guangdong (Table 12). Seven out of 11 provinces incur adaptation costs of more than $100 million per year (Figure 5), while Tianjin has the lowest adaptation costs. In both tables, the costs cover relative sea-level rise due to subsidence as well as climate change.

Under all scenarios with climate change, the adaptation costs are dominated by the capital cost for sea dikes. Over time, the balance of expenditure shifts from capital costs to maintenance cost increases over time as the stock of new and upgraded sea dikes increases. The large initial cost of building dikes reflects the 50-year planning horizon for dike upgrades used in this study. The costs of beach nourishment are minor in comparison—less than 10% of the total costs regionally and negligible in the Republic of Korea.

The estimated cost of coastal protection without climate change reflects both greater wealth and relative sea-level rise due to subsidence. For dikes, this is due to the demand-for-safety function which drives investment in increased protection without any rise in sea level. This is consistent with observed changing attitudes to risk during the 20th century in countries where living standards rose substantially.

Table 11 Average Total National Annual Adaptation Costs, 2010–2050 ($ million per year)

Scenario	Country	Beach Nourishment	Sea Dikes Capital	Sea Dikes Maintenance	Port Upgrade	Total Adaptation Costs
High (with cyclones)	PRC	155	2,116	741	379	**3,391**
	Japan	62	1,618	555	162	**2,396**
	Republic of Korea	1	1,505	516	35	**2,056**
High	PRC	155	1,347	507	379	**2,388**
	Japan	62	1,137	392	162	**1,753**
	Republic of Korea	1	792	281	35	**1,109**
Medium	PRC	146	964	418	313	**1,840**
	Japan	56	710	293	72	**1,131**
	Republic of Korea	1	517	218	20	**755**
Low	PRC	122	631	296	237	**1,285**
	Japan	49	338	156	2	**545**
	Republic of Korea	0	277	130	1	**408**
No change	PRC	95	364	168	164	**791**
	Japan	40	45	16	0	**101**
	Republic of Korea	0	83	36	0	**119**

PRC = People's Republic of China.
Source: Asian Development Bank project team.

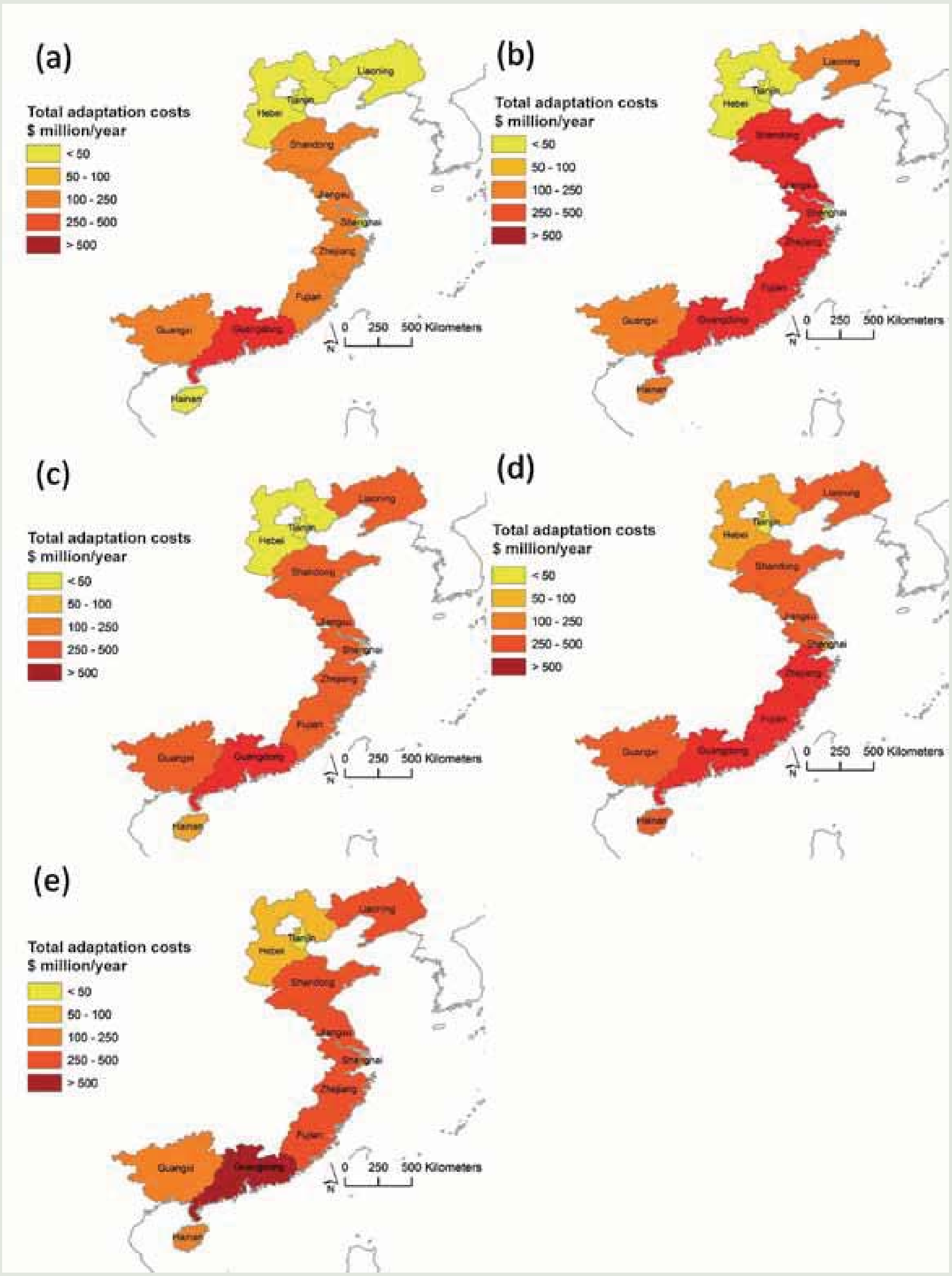
Table 12 Average Annual Adaptation Costs under the Medium Sea-Level Rise Scenario in Areas of the People's Republic of China, 2010–2050 ($ million per year, 2005 dollars)

Province, Municipality, or Autonomous Region	Beach Nourishment Costs	Sea Dike Costs Capital	Sea Dike Costs Maintenance	Total Adaptation Costs
Fujian	0	129	54	183
Guangdong	52	203	90	345
Guangxi Zhuang Autonomous Region	63	37	15	115
Hainan	0	68	27	96
Hebei	4	28	13	45
Jiangsu	3	121	55	179
Liaoning	1	96	41	138
Shandong	6	116	51	173
Shanghai	9	29	14	51
Tianjin	3	9	4	16
Zhejiang	4	128	55	186

Source: Asian Development Bank project team.

Significant costs of adaptation without climate change are observed in the PRC, especially in provinces containing deltas such as Guangdong (Pearl River delta), Jiangsu/Zhejiang (Yangtze River delta), and Shandong (Yellow River delta).

Figure 5 Average Annual Total Adaptation Costs for Coastal Areas of the People's Republic of China, 2010–2050



Notes: Scenarios: (a) = no change, (b) = low, (c) = medium, (d) = high, and (e) = high with cyclones. Total adaptation includes beach nourishment, sea dike upgrade, and incremental sea dike maintenance costs after 2010. (Port upgrade costs are not included.) In 2005 dollars.

Source: Asian Development Bank project team.

Table 13 Increase in Annual Adaptation Costs due to Tropical Cyclones ($ million per year)

	Combined Adaptation Costs[a]		
Scenario	PRC	Japan	Republic of Korea
High with cyclones	3,012	2,235	2,021
High	2,009	1,591	1,074
Increase due to cyclones (%)	50	40	88

PRC = People's Republic of China.

[a] Beach nourishment, dike building, and maintenance.

Source: Asian Development Bank project team.

When comparing the adaptation costs across scenarios, it is interesting to examine the effect of including cyclones in the scenarios (Table 13). Cyclones raise extreme water levels compared to the high sea-level rise scenario and, hence, trigger the raising of dikes to maintain safety. The resulting cost increase for adaptation in the three countries is significant. Compared to the high sea-level rise scenario, dike capital costs increase by 88% in the Republic of Korea, 40% in Japan, and 50% in the PRC. The PRC sees the largest absolute increase in dike capital costs. Dike maintenance costs increase by a similar degree, and hence the overall effect on adaptation costs is large.

The projected port upgrade costs are significant in the People's Republic of China

Estimates of the annual cost of port upgrades in the PRC averaged over 2010–2050 range from $219 million (low sea-level rise scenario) to $342 million (high sea-level rise scenario) (Table 14). The costs of upgrading the Republic of Korea's ports are small, reflecting the relatively small port area and lower unit costs. These port upgrade costs represent up to about 3% of the total coastal adaptation costs in the Republic of Korea, 9% in Japan, and 21% in the PRC (Tables 14–15). They are more important in relative terms than the earlier EACC results where they were less than 2% of national investment costs,[57] probably reflecting the importance of trade to these export-oriented countries. The costs reported here represent a substantial ongoing investment by the government and/or private companies responsible for maintaining future port activity levels.

In the PRC, Shanghai, Tianjin, and Jiangsu are the most sensitive to relative sea-level change. Tianjin, despite having only one port, has consistently high costs, both because of the large amount of trade the port handles and because of subsidence in the Yellow River delta. However, fewer than half of the ports listed in the PRC had traffic data available for the analysis. The missing ports tend to be classified as very small to medium sized (following the classification by World Port Source), so the calculated costs are a reasonable, if minimum, cost estimate. Ports in the PRC located in deltaic areas which subside will experience relative sea-level rise under the no-change scenario. Ports associated with substantial cities (such as Shanghai, Tianjin, and Guangzhou) would have greater adaptation costs if human-induced subsidence was considered, but this factor has not been included in this analysis because of large uncertainties.

These estimates are limited by the availability of data on ports. For example, the Republic of Korea has five ports for which there are no data, including Donghae, a medium-sized seaport with significant trade. In the case of Japan, additional data were obtained for 77 of the 131 ports, increasing the number of ports considered from 23% to 82% of total trade. This has a substantial effect on the potential costs; e.g., under the high sea-level rise scenario, estimated port upgrade costs increase by 70% from $95 million per year to $162 million per year, while for the medium sea-level rise scenario

[57] Nicholls, R. J. et al. (see footnote 5).

Table 14 Average Annual Port Area Upgrade Costs for All Scenarios, 2010–2050 ($ million per year)

Location	Coastal Ports		Scenario			
	Total Number	Included in Analysis[a]	No Change	Low	Medium	High
PRC	87	39	159	219	284	342
PRC Province, municipality, or autonomous region						
Fujian	7	3	0	0	3	8
Guangdong	21	9	1	4	9	14
Guangxi Zhuang Autonomous Region	3	3	0	0	0	0
Hainan	6	3	0	0	1	2
Hebei	3	1	0	0	0	0
Jiangsu	13	10	40	55	68	76
Liaoning	6	2	23	27	33	40
Shandong	11	3	0	0	2	8
Shanghai	5	1	35	61	83	99
Tianjin	1	1	59	70	79	86
Japan	131	107	0	0	38	95
Republic of Korea	17	12	0	1	20	35

PRC = People's Republic of China.

a With reported traffic in Lloyds List. 2009. *Ports of the World 2009.* London: Informa Maritime and Professional. Data for Japan supplemented from national sources.

Source: Asian Development Bank project team.

the increase in port upgrade costs is 92%. The PRC has a large number of the ports which do not have traffic data reported in the Lloyds List, so the results for the PRC must be treated as minimum bound.

Climate-related adaptation costs in East Asia range from $1.2 to $6.8 billion per year across scenarios

The incremental costs of adaptation in East Asia due to climate change vary from $1.2 billion per year in the low sea-level rise scenario to $6.8 billion in the high sea-level rise scenario with cyclones during 2010–2050 (Table 15). Across all scenarios, in the PRC climate change would be responsible for 38%–77% of costal adaptation costs, reflecting the significance of subsidence in its deltaic areas. In both the Republic of Korea and Japan, climate change is a much larger contributor to total adaptation costs: 71%–94% in the Republic of Korea and 82%–96% in Japan. The vast majority of the climate change adaptation costs are due to dike construction, followed by dike maintenance, port upgrades, and beach nourishment (Figure 6).

Conclusion

The main conclusion of this study is that coastal adaptation makes economic sense: the costs of adaptation, including residual damages, are much lower than the damages without adaptation.

Sea-level rise due to climate change is not the only driver of coastal change. Urban development and economic growth, subsidence, erosion due to sediment starvation and other factors are contributing to major environmental stresses on land in coastal zones. These pressures interact with climate change

Table 15 Average Annual Incremental National Climate Change Adaptation Costs, 2010–2050 ($ million per year)

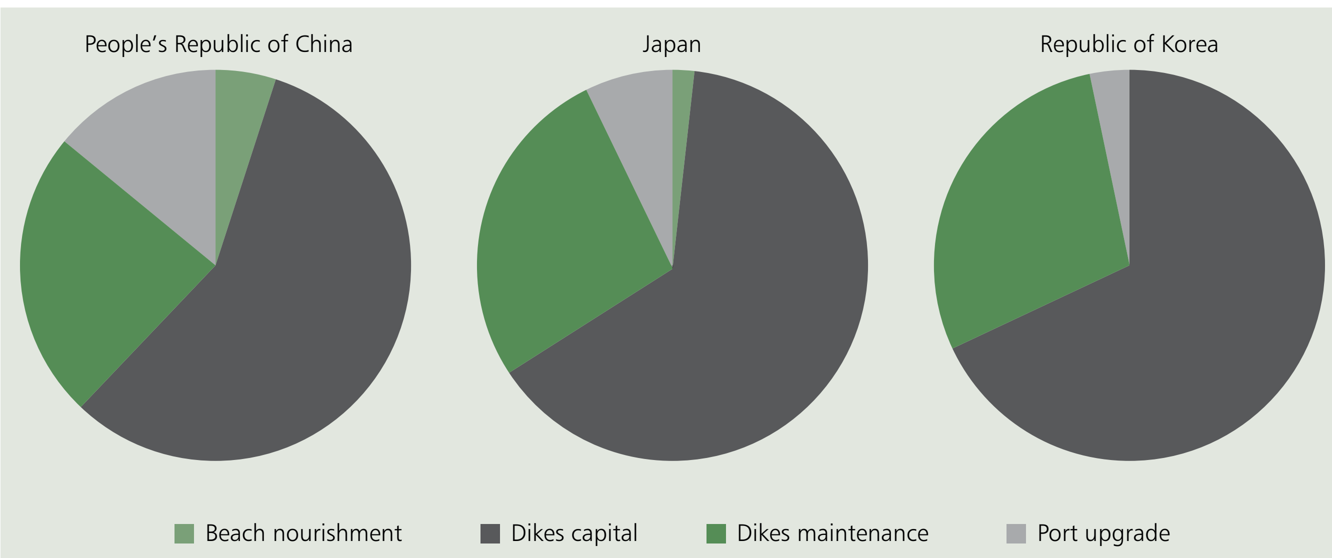
Scenario	Country	Beach Nourishment	Sea Dikes: Capital	Sea Dikes: Maintenance	Port Upgrade	Total Adaptation Costs
High (with cyclones)	PRC	60	1,752	573	215	2,600
	Japan	22	1,573	539	162	2,296
	Republic of Korea	1	1,421	480	35	1,937
High	PRC	60	982	339	215	1,596
	Japan	22	1,092	377	162	1,652
	Republic of Korea	1	708	246	35	990
Medium	PRC	51	599	250	149	1,049
	Japan	16	665	278	72	1,031
	Republic of Korea	1	433	182	20	636
Low	PRC	27	266	128	73	494
	Japan	9	293	140	2	444
	Republic of Korea	0	194	94	1	289

PRC = People's Republic of China.

Note: The no-change scenario results are excluded. Values in 2005 dollars.

Source: Asian Development Bank project team.

Figure 6 Relative Breakdown of Annual Climate Change Adaptation Costs for the Medium Sea-Level Rise Scenario, 2010–2050



Source: Asian Development Bank project team.

and will mean that investments in coastal protection will be greater than those required due to sea-level rise alone. This study has set out to identify the incremental contribution of climate change, focusing on sea-level rise with or without the increased risks from cyclones, but strategies for managing hazards in coastal zones must be based on a holistic analysis of the risks and adaptation options.

Chapter 4

The Economics of Adaptation in the Agriculture Sector

Key Messages

- **Considering only the biophysical impacts of climate change, crop yields in Japan and the Republic of Korea in 2050 are projected to increase in each of the climate scenarios examined. In the driest climate scenario for East Asia (the Global Medium scenario), crop yields in the People's Republic of China (PRC) may decline by 10%, but the changes are small for wetter scenarios.** Wheat is the major crop whose yield may be most affected by climate changes, with declines of nearly 24% in the PRC in 2050 under the driest scenario and nearly 8% in another scenario. The change in average yield of rice in the PRC ranges from –5.6% to 4.3% across scenarios.
- **After taking account of farmer responses and international trade, total crop production is expected to increase in 2050 in Japan, the Republic of Korea, and Mongolia under each climate scenario relative to the no-climate-change scenario. In contrast, total crop production is projected to decrease by 1%–4% in the PRC in 2050.**
- **Lower crop production will be accompanied by higher crop prices in the PRC, and the reverse in Japan.** In the driest climate scenario for the region, crop prices in the PRC may increase by 6% and in Mongolia by 38%. The outcome in Mongolia is a consequence of its reliance upon wheat, which may be severely affected by a drier climate.
- **The combination of lower domestic production and higher prices will reduce calorie consumption in 2050 in the PRC and, especially, Mongolia under the worst climate scenario.** The reduction in Mongolia will be nearly 200 calories per day on average, or about 8% of consumption, in the no-climate-change scenario.
- **Adaptation to climate change takes the form of a consumer subsidy designed to restore the average level of food consumption in calories. The cost of adaptation in 2050 for East Asia under the worst climate scenario varies from $10 billion to $33 billion depending upon the growth in agricultural yields due to technical progress.** The highest cost would be incurred if there was no technical progress, whereas a continuation of historical trends of yield growth would reduce the cost of adaptation by nearly 70%. Under other climate scenarios, the costs of adaptation in East Asia in 2050 will be less than $8 billion with a continuation of historical yield growth.
- **Adaptation to climate change via a consumer subsidy will benefit farmers in the PRC and the trade partners of Japan, Mongolia, and the Republic of Korea.** The consumer subsidy results in a significant increase in domestic production in the PRC in 2050. However, opportunities to expand production in the other countries in East Asia are more constrained, so most of the increase in consumption will be supplied from net imports.

Introduction

Agriculture accounts for a declining share of gross domestic product (GDP) and employment in East Asia but it remains important in the PRC and Mongolia, especially as a source of employment. The share of agriculture in GDP in 2011 was 15% in Mongolia and 10% in the PRC, while employment in agriculture was 33% and 37% of total employment, respectively.[1] This chapter examines the impact of climate change on crop yields in East Asia and, combined with a global agriculture trade model, calculates the cost of adaptation in 2050. Adaptation takes the form of a consumer subsidy that would restore the average calorie consumption level per capita to its level without climate change. (Chapter 5 explores the impact of changes in agriculture prices on poverty in the PRC and Mongolia.)

Adaptation measures in agriculture

Most of the adaptation measures in the agriculture sector are extensions or intensifications of existing risk-management or production-enhancement activities that farmers have always employed to deal with climate variability. The decentralized development and implementation of knowledge and technologies in response to changes in climate is referred to as *autonomous adaptation.* Such measures include

- crop varieties and livestock breeds that are better suited to increased temperatures or changed precipitation (e.g., drought-tolerant varieties);
- water harvesting and techniques to conserve soil moisture (e.g., crop residue retention) or increase water use efficiency (e.g., drip irrigation);
- changing the timing, location, or mix of cropping activities;
- changing the intensity of input use such as fertilizers;
- improving pest, disease, and weed management;
- diversifying income by integrating other farming activities (aquaculture, agroforestry) or pursuing nonfarm income;
- using seasonal climate forecasts or other climate and weather information to reduce potential risk; and
- selective migration.[2]

In the PRC, for example, there are many examples of autonomous adaptation in agriculture. Crop yields in the northern plain of the PRC have increased as a result of the adoption of new crop varieties that are better able to cope with increasing temperatures. In Ningxia Hui Autonomous Region, farmers faced with drought are inclined to choose a higher-yielding, higher-valued mix of corn, potatoes, and sunflowers.[3] Famers are selecting drought-resistant crop varieties in Hebei province and disease-resistant wheat varieties in Jiangsu province.[4] In the wheat–maize system of the northern plain of the PRC, the "double-delay" practice, i.e., delaying both the sowing time of wheat and the harvesting time of maize, has resulted in increases in total grain yield.[5] In terms of water management, a field survey in six provinces in northern PRC has shown that,

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1 Asian Development Bank. 2011. *Key Indicators for Asia and the Pacific 2012*. Manila (The employment figure for the PRC is from 2010).

2 Easterling, W. E. et al. 2007. *Food, Fibre and Forest Products. Climate Change 2007: Impacts, Adaptation and Vulnerability.* Edited by M. L. Parry et al. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK: Cambridge University Press, 273–313.

3 Lin, E. et al. 2006. National Assessment Report of Climate Change (II): Climate Change Impacts and Adaptation. *Advances in Climate Change Research* 2: 51–6.

4 Wang, J., J. Huang, and S. Rozelle. 2010. *Climate Change and PRC´s Agricultural Sector: An Overview of Impacts, Adaptation and Mitigation.* Geneva and Washington, DC: International Centre for Trade and Sustainable Development, and International Food and Agricultural Trade Policy Council.

5 Wang, J. et al. 2011. Increased Yield Potential of Wheat-Maize Cropping System in the North PRC Plain by Climate Change Adaptation. *Climatic Change* 1–16.

when faced with increasing water shortages, farmers will adopt water-saving technologies.[6] For livestock, adaptation measures in Inner Mongolia Autonomous Region include using groundwater to irrigate pastures, reducing the size of herds to increase the rate of off-take, and using fences to reduce overgrazing.[7]

The adaptation measures described above are farm-level responses to climate change. At the regional or national scale, governments can help foster adaptation in agriculture by funding agricultural research and development, providing climate and weather information, climate proofing infrastructure and improving logistics (i.e., the larger supply chain such as customs facilities, wholesale markets, warehouses, and cold storage), and measures to enhance access to international markets (e.g., risk arbitrage, improved procurement, and better management of stocks).[8]

At a macro level, the main adaptation policy considered in this chapter is a *consumer subsidy*—a direct payment to consumers to cover the cost of increased food prices in order to maintain the level of consumption that would occur in the absence of climate change. Indirectly, this will promote autonomous adaptation because the stimulus to demand will increase farm-gate prices and, thus, encourage farmers to adopt measures that increase agricultural production.

Previous estimates of the costs of adaptation in agriculture

The United Nations Framework Convention on Climate Change (UNFCCC) estimated the global cost of adaptation in the agriculture sector at $11 billion–$13 billion in 2030.[9] The World Bank's Economics of Adaptation to Climate Change (EACC) study estimated the cost of adaptation in agriculture, fisheries, and forestry for developing countries at $7 billion–$8 billion per year during 2010–2050.[10] Investment in irrigation systems is a major component of adaptation for agriculture: one study estimates the global cost at $8 billion in 2030.[11] The cumulative cost of developing new crop varieties may also be significant: the cost of developing 200 new crop varieties better adapted to local environments is estimated to be $43 million.[12]

Methodology

Crop yield model

The Environmental Policy Integrated Climate (EPIC)[13] model was used to project global crop yields for 18 major crops.[14] The EPIC model simulates the spatial and temporal dynamics of the major processes

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6 Blanke, A. et al. 2007. Water Saving Technology and Saving Water in the PRC. *Agricultural Water Management* 87: 139–50.
7 Liu, S. and T. Wang. 2012. Climate Change and Local Adaptation Strategies in the Middle Inner Mongolia, Northern PRC. *Environmental Earth Sciences* 66: 1,449–58.
8 World Bank. 2010. Development and Climate Change. Chapter 3: Managing Land and Water to Feed Nine Billion People and Protect Natural Systems. *World Development Report 2010.* Washington, DC.
9 McCarl, B. 2007. Adaptation Options for Agriculture, Forestry and Fisheries. United Nations Framework Convention on Climate Change (UNFCCC) Secretariat Financial and Technical Support Division.
10 World Bank. 2010. (see Introduction, footnote 4).
11 Fischer, G. et al. 2007. Climate Change Impacts on Irrigation Water Requirements: Effects of Mitigation, 1990–2080. *Technological Forecasting and Social Change* 74: 1,083–107.
12 Parry, M. et al. 2009. *Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates*. London: International Institute for Environment and Development and Grantham Institute for Climate Change.
13 Williams, J. R. 1995. The EPIC Model. In *Computer Models of Watershed Hydrology*. Edited by V. P. Singh. Highlands Ranch: Water Resources Public, 909–1,000; Liu, J. et al. 2007. Modelling the Role of Irrigation in Winter Wheat Yield, Crop Water Productivity, and Production in [the PRC]. *Irrigation Science* 26 (1): 21–33; Liu, J. et al. 2007. EPIC – Modelling Wheat Yield and Crop Water Productivity with High Resolution on a Global Scale. *Agricultural Systems* 94 (2): 478–93; Izaurralde, R. C. et al. 2003. Integrated Assessment of Hadley Center (HadCM2) Climate-Change Impacts on Agricultural Productivity and Irrigation Water Supply in the Conterminous United States. Part II. Regional Agricultural Production in 2030 and 2095. *Agricultural and Forest Meteorology* 117: 97–122.
14 For further description of the methodology used in this chapter see the respective background report: A. Mosnier et al. *Globally Consistent Climate Adaptation in Agriculture for the People's Republic of China, Japan, Republic of Korea and Mongolia* (TA 7465 report).

of the soil–crop–atmosphere management systems. The processes simulated include leaf interception of solar radiation; conversion to biomass; division of biomass into roots, above-ground biomass, and economic yield; root growth; water use; and nutrient uptake. EPIC simulates crop growth on a daily time step at a resolution of 30 arc-min, and crop yield is calculated by multiplying the potential daily photosynthetic production of biomass by a factor that accounts for decreases due to stress caused by shortages of radiation, water, and nutrients; by temperature extremes; and by inadequate soil aeration in proportion to the extent of the most severe stress during that day. The input data for the EPIC model include daily and monthly weather data (minimum temperature [Tmin], maximum temperature [Tmax], and precipitation), solar radiation, wind speed, relative humidity, soil data, harvest area of the crops, fertilizer application rates, digital elevation model data, and terrain slopes. EPIC has been validated successfully for simulating crop yield and evapotranspiration in the PRC as well as globally.[15]

EPIC was used to simulate crop yields for 1961–1990 and three future periods: the 2030s, 2050s, and 2090s. Three management systems were considered: automatic nitrogen (nitrogen fertilizer is added), automatic nitrogen and irrigation (simulates the addition of both nitrogen and water), and subsistence (no fertilizer or irrigated water is added).

Climate scenarios

Three General Circulation Models (GCMs) were used in the EPIC simulation of future crop yields: MRI-CGCM232A, UKMO-HADGEM1, and CNRM-CM3 (Chapter 1 Appendix). These three were chosen because they represent the Global Wet, Global Dry and Global Medium scenarios, respectively, based on the global average changes in the annual Climate Moisture Index. The index is an indicator of aridity, a function of both annual precipitation and average annual potential evapotranspiration.[16] It should be noted, though, that a GCM which is “dry” or “wet” globally may not be so at the regional level. Of the three GCMs, CNRM-CM3 is the driest for East Asia, whereas both MRI-CGCM232A and UKMO-HADGEM1 are (relatively) wetter climate scenarios for the region.

Future projections of daily precipitation and temperature are unreliable, and thus a variation of the “delta method” was used to produce future daily values of precipitation and temperature from the Princeton daily historical climate dataset (Chapter 1 Appendix). For temperature, the projected change (“delta”) in mean monthly temperature between the future period (2030s, 2050s, or 2090s) and the 1961–1990 baseline period for each GCM is added to the historical daily temperature value (Tmin, Tmax). The method was similar for precipitation, except that the number of “wet” days between the historical and future periods was preserved.

Other physical variables needed for EPIC include solar radiation, wind speed and relative humidity. These can either be inputted or calibrated directly by the model; given the lack of reliable future projections of wind speed and relative humidity, EPIC was used to calibrate these values for both the historical and future time periods. Due to the computation requirements of simulating potential crop yields for 18 crops for the entire globe in order to provide inputs into the global trade and economic model (GLOBIOM), the EPIC runs include carbon fertilization (Box 1). For the historical period 1961–1990, the carbon dioxide (CO_2) concentration varies from 316 parts per million (ppm) to 352 ppm, while the future concentrations were assumed to be 444 ppm for the 2030s, 522 ppm for the 2050s, and 754 for the 2090s.[17]

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15 Liu, J. et al. 2007. Modelling the Role of Irrigation in Winter Wheat Yield, Crop Water Productivity, and Production in [the PRC]. *Irrigation Science* 26 (1): 21–33; Liu, J. et al. 2009. Global Consumptive Water Use for Crop Production: The Importance of Green Water and Virtual Water. *Water Resources Research* 45 (5): W05428; Liu, J. and H. Yang. 2010. Spatially Explicit Assessment of Global Consumptive Water Uses in Cropland: Green and Blue Water. *Journal of Hydrology* 384 (3-4): 187–97.

16 Strzepek, K. 2012. *Indicators to Understanding the Impact of Climate Variability and Change to Flood Risk* (TA 7465 report). Manila; and Strzepek, K. 2012. *A Basin Scale Indicator Approach to Understanding the Risk of Climate Variability and* Strzepek, K. 2012. *Change to Water Resources Development and Management* (TA 7465 report). Manila.

17 See carbon cycle models and GCMs documentation of the IPCC Fourth Assessment Report. http://www.ipcc-data.org/ddc_co2.html. The BERN CO_2 concentration was used for all GCMs for the sake of consistency. This is the concentration used in 11 out of 17 GCMs employed for this study.

Box 1 Carbon Fertilization

Since plants convert carbon dioxide (CO_2) to carbohydrates in photosynthesis, the concentration of CO_2 in the atmosphere may be a limiting factor on crop growth and final yields. In addition, higher CO_2 concentrations reduce plant stomatal openings (the pores through which plants transpire, or release water) and thus reduce water loss. The so-called C3 crops—such as rice, wheat, soybeans, legumes as well as trees—should benefit more than the C4 crops, such as maize, millet, and sorghum. Most global crops models, including the Environmental Policy Integrated Climate (EPIC) model, incorporate the carbon fertilization effect. Holding other variables constant, higher CO_2 concentrations result in higher yields. For the PRC, projections of future cereal yields differ significantly according to whether carbon fertilization is included or not.[a] The magnitude of the fertilization effect on global crop yields remains a matter of debate.[b]

[a] Piao, S. et al. 2010. The Impacts of Climate Change on Water Resources and Agriculture in the PRC. *Nature* 467: 43–51.

[b] Baker, J. T. 2004. Yield Responses of Southern US Rice Cultivars to CO_2 and Temperature. *Agricultural and Forest Meteorology* 122: 129–137; Li, W. L. et al. 2007. Effects of Elevated CO_2 Concentration, Irrigation and Nitrogenous Fertilizer Application on the Growth and Yield of Spring Wheat in Semi-arid Areas. *Agricultural Water Management* 87: 106–114; Ziska, L. H. 2008. Three-Year Field Evaluation of Early and Late 20th Century Spring Wheat Cultivars to Projected Increases in Atmospheric Carbon Dioxide. *Field Crops Research* 108: 54–9; Sakai, H., T. Hasegawa, and K. Kobayashi. 2006. Enhancement of Rice Canopy Carbon Gain by Elevated CO_2 is Sensitive to Growth Stage and Leaf Nitrogen Concentration. *New Phytologist* 170: 321–26; Bannayan, M. et al. 2005. Modeling the Interactive Effects of Atmospheric CO_2 and N on Rice Growth and Yield. *Field Crops Research* 93: 237–51; Ma, H. L. et al. 2007. Responses of Rice and Winter Wheat to Free-Air CO_2 Enrichment ([PRC] FACE) at Rice/Wheat Rotation System. *Plant Soil* 294: 137–46.

Global agricultural trade and price projections

The Global Biosphere Management Model (GLOBIOM) was used to simulate future changes in global production, prices, and consumption of the major agricultural products up to 2050. GLOBIOM is an optimization model wherein market equilibrium is determined by choosing land use and processing activities across the globe to maximize social welfare (i.e., the sum of producer and consumer surplus[18]) subject to resource, technological, and policy constraints.[19] It simulates 18 major crops, a range of livestock production activities, major forestry commodities, and multiple bio-energy transformation pathways (e.g., biofuels). Countries are assigned to one of 33 regions; for this study Japan, Mongolia, the PRC, and the Republic of Korea have been disaggregated and simulated separately. Prices; demand for food, feed, and energy; processed quantities; and bilateral trade flows are endogenously determined at the level of these regions. The main drivers for demand are GDP and population change as well as bioenergy demand, the latter derived from bioenergy projections of the POLES energy model.[20] Potential agricultural production is derived from a variety of biophysical models: EPIC for crops (see above), G4M for timber,[21] and RUMINANT for livestock.[22] The GLOBIOM model is run over the period 2000–2050 and is solved in 10-year steps at a spatial resolution of 50 kilometers by 50 kilometers.

18 Consumer surplus is the monetary gain obtained by consumers because they have purchased a product(s) for a market price that is less than the highest price that they would be willing to pay, while producer surplus is the monetary gain obtained by producers because they have sold a product(s) for a market price that is higher than the highest price that they would settle for.

19 Havlík, P. et al. 2011. Global Land-Use Implications of First and Second Generation Biofuel Targets. *Energy Policy* 39: 5,690–702; Sauer, T. et al. 2010. Agriculture and Resource Availability in a Changing World: The Role of Irrigation. *Water Resources Research* 46; Schneider, U. A. et al. 2011. Impacts of Population Growth, Economic Development, and Technical Change on Global Food Production and Consumption. *Agricultural Systems* 104: 204–15.

20 European Commission. 2011. A Road Map for Moving to a Competitive Low Carbon Economy in 2050. Communication from the commission to the European Parliament, the European Council, the European Economic and Social Committee, and the Committee of the Regions. http://ec.europa.eu/clima/policies/roadmap/index_en.htm

21 Kindermann, G. et al. 2008. Global Cost Estimates of Reducing Carbon Emissions Through Avoided Deforestation. *Proceedings of the National Academy of Sciences of the United States of America* 105: 10,302–7.

22 Herrero, M. et al. 2008. Systems Dynamics and the Spatial Distribution of Methane Emissions from African Domestic Ruminants to 2030. *Agriculture, Ecosystems & Environment* 126: 122–37.

GLOBIOM aggregates available land into several land cover classes, which may or may not be used for production. The model allows land cover (land use) conversions, but the total land area across all categories remains fixed. For every potential cultivated area on the globe,[23] EPIC simulates potential yield of all 18 crops for the three generic management systems, and then GLOBIOM chooses the optimal management system, depending on the overall market condition. Cropland can expand into areas presently uncultivated in the future in the GLOBIOM simulations. GLOBIOM is recursive dynamic in that changes in land use made in one period alter land availability in the various categories in the next period.

In GLOBIOM, imported goods and domestic goods are assumed to be identical (homogenous), meaning that price differences are only due to trading costs. GLOBIOM models bilateral trade flows through the inclusion of both tariffs and transportation costs. The tariff data are from the Market Access Map database (MAcMap) database.[24] To approximate transportation costs, for which detailed data are lacking, the analysis uses standard coefficients linking freight rates to distance.[25]

As discussed above, GLOBIOM includes *endogenous* yield change, i.e., yield changes due to the switch between different crop types or management systems, and to changes in output prices and resource costs (e.g., land and water prices). Future yield change also depends on genetic advances and other research and development advances, mechanization, and other factors. These are not taken into account in the model explicitly but they can be aggregated as an *exogenous* trend in crop yield growth, based on historical evidence. These exogenous yield changes are often referred to as *input-neutral* yield growth or technological change. This chapter focuses on endogenous yield growth, but also includes a sensitivity analysis using the exogenous yield growth from two sources:

- estimates from the International Food Policy Research Institute's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model,[26] and
- historical yield growth over 1990–2010 in East Asia.[27]

Adaptation policy

The adaptation policy considered in this chapter is a global *consumer subsidy* to restore future consumption to the level that would occur in the absence of climate change. The cost of this policy is calculated separately for 2030 and 2050 both globally and for the countries of East Asia (in constant 2005 dollars).

This analysis has not attempted to estimate the cost of adaptation measures focusing on agricultural production. The primary forms of adaptation considered in the EACC study were investments in irrigation and agricultural research and development, including development of more climate-resilient crop varieties. There is insufficient empirical data for the region to calibrate statistical relationships. In any case, agricultural technology is advancing at such a pace that relationships based on historical data are unlikely to be valid for the future.

[23] This includes currently uncultivated areas but excludes certain land cover types such as built-up areas or glaciers.

[24] Bouët, A. et al. 2004. Computing an Exhaustive and Consistent, Ad-valorem Equivalent Measure of Applied Protection: A Detailed Description of MAcMap-HS6 Methodology. CEPII, Paris. Available at http://siteresources.worldbank.org/INTRANETTRADE/Resources/239054-1101918045494/Bouet-et-al(2004).pdf

[25] Hummels, D. 2001. Toward a Geography of Trade Costs. *GTAP Working Paper* No. 17; Jansson, T. and T. Heckelei. 2009. A New Estimator for Trade Costs and Its Small Sample Properties. *Economic Modelling* 26: 489–98.

[26] Rosegrant, M. W. et al. 2008. *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description*. Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/book-751/ourwork/program/impact-model

[27] Food and Agriculture Organization of the United Nations FAOSTAT Database. http://faostat.fao.org

Results

Focusing on the biophysical impacts of climate change, total crop production in 2050 is expected to increase by 2%–7% in Japan and the Republic of Korea, while it may decline by 10% in the People's Republic of China under the Global Medium scenario

Under all three climate scenarios, total calorie production (i.e., total crop area multiplied by crop yield, converted to units of calories) is projected to increase in Japan and the Republic of Korea in both 2030 and 2050 compared to the situation of no climate change, assuming that the total crop area and the management system does not change, and ignoring the global dynamics of trade (Table 1). Compared to the situation of no climate change in 2050, for example, production is projected to increase 2.6%–4.7% in Japan and 2.0%–6.7% in the Republic of Korea. For Mongolia, the change in total calorie production ranges from –1.7% to 3.8%, depending on the climate scenario. For the PRC, production may decline 10% under the Global Medium scenario (CNRM-CM3, which is the driest scenario for East Asia) and increase slightly (1.6%) under the wettest climate scenario for the region (MRI_CGCM232A).

In the rest of the world, climate change is expected to result in production increases in Europe (5.8%–8.7%) and the Pacific (mainly Australia) (1.3%–7.7%) in 2050, while under all three climate scenarios, climate change is projected to have deleterious impacts on calorie production in North America, sub-Saharan Africa, and Central America.

The projected changes for corn, rice, and wheat in East Asia largely mirror the aggregated results across all crops (Table 2). For example, the rice yield is projected to increase 2.5%–4.8% in Japan and 1.5%–6.7% in the Republic of Korea across climate change scenarios in 2050 compared to the scenario of no climate change. In the PRC the yield of maize corn is projected to decrease by 3.7%, rice by 5.6%, and wheat by 23.7% under the driest climate scenario for the region (Global Medium scenario). The results are consistent with the range of impacts from other studies for the region[28] and the globe.[29] It must be emphasized that these results are projections for areas that are currently cultivated; they are biophysical potentials.

There is one methodological note that deserves more explanation. The EPIC crop yield simulations using the climate of 1961–1990, which are spatially explicit and have a spatial resolution of 50 kilometers (km) by 50 km, were rescaled to 2000 using the national historical crop yields from 2000 (footnote 26). As the crop area and crop management are fixed, there is no difference between the crop yields in 2000 and the crop yields in 2050 without climate change.

At least 40% of the cropland under cultivation in 2000 in the PRC is projected to experience declines in production in 2050 (Figure 1). Under the most deleterious climate scenario, almost 90% of the cropland in Mongolia is projected to have reduced crop yields in 2050, but this is somewhat misleading as most of the production is concentrated in a few grid cells. In comparison, 20% of cropland in Japan and 10% in the Republic of Korea is projected to experience reductions in crop yields in 2050; in the rest of the region, yields are projected to remain constant or increase.

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[28] Matthews, R. B. et al. 1997. Simulating the Impact of Climate Change on Rice Production in Asia and Evaluating Options for Adaptation. *Agricultural Systems* 54: 399–425; Piao, S. et al. 2010. (see Chapter 1, footnote 26); Tao, F. and Z. Zhang. 2011. Climate Change, Wheat Productivity and Water Use in the North PRC Plain: A New Super-Ensemble-Based Probabilistic Projection. *Agricultural and Forest Meteorology*. http://dx.doi.org/10.1016/j.agrformet.2011.10.003; Iizumi, T., M. Yokozawa, and M. Nishimori. 2010. Probabilistic Evaluation of Climate Change Impacts on Paddy Rice Productivity in Japan. *Climatic Change* 107: 391–415.

[29] Lobell, D. B. et al. 2008. Prioritizing Climate Change Adaptation Needs for Food Security in 2030. *Science* 319: 607–10.

Table 1 Changes in Total Calorie Production due to Climate Change, 2030 and 2050 (%)

Region/Country	2030 Global Medium scenario	2030 Global Wet scenario	2030 Global Dry scenario	2050 Global Medium scenario	2050 Global Wet scenario	2050 Global Dry scenario
PRC	(3.0)	0.3	(3.6)	(10.0)	1.6	(1.0)
India	(1.3)	0.8	0.1	(9.0)	0.1	(4.0)
Japan	1.7	2.8	1.0	3.4	4.7	2.6
Republic of Korea	1.9	3.1	1.9	2.0	6.6	6.7
Mongolia	0.5	3.0	(1.2)	(1.7)	3.8	1.0
Latin America	0.8	1.6	(0.2)	(1.4)	2.1	(3.0)
North America[a]	(0.6)	4.1	(0.7)	(2.1)	(0.7)	(10.8)
Russian Federation and Central Asia	(1.6)	3.7	1.7	(1.6)	4.1	4.7
Europe[b]	2.0	3.8	4.4	8.7	8.7	5.8
Central America	(0.3)	(0.4)	(1.1)	(5.5)	(0.4)	(8.4)
Sub-Saharan Africa	(0.2)	(0.2)	0.6	(5.2)	(0.6)	(2.8)
Mediterranean countries[c]	1.8	1.3	0.8	3.7	5.3	3.0
South Asia and Southeast Asia[d]	0.3	0.4	0.3	(5.8)	2.1	(1.2)
Pacific[e]	2.9	4.5	5.2	1.3	7.7	2.1

( ) = negative, PRC = People's Republic of China.

a United States and Canada

b Austria, Belgium, Bulgaria, Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Ireland, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.

c Middle East and North Africa, Turkey, Albania, Bosnia and Herzegovina, Croatia, Macedonia, Serbia-Montenegro.

d Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka, Brunei Darussalam, Indonesia, Singapore, Malaysia, Myanmar, Philippines, Thailand, Cambodia, Democratic People's Republic of Korea, Lao People's Democratic Republic, Viet Nam.

e Australia, New Zealand, Pacific islands.

Notes: The results are weighted by the total area of each management system. This only considers the biophysical impact of climate change and does include economic feedbacks. It is assumed that crop allocation and the type of crop management at each location (grid cell) remains unchanged from the 2000 conditions, and crop expansion into new areas is not considered. Thus, crop yields in 2000 (EPIC crop yield simulations using the climate of 1961–1990 [spatial resolution of 50 km x 50 km] are rescaled to 2000 using the historical crop yields from 2000 [see Food and Agriculture Organization of the United Nations FAOSTAT Database: http://faostat.fao.org]) are the same as crop yields in 2050 without climate change. No exogenous yield growth is assumed. (Medium Scenario = CNRM_CM3, Wet Scenario = MRI_CGCM232A, Dry Scenario = UKMO_HADGEM1).

Source: Asian Development Bank project team.

Table 2 Changes in Crop Yields due to Climate Change in East Asia, 2050 (%)

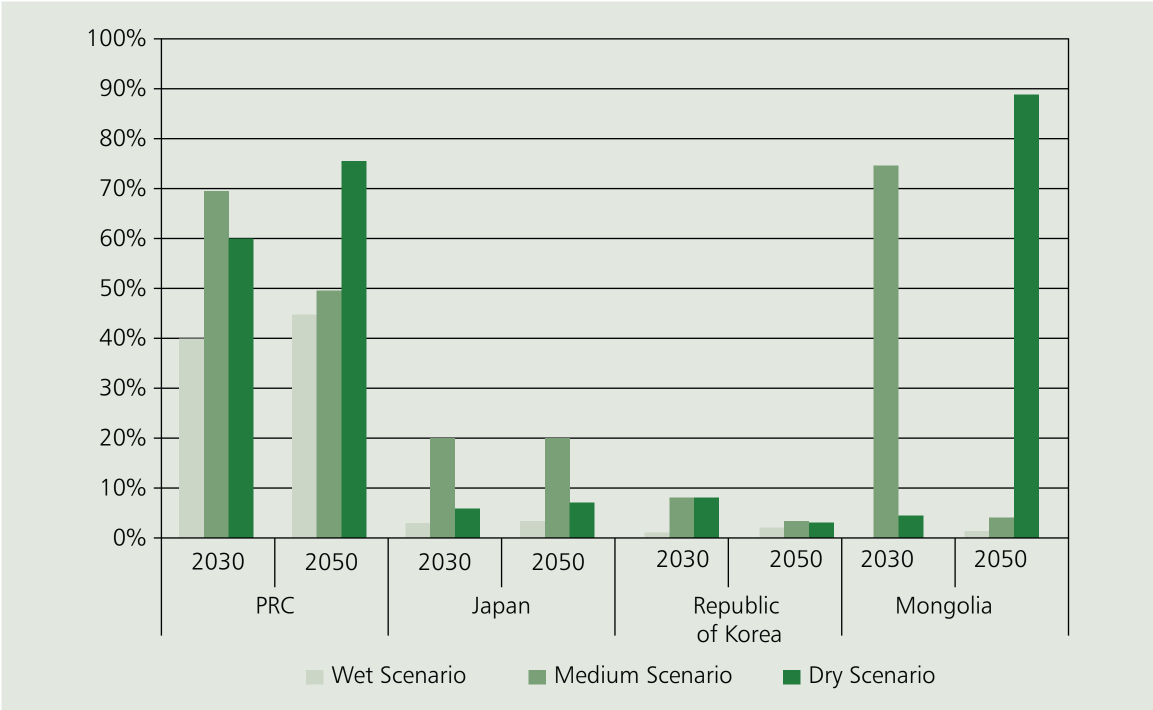
Country	Global Medium Scenario Corn	Global Medium Scenario Rice	Global Medium Scenario Wheat	Global Wet Scenario Corn	Global Wet Scenario Rice	Global Wet Scenario Wheat	Global Dry Scenario Corn	Global Dry Scenario Rice	Global Dry Scenario Wheat
PRC	(3.7)	(5.6)	(23.7)	(0.6)	4.3	(1.8)	1.6	1.6	(7.7)
Japan	2.1	3.5	4.9	0.4	4.8	4.4	(1.2)	2.5	6.5
Republic of Korea	0.0	1.5	1.5	(0.2)	6.7	4.6	0.0	6.5	10.7
Mongolia	------	------	(1.5)	------	------	3.0	------	------	1.5

( ) = negative, PRC = People's Republic of China.

Note: The results are weighted by the total area of the management system. This only considers the biophysical impact of climate change and does include economic feedbacks. It is assumed that crop allocation and the type of crop management at each location (grid cell) remains unchanged from the 2000 conditions, and crop expansion into new areas is not considered. Thus, crop yields in 2000 (EPIC crop yield simulations using the climate of 1961–1990 [spatial resolution of 50 km x 50 km] are rescaled to 2000 using the historical crop yields from 2000 [see Food and Agriculture Organization of the United Nations FAOSTAT Database: http://faostat.fao.org]) are the same as crop yields in 2050 without climate change. No exogenous yield growth is assumed. (Medium Scenario = CNRM_CM3, Wet Scenario = MRI_CGCM232A, Dry Scenario = UKMO_HADGEM1).

Source: Asian Development Bank project team.

Figure 1 **Share of the Cropland Area in 2000 Where Yields Decline by Climate Scenario, 2030 and 2050** (%)



PRC = People's Republic of China.

Note: This only considers the biophysical impact of climate change and does include economic feedbacks. It is assumed that crop allocation and the type of crop management at each location (grid cell) remains unchanged from the 2000 conditions. No exogenous yield growth is assumed. (Medium Scenario = CNRM_CM3, Wet Scenario = MRI_CGCM232A, Dry Scenario = UKMO_HADGEM1).

Source: Asian Development Bank project team.

When global trade and economic feedbacks are taken into account, crop production is projected to increase in East Asia in 2050, except in the PRC

In this section, the feedbacks of global trade and economics are considered. GLOBIOM allows for changes in

- consumption patterns in response to prices,
- cropping areas within overall land constraints,
- cropping patterns including relocation of crops and livestock in response to agro-climatic and market conditions,
- management systems including the use of fertilizers and irrigation water, and
- international trade patterns in response to shifts in the composition of production and consumption.

Across all three climate scenarios, total crop production (total calorie production from crops) is projected to increase in Japan (2.1%–7.0%), the Republic of Korea (4.2%–13.2%), and Mongolia (14.5%– 29.4%) in 2050 (Table 3). The changes in production are a function of changes in yields, autonomous adaptation, and shifts in international trade which reflect changes in production in other parts of the world.

Table 3 Change in Total Calorie Production from Crops across Climate Change Scenarios, 2030 and 2050 (%)

Country/ Region	2030			2050		
	Global Medium Scenario	Global Wet Scenario	Global Dry Scenario	Global Medium Scenario	Global Wet Scenario	Global Dry Scenario
PRC	(1.0)	0.7	(1.4)	(4.3)	(0.7)	(1.6)
India	(1.6)	0.3	(0.2)	(6.5)	0.3	(1.9)
Japan	(0.1)	1.1	(2.5)	2.1	6.4	7.0
Republic of Korea	8.1	8.9	8.1	4.2	12.5	13.2
Mongolia	21.6	13.7	13.0	14.5	16.9	29.4
Latin America	1.4	(0.1)	(1.1)	(0.7)	(0.9)	(0.5)
North America	(1.7)	1.3	(1.5)	(3.4)	(2.6)	(8.4)
Russian Federation and Central Asia	(2.1)	3.0	1.5	(4.9)	0.7	3.4
Europe	3.4	2.9	3.8	10.9	7.0	7.2
Central America	0.9	(1.1)	0.8	0.4	0.2	(5.3)
Sub-Saharan Africa	(1.9)	(2.1)	(0.6)	(8.5)	(3.3)	(4.6)
Mediterranean Countries	1.9	(2.3)	(1.9)	5.4	7.0	9.2
South and Southeast Asia	(0.3)	0.0	(0.4)	(3.3)	1.2	(1.1)
Pacific	0.9	0.4	4.7	(2.0)	2.0	(0.3)

( ) = negative, PRC = People's Republic of China.

Notes: The percentages are changes compared to the situation without climate change once economic feedbacks and trade are taken into account. Deviations are calculated as percent of the no-climate-change calorie production. These results are without the global adaptation policy (consumer subsidy). No exogenous yield growth is assumed. (Medium Scenario = CNRM_CM3, Wet Scenario = MRI_CGCM232A, Dry Scenario = UKMO_HADGEM1).

Source: Asian Development Bank project team.

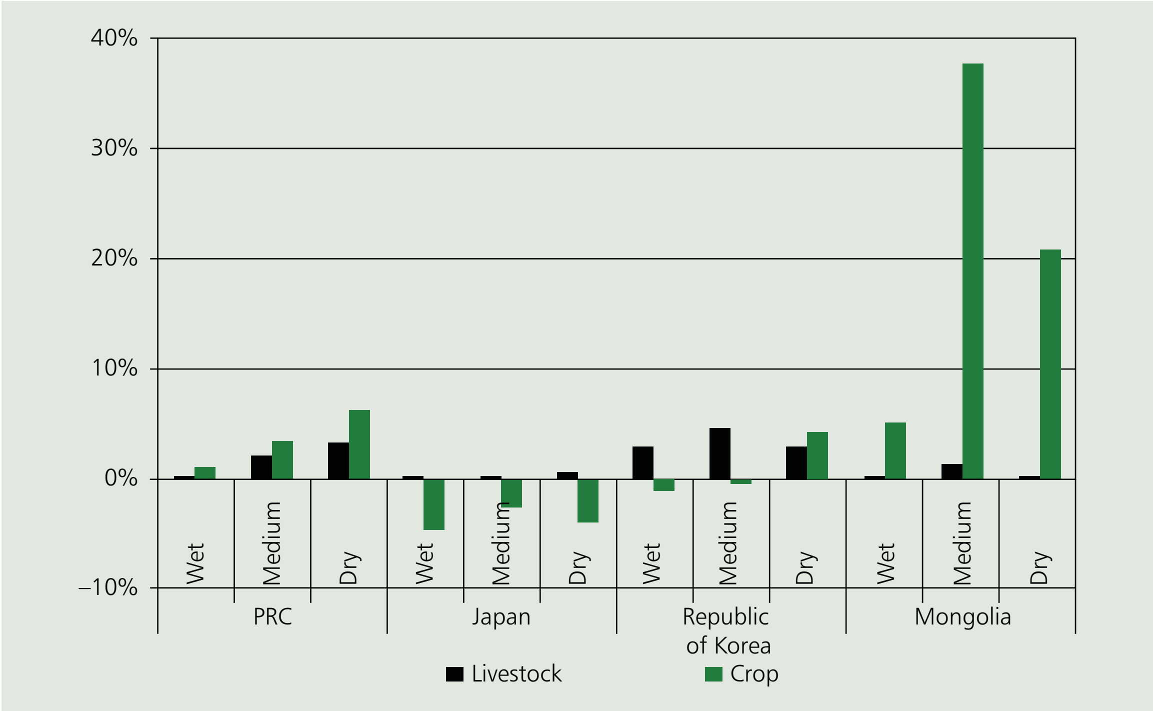
The results for Japan and the Republic of Korea are driven largely by changes in rice production, as the production of other cereals is marginal. Domestic rice production increases because major trading partners like the United States are projected to experience declines in rice yields. When global trade and economic feedbacks are taken into account, the decline in crop production for 2050 in the PRC in the Global Medium scenario is lower than the biophysical declines in crop yield, so that autonomous adaptation tends to increase crop production. On the other hand, for the Global Wet and Global Dry scenarios, there is a small shift away from production in the PRC to production in other regions of the world, such as Europe.

There are significant increases in crop production in Mongolia in each climate scenario. This is largely because the initial level is low, with less than 1% of land under crops, so bringing a small percentage of total land area under cultivation in response to higher prices for imported food products has a large impact on production. Indeed, the increase in total calorie production might have been larger but for a projected decline in yield of potatoes, one of Mongolia's staple crops.

Climate change may increase crop prices by up to 40% in Mongolia in 2050

Livestock prices are projected to increase in all countries in East Asia in 2050 for all climate scenarios (Figure 2). The largest change is an increase of 5% in the Republic of Korea for the Global Medium scenario. The pattern of changes in crop prices is much more variable. In Japan, prices decrease by 3%–5% in all scenarios, whereas they increase in both the PRC and Mongolia in all scenarios. The

Figure 2 Impact of Climate Change on Agricultural Prices in East Asia, 2050 (%)



PRC = People's Republic of China.

Note: The percentage changes are relative to the situation of no climate change in 2050. The figures represent the weighted average, where the weighting is the economic value of each commodity. The adaptation policy (consumer subsidy) is not included. No exogenous yield growth is assumed. (Medium Scenario = CNRM_CM3, Wet Scenario = MRI_CGCM232A, Dry Scenario = UKMO_HADGEM1).

Source: Asian Development Bank project team.

decreases in Japan are a consequence of higher domestic rice production. Similarly, the increases in crop prices of 1%–6% in the PRC are a consequence of lower domestic production.

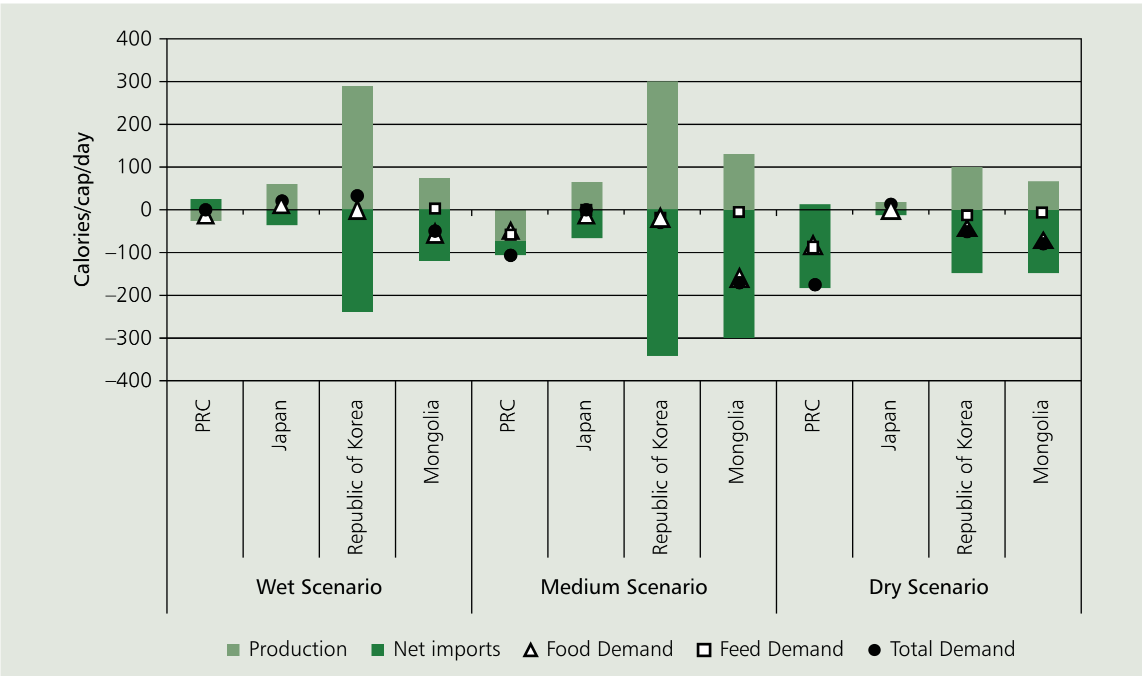
The biggest changes in prices concern crops in Mongolia under the Global Medium scenario with an increase of about 38%. The main component of this change is an increase in the domestic price of wheat, notwithstanding higher production. The problem is that, as noted above, the area of cultivated land is small while demand for consumption by both people and livestock is expected to increase so that domestic prices have to increase sufficiently to stimulate imports. There is a further complication because the increases in feedstock prices may be offset by increased grazing activities for ruminant meat and milk production. The effect of climate change on pasture productivity is not assessed in this study.

Per capita calorie consumption may decline significantly in Mongolia

Change in livestock and crop prices will affect domestic consumption. Calorie consumption per person in 2050 changes only marginally in the PRC, Japan, and the Republic of Korea, but it is projected to decline more significantly in Mongolia—by up to 8% or 200 calories per person per day under the Global Medium scenario.

Figure 3 summarizes the projected changes in agricultural production, demand, and net imports for East Asia. Production increases and imports decrease to offset this in Japan, the Republic of Korea, and Mongolia in 2050. In the PRC, production decreases, while the changes in net imports are small.

Figure 3 Impacts of Climate Change on Crop Supply and Demand in 2050
(calories per person per day)



PRC = People's Republic of China.

Note: Differences in these variables between the projected climate change scenarios and the no-climate-change scenario are expressed in calories per capita per day. No exogenous yield growth is assumed.

Source: Asian Development Bank project team.

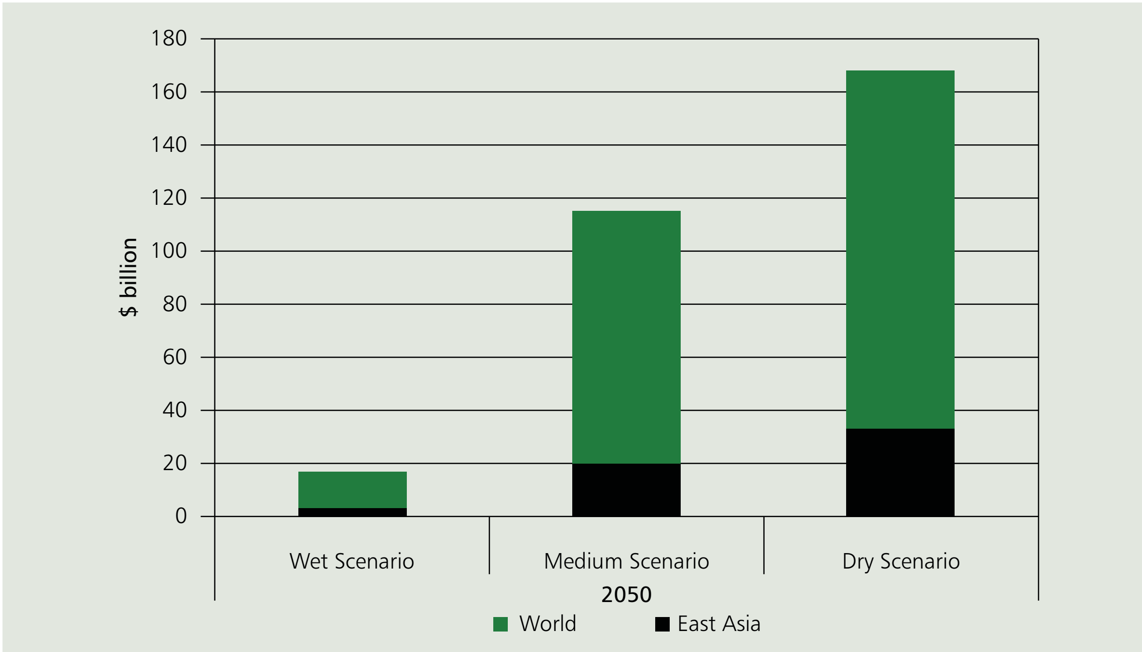
The cost of adaptation in East Asia—a consumer subsidy—is estimated to be $3 billion–$33 billion per year in 2050

Across the full range of assumptions about future technological change (exogenous growth in yields) and climate scenarios, the consumer subsidy required to restore consumption in 2050 ranges from $3 billion to $33 billion (in 2005 dollars), while the range globally is $14 billion to $165 billion (Figures 4a–4c). Adaptation costs are lowest for the Global Wet climate scenario, which is the driest scenario for East Asia, Europe, and India. Except for the Global Wet scenario, assuming yield growth through technological change reduces adaptation costs by more than 50%.

A consumer subsidy will benefit producers in the People's Republic of China and the trade partners of Japan, Mongolia, and the Republic of Korea

Adaptation via a consumer subsidy causes a significant increase in domestic production in the PRC and in net imports in Mongolia and the Republic of Korea (Figure 5) when compared to the situation in 2050 without this policy. Demand rises in all countries, as this is the role of the consumer subsidy. Almost all of this increase is met from higher domestic production in the PRC but from net imports in the other countries. Under the Global Wet scenario, worldwide production is higher, so the size of the consumer subsidy needed is smaller. Concomitantly, the changes in production and importation are also smaller. Figure 6 shows that implementation of the global consumer subsidy results in higher production in most regions, with a notable exception of a decline in Europe under the Global Wet scenario.

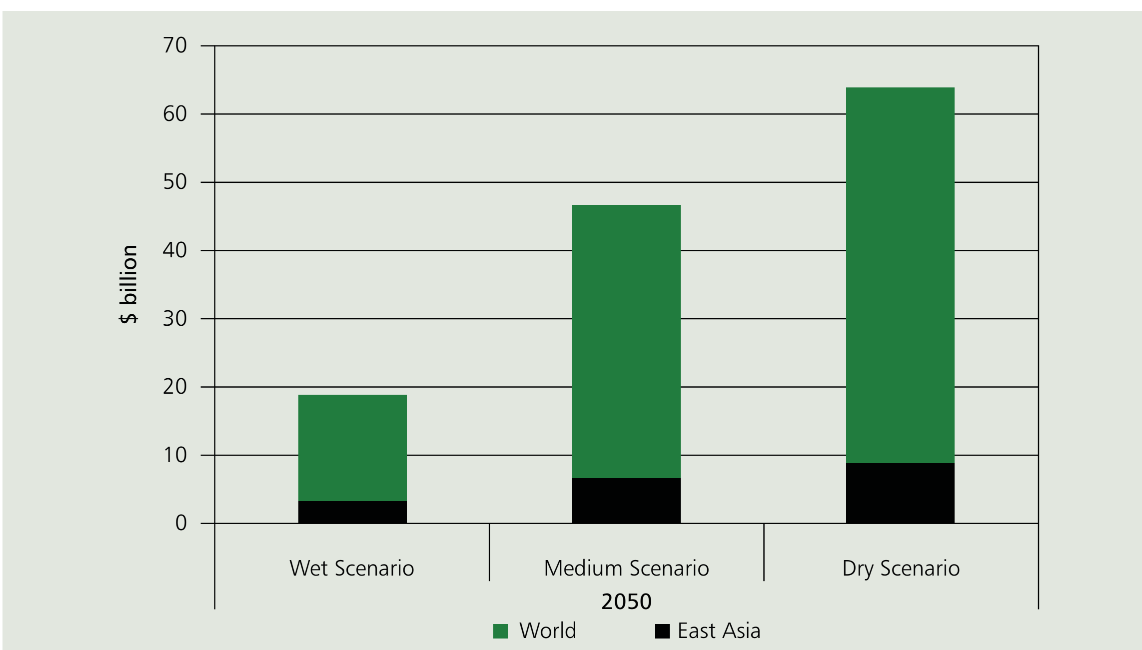
Figure 4A Adaptation Cost in 2050 with No Exogenous Yield Growth ($ billion)



Note: The costs are the amount needed to restore consumption to the level that would occur in the absence of climate change in 2050 (in 2005 dollars). Cost estimates assume no exogenous yield growth in crop production. (Medium Scenario = CNRM_CM3, Wet Scenario = MRI_CGCM232A, Dry Scenario = UKMO_HADGEM1.)

Source: Asian Development Bank project team.

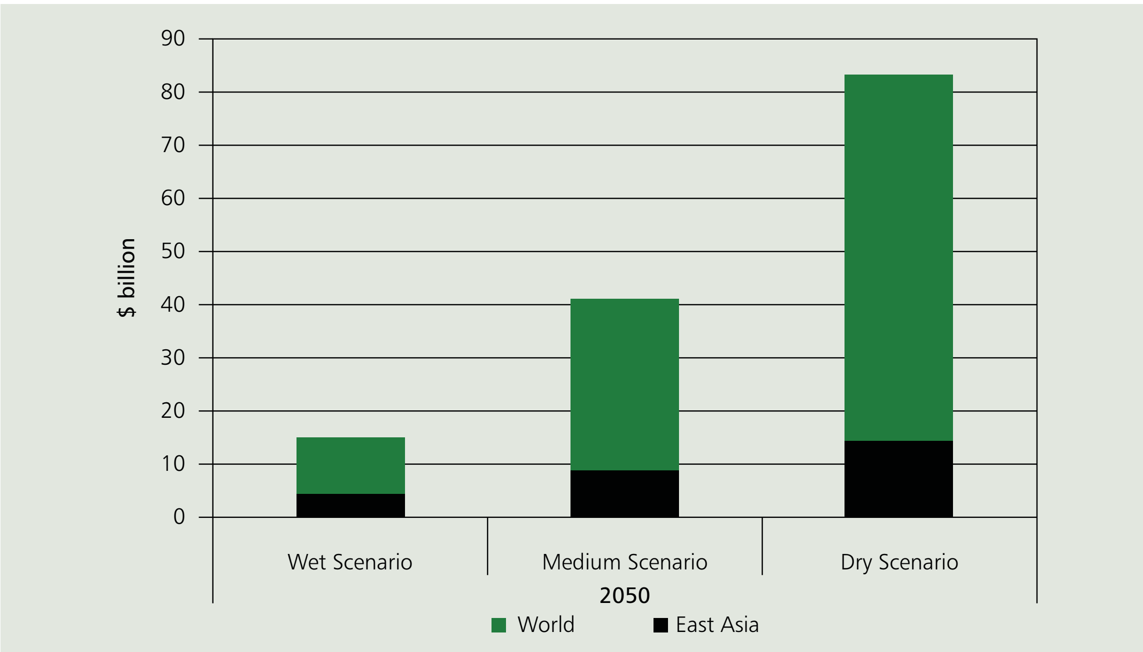
Figure 4B Adaptation Cost in 2050 Allowing for Historical Exogenous Yield Growth ($ billion)



Note: Cost estimates assume exogenous yield growth in the future equivalent to the historical (1990–2010) rate. (Medium Scenario = CNRM_CM3, Wet Scenario = MRI_CGCM232A, Dry Scenario = UKMO_HADGEM1.)

Source: Asian Development Bank project team.

Figure 4C Adaptation Cost in 2050 Allowing for IMPACT Exogenous Yield Growth ($ billion)



Note: Cost estimates assume exogenous yield growth from the IMPACT model (Rosegrant, M. W. et al. 2008. International Model for Policy Analysis of Agricultural Commodities and Trade [IMPACT]: Model Description. Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/book-751/ourwork/program/impact-model). (Medium Scenario = CNRM_CM3, Wet Scenario = MRI_CGCM232A, Dry Scenario = UKMO_HADGEM1.)

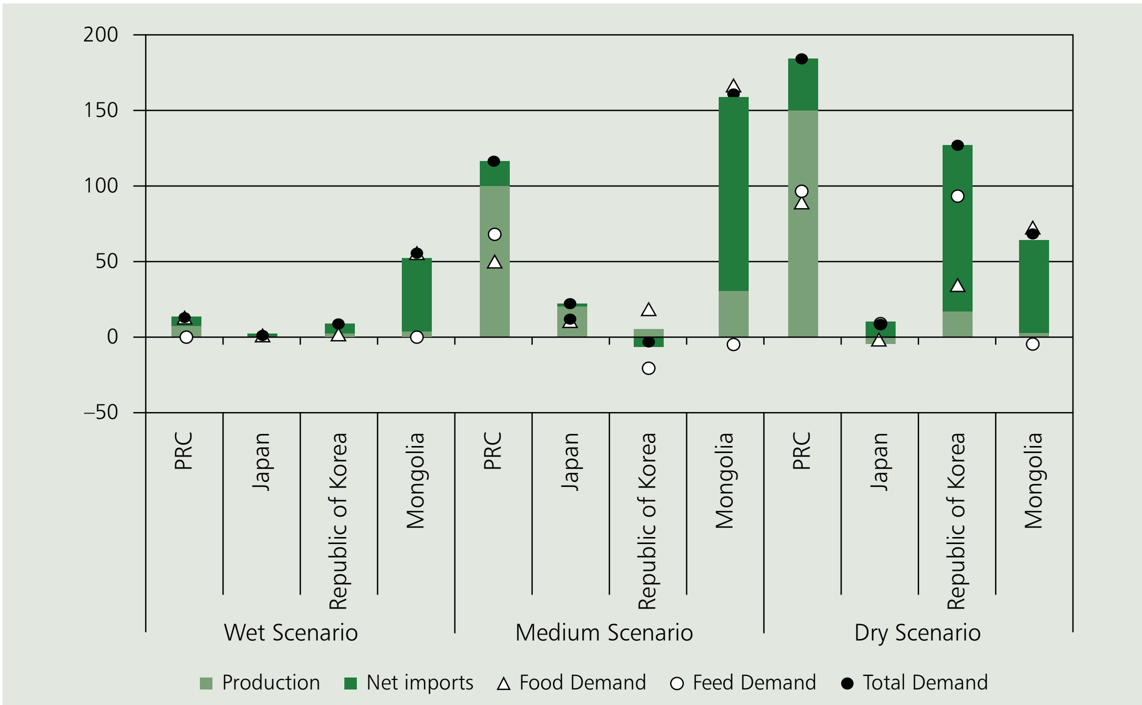
Source: Asian Development Bank project team.

Factors affecting success and cost of adaptation via a consumer subsidy policy

The success and the overall cost of adaptation via a consumer subsidy would depend on technological change, storage and transport, and the international trade regime. Technological change in crop or livestock breeding will reduce the price increase due to climate change and consequently the level required to maintain consumption. Investments in storage and transport may be required to ensure that food production in food-surplus regions and/or countries can be transferred to consumers in food-deficit regions and/or countries. The advantage of a consumer strategy is the potential for using trade to adjust to climate shocks. Unfortunately, foreign exchange and trade policies may hinder this mode of adjustment.

Instead of a universal scheme, a climate adaptation policy might favor a targeted funding mechanism designed to protect the poor and populations most affected by food insecurity. In principle, such a scheme should reduce the costs of the policy, even taking into account the administrative costs of targeting. The practical problems of implementation could be significant but there are multiple examples of policies of targeted income support which could be expanded to channel additional funding to reduce the impacts of climate change on vulnerable peoplethereby immediately reducing poverty and inequality; they enable households to invest in the human capital of their children and in the livelihoods of their earners; they help households manage risk, both ex ante and ex post; and they allow governments to implement macroeconomic or sectoral reforms that support efficiency and growth.To be effective, safety nets must not only be well intended, but also well designed and well implemented. A good safety net system and its programs are tailored to country circumstances, adequate in their coverage and generosity, equitable, cost-effective, incentive compatible, and sustainable. Good safety nets are also dynamic and change over time as the economy changes or as management problems are solved and new standards are set.

Figure 5 Impact of a Consumer Subsidy on Crop Supply and Demand in 2050
(calories per person per day)



PRC = People's Republic of China.

Note: The impact of adaptation is in reference to no adaptation policy in 2050, but still considering the climate change scenarios.

Source: Asian Development Bank project team.

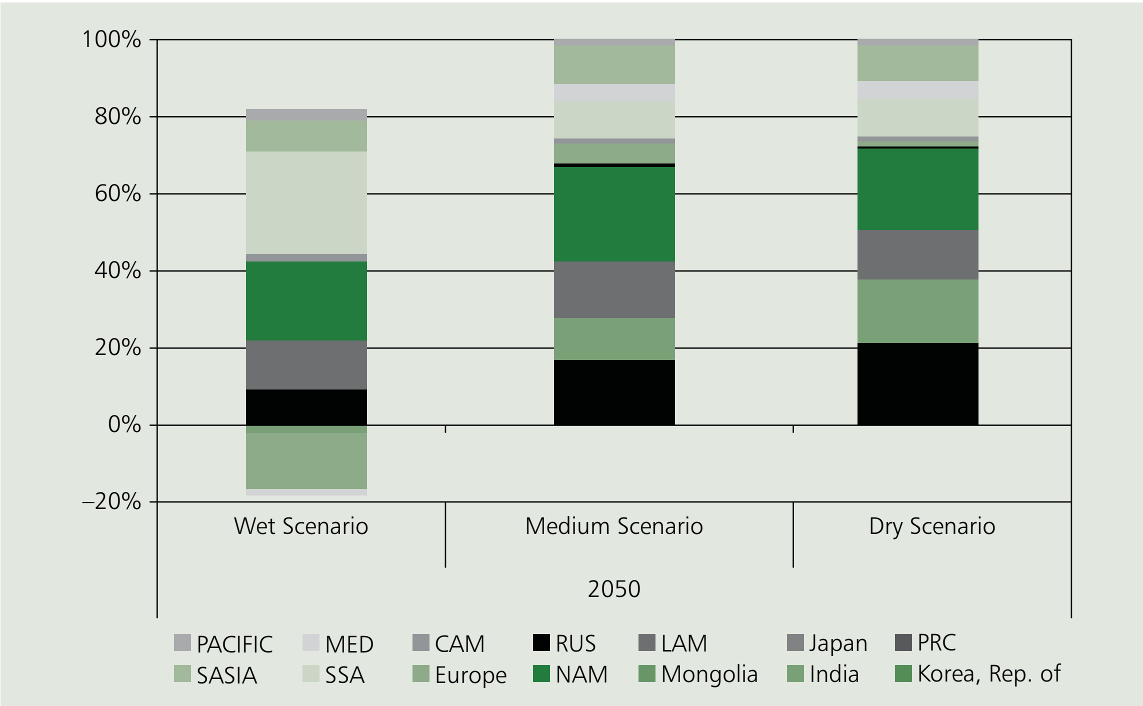
Conclusion

The biophysical impact of climate change—including temperatures, precipitation, and carbon fertilization—are expected to increase the yields of major food crops in Japan and the Republic of Korea but to have a mixed effect in the PRC. Wheat yields in the PRC fall in all of the climate scenarios examined, but the variation across scenarios is large. Rice yields fall in the driest scenario for East Asia (Global Medium) but they increase in other scenarios.

When these biophysical impacts are incorporated in modeling of agricultural production and trade, the PRC experiences a reduction in total calorie production in 2050 of up to 5% across climate scenarios. In contrast, agricultural production in the rest of East Asia increases in all climate scenarios. These changes feed through to lower domestic crop prices in Japan, higher crop prices in the PRC, and a mixed pattern of quite small changes in the Republic of Korea. Mongolia may face large increases in crop prices (up to 40%) in the drier scenarios for East Asia with a consequential decline in calorie consumption of up to 8%.

Adaptation to climate change takes the form of a consumer subsidy at a level that is sufficient to restore calorie consumption in 2050 to the level that it would have reached without climate change. If there is no technical progress, i.e., no exogenous growth in yields over time, the cost of adaptation in East Asia would vary from $3 billion to $33 billion across climate scenarios. With technical progress, the cost of adaptation in East Asia under the worst climate scenario would be $9 billion–$15 billion

Figure 6 Shifts in Crop Production due to Consumer Adaptation Policy in 2050 (%)



CAM = Central America, LAM = Latin America, MED = Mediterranean countries, NAM = North America, PRC = People's Republic of China, RUS = Russian Federation, SASIA = South and Southeast Asia, SSA = sub-Saharan Africa.

Notes: Units are percentage shares of the total increase in calorie production due to the climate adaptation policy compared to the situation with climate change but no adaptation policy in 2050.

No exogenous yield growth.

Source: Asian Development Bank project team.

in 2050. A continuation of historical trends for yield growth would mean that the cost of adaptation would be less than $10 billion in 2050.

The EACC study examined a different approach to adaptation, taking the form of investments in irrigation, roads, and agricultural research and development with a similar goal of avoiding any increase in the proportion of the population falling below a minimum standard of food consumption.[30] The cost of adaptation for the PRC was estimated to be less than $1 billion per year during 2010–2050. This suggests that a production-oriented approach to adaptation may be significantly less expensive than the demand-oriented approach considered in this study.

[30] Nelson, G. C., M. W. Rosegrant, J. Koo, R. Robertson, T. Salser, T. Zhu, C. Ringler, S. Msangi, A. Palazzo, M. Batka, M. Magalhaes, R. Valmonte-Santos, M. Ewing, and D. Lee. 2010. *The Costs of Agriculture Adaptation to Climate Change*. Washington.

Chapter 5

The Impacts of Climate Change on Poverty in East Asia

Key Messages

- **Rapid economic growth is expected to reduce poverty by over 80% in all of the major regions of the People's Republic of China (PRC) as well as in Mongolia without climate change in 2050.** For this analysis the poverty line is defined as $2 per person per day at 2005 international prices. The main concentration of poverty remaining in 2050 will be in the southwestern region of the PRC.
- **Projected increases in precipitation variability due to climate change in the PRC and Mongolia may increase the poverty headcount ratio in the two countries by a very small amount.** The climate-related changes for the poverty gap ratio are minimal. Under the worst climate scenario considered, the number of households in poverty is projected to increase by a maximum of 0.5% in the southwestern region of the PRC in 2050. Even the worst impact of climate change will be very small relative to the reduction in poverty due to economic growth.
- **The projected increase in food prices up to 2050 without climate change is likely to result in an overall decrease in rural poverty in the PRC.** This effect may be partly offset by a reduction in food production due to climate change. Higher food prices increase the cost of living for net purchasers of food, but in the medium term they stimulate agricultural employment and wages. In the PRC, where poverty is largely a rural phenomenon, evidence suggests that the increase in agricultural incomes outweighs the increase in the cost of living.

Introduction

The previous chapters have estimated the costs of adaptation in key sectors in East Asia. It is also important to explore whether and how climate change will affect absolute poverty in the region. Absolute poverty is measured in this study by using a poverty line defined as average household consumption of $2 per person per day at 2005 international prices at purchasing power parity (PPP). This poverty line was proposed by the World Bank as the median of the national poverty lines for low- and middle-income countries. This chapter focuses on poverty in the PRC and Mongolia since poverty rates in Japan and the Republic of Korea are already low and are likely to fall in the future.

Two poverty indexes are considered. The *poverty headcount ratio* is defined as the proportion of the population living in households with an average consumption of less than $2 per person per day. It is a measure of the incidence of poverty for a given poverty line, since a higher poverty headcount ratio means that more people in a given population have levels of consumption that are less than the poverty line. The *poverty gap ratio* is the difference between mean actual consumption for households in poverty and the poverty line, expressed as a proportion of the poverty line. It is a measure of the severity of poverty, since a higher poverty gap ratio means that more resources are required to lift all households in poverty up to the poverty line. By definition both of the poverty indexes must fall between 0 and 1. The alternative to using measures of absolute poverty is to examine poverty ratios based on national poverty lines, but there is little consistency in the definition of national poverty lines across countries or over time, so it is not possible to use such data to make econometric projections of the evolution of poverty rates as countries develop.

Methodology and Results

The World Bank has published estimates of poverty indexes for the PRC using the $2 per day poverty line. In 2008 the values of the indexes were 29.8% for the poverty headcount ratio and 10.1% for the poverty gap ratio.[1] At a provincial level, various estimates of both poverty indexes have been published based on household surveys carried out by the National Bureau of Statistics.[2] Most of these studies focus on rural poverty and almost all of them rely on the PRC's national poverty line, which was roughly equivalent to the $1 per person per day poverty line.[3] The studies of provincial poverty show that rural poverty in the early 2000s using the national poverty line was highest for provinces in the southwest and west—particularly Qinghai, Guizhou, and Gansu, and the Tibet Autonomous Region and Ningxia Hui Autonomous Region. The exception was Inner Mongolia Autonomous Region. Urban poverty rates in the same period were considerably lower than rural poverty rates, and the estimates are generally regarded as being less reliable. Studies of urban poverty which rely upon local estimates of the minimum living standard allowance yield a poverty headcount ratio of 3.9% for all of urban

1 As of 2012, the most updated data were for 2008. However, after this analysis was done, the World Bank published data for 2009 in 2013. For example, the poverty headcount ratio for 2009 is 27% for $2 per day. These updated data will not change the main messages of this chapter. The World Bank World Data Bank: http://databank.worldbank.org/data/views/variableSelection/selectvariables.aspx?source=world-development-indicators

2 See: Ravallion, M. and S. Chen. 2007. PRC's (Uneven) Progress Against Poverty. *Journal of Development Economics* Vol. 82: 1–42; Shen, C. 2005. Regional Disparities in the PRC: A Poverty Perspective. *PRC Public Affairs Quarterly* Vol. 2: 38–80.

3 In late 2011 the PRC revised its national poverty line to an income of CNY2,300 per person per year at 2010 prices. This is equivalent to $1.33 per day at 2005 purchasing power parity, which is close to the World Bank's extreme poverty line, though there is a difference in the treatment of saving (included in the PRC's poverty line, excluded from the World Bank definition). Ravallion and Chen (2007) (footnote 1) point out that the purchasing power parity exchange rates for the PRC overstate the rural cost of living, so that the revised poverty line lies somewhere between the World Bank's $1.25 and $2.00 per day poverty lines.

PRC.[4] Urban poverty is concentrated in provinces and autonomous regions in the west—Gansu and Qinghai, Ningxia Hui Autonomous Region, and Xinjiang Uyghur Autonomous Regions—followed by the provinces of Heilongjiang and Jilin in the northeast.

It is more difficult to estimate the poverty indices for Mongolia because there is no estimate of the PPP exchange rate for 2005. Studies of poverty in Mongolia indicate that the current value of the national poverty line, which was increased for the analysis of the 2007/08 household survey, is reasonably close to the $2 per day poverty line. Hence, the baseline estimate of the poverty headcount ratio in 2010 is assumed to be equal to the most recent estimate of 35.2% based on the 2007/08 survey.[5]

Poverty is projected to fall by more than 80% in the regions of the People's Republic of China and Mongolia in 2050 in the absence of climate change

An econometric approach is used to project poverty in the future for the PRC and Mongolia. Beta regression[6] is used to estimate a model of poverty rates across countries and over time with the location parameter for each country and time period expressed as a function of a suite of socioeconomic, geographic, and climatic explanatory variables. As would be expected, the poverty indicators fall as gross domestic product (GDP) per person and urbanization increase. The higher the proportion of the population under 15 years of age, the higher is the poverty gap ratio. Country size and the proportions of land classified as arid or semi-arid affect both poverty indices. Of the climate variables, only precipitation range is significant, with higher values of the precipitation range being associated with higher levels of poverty.

Looking ahead to 2050 with no climate change, projections that take account of future changes in the socioeconomic variables suggest that the poverty headcount ratios will fall by 85%–94% in the PRC and 95% in Mongolia compared to 2010 (Table 1). Similarly, the poverty gap ratios fall by 83%–89% in the PRC and 89% in Mongolia. Over time, poverty in the PRC becomes more concentrated in the southwest; this region accounts for about 24% of the population in poverty in 2010 but this share increases to 34% in 2050.

The increase in precipitation variability with climate change is only projected to slightly increase poverty headcount ratios under the most conservative climate scenario

The beta regression model indicates that an increase in variation in precipitation across months may increase poverty. So, each of the 17 climate scenarios have been used to project poverty taking account of the changes in precipitation patterns due to climate change. Table 2 summarizes the impact of climate change on the two poverty indicators in 2050 for the minimum, median, and maximum values across the various climate scenarios relative to the baseline values with no climate change. The climate-related changes for the poverty gap ratio are minimal. For the poverty headcount ratio, the maximum impacts over all climate scenarios represent a very small increase in poverty in the PRC (at most 0.5% in southwestern PRC), but this is very small relative to the reduction in poverty due to economic growth.

4 Hao, Y. 2009. Urban Poverty and Exclusion in the PRC. *Discussion Paper* I2009-202. Berlin: Wissenschaftszentrum für Sozialforschung.

5 See United Nations Development Programme. 2007. *Mongolia Human Development Report 2007*. Ulaanbaatar; World Bank. 2011. *Mongolia Quarterly Economic Update – August 2011*. Ulaanbaatar; World Bank. 2006. *Mongolia Poverty Assessment*, Report 35660-MN. Washington, DC.

6 A beta distribution has location and dispersion parameters denoted by μ and ϕ in which the location parameter μ is assumed to be a function of the explanatory variables.

Table 1 Baseline Projections of Poverty Indices with No Climate Change, 2010–2050

Poverty Index	2010	2030	2050
Poverty headcount ratio			
Northern PRC	29.0	7.1	2.2
Northeast PRC	26.4	6.4	1.7
Eastern PRC	20.3	4.7	1.5
Southeastern PRC	28.1	7.3	2.5
Southwestern PRC	49.8	18.5	7.7
Western PRC	40.1	12.5	4.8
Mongolia	49.0	11.8	3.8
Poverty gap ratio			
Northern PRC	9.4	2.6	1.0
Northeast PRC	9.9	3.0	1.1
Eastern PRC	7.1	1.9	0.8
Southeastern PRC	10.5	3.1	1.4
Southwestern PRC	20.0	7.2	3.5
Western PRC	16.0	5.3	2.4
Mongolia	17.0	4.7	1.9

PRC = People's Republic of China.

Note: Based on $2 per person per day poverty line. See Chapter 2 Appendix for the geographical groupings for each region in the PRC.

Source: Asian Development Bank project team.

Table 2 Impact of Climate Change on Poverty Indices, 2050 (%)

	Change in Poverty Headcount Ratio			Change in Poverty Gap Ratio		
Region	**Min**	**Median**	**Max**	**Min**	**Median**	**Max**
Northern PRC	(0.1)	0.0	0.2	(0.0)	(0.0)	0.1
Northeastern PRC	(0.0)	0.1	0.1	(0.0)	0.0	0.1
Eastern PRC	(0.0)	0.0	0.2	(0.0)	0.0	0.0
Southeastern PRC	0.0	0.1	0.3	(0.0)	0.0	0.1
Southwestern PRC	(0.0)	0.2	0.5	(0.0)	0.0	0.1
Western PRC	(0.2)	0.1	0.4	(0.1)	0.0	0.1
Mongolia	(0.1)	0.0	0.2	(0.1)	0.0	0.1

( ) = negative, PRC = People's Republic of China.

Note: Percentage change relative to the no-climate-change baseline using $2 per person per day poverty line. See Chapter 2 Appendix for the geographical groupings for each region in the PRC.

Source: Asian Development Bank project team.

The projected future increase in food prices—with or without climate impacts—will likely result in an overall decrease in rural poverty in the People's Republic of China

There has been an extensive and somewhat inconclusive debate about the net effect of changes in agricultural prices on the extent and nature of poverty in developing countries. At the risk of some oversimplification, the key considerations in the debate may be summarized as follows:

- In the short term, an increase in food prices is likely to increase poverty (with an increase in both the poverty headcount and poverty gap measures) among households who are net buyers of food. On the other hand, poverty will fall among households who are net sellers of food. Almost all urban households are net buyers of food, so urban poverty will increase, though the impact may be small because few urban households spend a large share of their total consumption on food. For rural households, the issue is complicated by the fact that poor households are often net buyers of food for some periods of the year and net sellers in other periods. The poorest households may rely heavily upon income earned as hired laborers rather than from the sale of agricultural produce. Such households are likely to be net buyers of food and would, therefore, be worse off if food prices increase.
- Changes in agricultural prices will alter the level and composition of agricultural production which will, in turn, affect the demand for labor and average wages both in agriculture and the rest of the economy. In the medium term, the indirect impact of changes in agricultural prices on labor markets may outweigh the direct impact on the cost of consumption.

An analysis of the impact of the increase in international food prices in 2007/08 in the PRC carried out by the Asian Development Bank provides an illustration of the way in which the two elements may work out.[7] The analysis examined an extreme case in which international prices of food grains increase by 100%. For the PRC, this translates into a 2.5% increase in the urban consumer price index relative to the baseline with no increase in international food prices. Poor urban households are affected more severely than middle- or high-income urban households, with the consequence that the urban poverty headcount and the urban Gini coefficient[8] (in terms of real income) increase by about 10%. On the other hand, there is a large supply response with the production of food grains increasing by about 20%. Poor rural households gain more from the increase in the demand for labor than they lose as a consequence of higher food prices. The rural poverty headcount falls significantly, along with the rural Gini coefficient. Since poverty rates are much higher for rural than for urban households in the baseline scenario, the combined effect of these changes would be a reduction in the total poverty headcount. However, a continuation of the recent trend towards an increasing level of urban inequality could reverse the potential reduction in the national Gini coefficient.

In a more general study, Zhai and Hertel (2008) emphasize that poverty in the PRC is now largely a rural phenomenon.[9] Hence, exogenous shocks or policy reforms that boost returns to agriculture or enhance off-farm opportunities for rural households employed in agriculture will reduce poverty and inequality in the PRC. This assessment is likely to apply even more strongly in 2030 or 2050.

Using the results from Chapter 4 it is possible to make some inferences on how agricultural production and prices will affect poverty in the PRC. With no climate change, agricultural prices in the PRC are projected to rise by 15%–21% from 2010 to 2030 and then to fall marginally during 2030–2050, while still being higher than in 2010 (Table 3). The increase in prices is slightly greater for food crops than for other agricultural products. Total agricultural production in the PRC increases up to 2050 but there is a significant shift in the composition of output with a fall in production of food crops, particularly rice and wheat, and an increase in livestock output. The shift in agricultural production in favor of livestock is consistent with general patterns of development; as a country gets richer, domestic demand for livestock increases.

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7 Asian Development Bank. 2008. *Food Prices and Inflation in Developing Asia: Is Poverty Reduction Coming to an End?* Manila.

8 The Gini coefficient is a measure of income inequality.

9 Zhai, F. and T. Hertel. 2008. Economic and Poverty Impacts of Agricultural Price Distortions in [the PRC]. *Working Paper*. Manila: Asian Development Bank.

Table 3 Agricultural Prices and Production in the People's Republic of China, 2030 and 2050

Category	Climate Scenario[b]	Price Indices		Production Without Adaptation[a]		Production With Adaptation	
		2030	2050	2030	2050	2030	2050
All agricultural products	NoCC	115.6	110.0	111.1	116.1	111.1	116.1
	Global Medium	116.6	116.3	111.2	113.9	111.0	115.8
	Global Wet	114.5	110.7	111.8	115.9	111.8	116.0
	Global Dry	116.8	112.4	111.2	114.8	111.1	115.9
Food products[c]	NoCC	115.5	109.9	111.4	116.6	111.4	116.6
	Global Medium	116.4	116.0	111.5	114.5	111.3	116.4
	Global Wet	114.4	110.4	112.1	116.5	112.0	116.6
	Global Dry	116.6	112.0	111.5	115.4	111.4	116.5
Food crops	NoCC	119.2	113.1	94.9	90.1	94.9	90.1
	Global Medium	120.7	122.0	93.9	87.9	94.7	89.9
	Global Wet	117.9	114.0	95.2	89.9	95.2	90.1
	Global Dry	120.6	115.7	94.2	89.3	94.9	90.0

Notes: Indices with 2010 = 100. "NoCC" refers to no climate change.

[a] Adaptation refers to implementation of the consumer subsidy, which acts through a number of mechanisms: changing the structure of consumption, increasing food imports, or increasing domestic production through the use of more inputs (fertilizers and water) or the expansion of crop area.

[b] See Chapter 4 for the description of the climate scenarios.

[c] Food products include food crops plus all livestock products, such as meat, milk, and eggs. This means that cotton, sugar cane, and biomass are excluded. Sugar cane is not directly consumed and prices are heavily influenced by ethanol demand.

Source: Asian Development Bank project team.

Following the Zhai and Hertel analysis, this increase in agricultural prices implies that, without climate change, the rural poverty headcount and poverty gap will be lower in 2050 than it would have been without this shift in world agricultural markets. The urban poverty headcount may increase by a small amount. However, by 2050 the share of food consumption in the expenditure of the poorest quintile of the urban population will be significantly lower than it was in 2010, so any effect of food prices on urban poverty is likely to be small.[10]

The prices of food crops under the climate change scenarios rise by 0.8%–7.9% in 2050 relative to the projections without climate change. With adaptation, the decrease in food production that would occur as a consequence of climate change is partially offset by the boost to demand provided by the expenditure on a consumer subsidy. In aggregate, climate change will decrease domestic agricultural production in the PRC very marginally, and so higher agricultural prices will not increase agricultural employment relative to the no-climate-change scenario. However, the impact of the price increases is expected to be slight. In 2009, cash expenditure on food accounted for 28.6% of total consumption expenditure for the lowest quintile of rural households.[11] Considering the worst climate scenario in 2050 for the region (the Global Medium scenario, but the driest for East Asia), the impact of climate change on agricultural prices would translate into a 1.6% increase in the cost of living for the lowest quintile of rural households.

10 In 2009 food expenditures accounted for 47% of total expenditures for the bottom 10% of urban households by income and 28% for the top 10%. See: National Bureau of Statistics. 2010. *[People's Republic of] China Statistical Yearbook 2010*. Beijing, Table 10.7.

11 National Bureau of Statistics. 2009. *[People's Republic of] China Statistical Yearbook 2009.* Beijing, Table 10–24.

Overall, the stimulus effect of increases in agricultural prices up to 2050 on employment in rural areas without climate change is likely to outweigh the impacts on rural households of the small increase in the cost of living due to climate change. Set in the context of macro trends in poverty as a result of continued economic growth in the PRC, it is reasonable to conclude that the combined impact of the changes in agricultural prices and production will be very small.

Chapter 6

Greenhouse Gas Projections and the Costs of Sector-Specific Mitigation Options

Key Messages

- **The maximum abatement potential in East Asia is large—5.3 gigatons of carbon dioxide equivalent ($GtCO_2e$) in 2020 and 9.7 $GtCO_2e$ in 2030.** About 90% of this maximum abatement potential in 2030 is in the People's Republic of China (PRC). To put this in context, energy-related emissions in East Asia totaled 8.9 $GtCO_2e$ in 2010. The energy sector is the greatest source of potential emission reductions in all countries in the region.
- **About 70% of this abatement potential—6.8 $GtCO_2e$ in 2030—has a marginal abatement cost of less than $100 per ton of carbon dioxide equivalent (tCO_2e).** This reduction in emissions could be achieved by the adoption of abatement technologies that are already competitive or are expected to become competitive within the next decade.
- **Many of the abatement technologies in East Asia are "win–win."** Some abatement options—particularly improvements in energy efficiency—are economic without consideration of the reduction in emissions. In such cases, the marginal cost of abatement is negative. Even with high discount rates and low payback periods, greenhouse gas emissions could be reduced by 1.7 $GtCO_2e$ in 2030 by adopting negative cost abatement options. Most of this—1.5 $GtCO_2e$—would be in the PRC.
- **A 5-year delay in the adoption of abatement options in the power sector in the PRC reduces potential abatement by up to 15% in 2030.** This "lock-in" effect occurs because the construction during this period of power plants using technologies that are less efficient and have higher emissions constrains future abatement during the life of those plants.
- **Mitigation efforts in the PRC will reduce its dependence on imports of coal and oil but will increase its dependence on imports of gas.** By comparison with the business-as-usual scenario, abatement with a ceiling of $100 per tCO_2e will increase the share of gas in primary energy consumption in 2030 from 2% to 25%, offset by falls in the share of coal from 57% to 43% and of oil from 18% to 10%.
- **Mitigation has large co-benefits in the PRC, particularly in the form of reduced health costs from air pollution.**
- **A regional carbon market would be cost-effective in East Asia.** The PRC has many more inexpensive abatement options than Japan or the Republic of Korea. The potential for abatement in the PRC at costs between $0 and $100 per tCO_2e with high discount rates is about 19 times the equivalent potential for Japan and the Republic of Korea combined in 2030, so the scope for efficient trades are large.

Introduction

Reducing greenhouse gas emissions in East Asia will have significant impacts on global mitigation efforts. In 2005, the PRC, Japan, and the Republic of Korea were among the top 10 emitters of greenhouse gases.[1] In 2010 the PRC was the world's largest emitter of carbon dioxide (CO_2) from fuel combustion, at about 7,200 million tons (Mt).[2] This chapter examines the prospect for greenhouse gas emissions in East Asia without mitigation, and explores the costs and abatement potential of sector-specific mitigation options in the region. The analysis allows the countries in the region to identify sectors and specific technologies that offer the best opportunities to reduce greenhouse gas emission at low cost.

Methodology

The study employed the Asia-Pacific Integrated Model's (AIM's) Enduse model[3] to project greenhouse gas emissions and potential reductions (Figure 1). AIM Enduse is a bottom-up technology model that quantifies energy and material flows in an economy, and consequent emissions. It allows for the selection of technologies each year that minimize total costs subject to constraints such as satisfaction of service demands, availability of energy and material supplies, and other system constraints. A module of AIM Enduse, Abatement Cost Curve (ACC), was used to specifically generate *marginal abatement cost* (MAC) curves that show the costs and emissions potential of abatement technologies.

The analysis starts from data on service demands. A service is a need in some sector of the economy (e.g., steel), while a service demand is the exact amount needed (e.g., millions of tons). Examples of service demands include volumes of iron, steel, and cement production; person-kilometers (km) traveled in the transport sector; the amount of household heating and lighting; and the number of livestock. These service demands are exogenous to the model and are a function of such factors as future population, gross domestic product (GDP) growth, and industrial structure. Each service demand can be met by various devices, or technologies, that consume energy, e.g., fossil fuel combustion directly or electricity usage. For each technology, emissions of greenhouse gases are calculated by the amount of energy consumed and the emissions factors of the various energy sources. The total system costs include not only the investment and operating costs of each technology, but also the total energy costs. The technology costs and energy prices are endogenous to the model, as are such factors as the present and future share of the technology—e.g., the percentage of cars that are gasoline–electric hybrids—and improvements in each technology over time as they relate to cost, energy usage, and emissions.

The MAC curves represent pair-wise comparisons of technologies of a certain service type, showing the additional cost of the abatement technology and the total possible emissions reduction for deployment of that technology (Box 1).

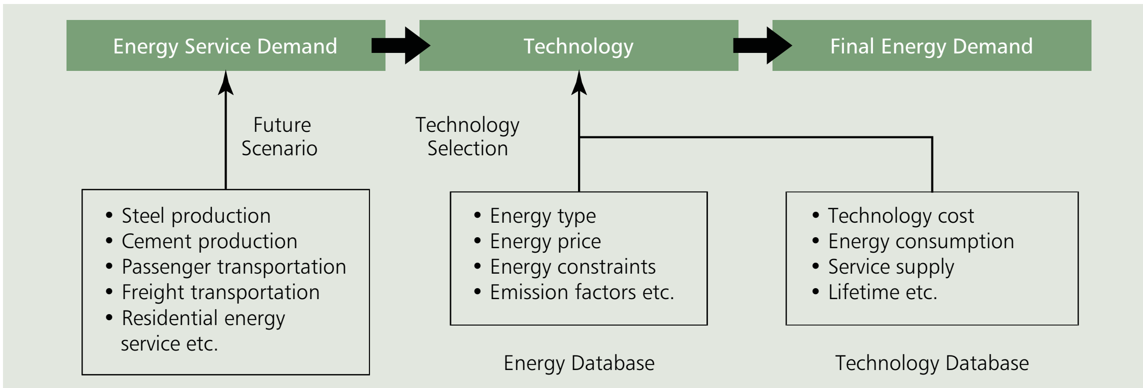
Greenhouse gases and sectors considered

The model covers emissions of the six Kyoto Protocol greenhouse gases—CO_2, methane (CH_4), nitrous oxides (N_2O), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride—which are measured in millions of tons of CO_2 equivalent ($MtCO_2e$). The emissions are calculated by the model, which explicitly considers

(i) energy and power generation;
(ii) industrial processes, including CO_2 and N_2O emissions from such processes as iron, steel, and cement production;

1 Climate Analysis Indicators Tool. World Resources Institute. http://cait.wri.org/
2 International Energy Agency. 2012. *CO_2 Emissions From Fuel Combustion.* Paris.
3 National Institute for Environmental Studies. 2006. Asia-Pacific Integrated Model Enduse Model. Manual 1. http://www-iam.nies.go.jp/aim/AIM_datalib/Enduse_model/Manual_EnduseModel1030.pdf

Figure 1 Asia-Pacific Integrated Model Enduse Model



Source: Asian Development Bank project team.

(iii) residential and commercial buildings;
(iv) transportation;
(v) agriculture, which includes CO_2, CH_4, and N_2O but excludes changes in land-use; and
(vi) other sources, which includes fugitive emissions of CH_4.

AIM Enduse includes a technology database of 200–300 mitigation technologies (Appendix A). Only direct emissions are counted towards each sector. The energy price projections were obtained from Hanaoka et al. (2009), which are based on International Energy Agency projections.[4]

Service demands

For this analysis, national consultants were used to elaborate current and future service demands for each country, as shown in Tables 1A–1D. There are two points to note: Economic growth is projected to continue in the PRC and Mongolia. Since the Japanese population peaked in 2004, the service demands mostly level off in 2020. Secondly, transportation demands are expected to increase significantly in the Republic of Korea, where, for example, passenger transport is projected to increase 34% between 2008 and 2030. The Appendix to Chapter 2 provides details on the socioeconomic projections which underpin the service demands in the model.[5]

Scenarios

Two scenarios were evaluated: business-as-usual (BAU) and mitigation. In the business-as-usual scenario, the future technology shares are fixed to the same levels as in the base year (2008), and the AIM Enduse model is run up to the target years 2020 and 2030 to generate greenhouse gas emission projections (Table 3). For the mitigation scenario, abatement technologies are included for various carbon price "cut-offs" or MAC ceilings—$50, $100, $200, and $1,000. The inclusion of the abatement technologies results in reduced projected emissions in 2020 and 2030.

The mix of technology changes under the various MAC ceilings because, if there are competing abatement technologies, the model selects the combination which yields the highest reduction in emissions subject to the ceiling on the MAC. This means that a low-cost abatement technology that reduces emissions by 70% will be displaced by a more expensive technology that reduces emissions by 95% as the MAC ceiling is raised.

4 Hanaoka, T. et al. 2009. Global Emissions and Mitigation of Greenhouse Gases in 2020. *Journal of Global Environment Engineering* Vol. 14: 15–26.

5 In the case of Mongolia the projections of GDP used in this chapter are based on earlier projections that pre-date the mining boom. This does not alter the marginal abatement cost of the technologies presented nor the qualitative results for the country.

Table 1A Service Demands in the People's Republic of China, 2020 and 2030

Sector		Indicator	Unit	Base year 2008	Target Year 2020	2030
Industry						
	Iron and Steel	Production	million tons	406	610	570
	Cement	Production	million tons	1,168	1,600	1,600
	Other	Change in GDP	2008 = 100	100	213	340
Residential		Population	million	1,329	1,388	1,394
Commercial		Energy Service Demand Growth Rate	2008 = 100	100	122	141
Transportation						
	Passenger	Traffic Volume	billion per km	2,571	4,999	8033
	Freight	Traffic Volume	billion tons per km	3,224	6,188	9,357
Agriculture						
	Livestock	Number of Livestock	million head	10,544	12,884	14,520
	Crops	Cultivation Area	million hectares	123	151	170

GDP = gross domestic product.

Sources: See Chapter 2 Appendix for the projections of GDP and population. Projections for industrial production, transportation, and agriculture are obtained from: Energy Research Institute. 2009. *2050 [People's Republic of] China Energy and CO_2 Emissions Report*. Beijing: Science Press (in Chinese). The energy service demand growth rate is derived from other AIM Enduse work.

Table 1B Service Demands in Japan, 2020 and 2030

Sector		Indicator	Unit	Base Year 2008	Target Year 2020	2030
Industry						
	Iron and Steel	Production	million tons	106	120	120
	Cement	Production	million tons	66	67	66
	Other	Industrial Production Index	2008 = 100	100	100	101
Residential		No. of Households	million	51	54	52
Commercial		Floor space	million sq. meters	1,817	1,932	1,920
Transportation						
	Passenger	Traffic Volume	billion per km	1,292	1,307	1,304
	Freight	Change in Traffic Volume	2008 = 100	100	114	114
Agriculture						
	Livestock	Number of Livestock	head ('000)	4,420	4,280	4,280
	Crops	Cultivation Area	hectares ('000)	4,270	4,950	4,950

Source: Projections from the Japanese Ministry of the Environment. 2011. Mid- and Long-term Roadmap for Global Warming Measures Investigative Committee. http://www.challenge25.go.jp/roadmap/

Discount rates

The analysis has been carried out using two scenarios for the discount rates that are applied in evaluating the economic viability of alternative technologies (Table 2). The high discount rate (HDR) scenario reflects the discount rates that are typically applied by different agents when choosing whether to invest in energy efficiency and related technologies. The discount rate is particularly high for the residential and commercial sectors as experience has shown that households and small businesses will

Table 1C Service Demands in the Republic of Korea, 2020 and 2030

Sector		Indicator	Unit	Base Year 2008	Target Year 2020	Target Year 2030
Industry						
	Iron and Steel	Production	tons ('000)	56,344	73,845	87,676
	Cement	Production	tons ('000)	53,486	70,100	83,229
	Other	Change in GDP	2008 = 100	100	131	156
Residential		Population	million	48	50	50
Commercial		Change in GDP	2008 = 100	100	131	156
Transportation						
	Passenger	Traffic Volume	billion per km	332	393	445
	Freight	Traffic Volume	billion tons per km	171	426	639
Agriculture						
	Livestock	Livestock	million head	615	593	595
	Crops	Cultivation Area	hectares ('000)	1,210	1,248	1,267

GDP = gross domestic product.

Sources: The industrial production projections are calculated from the GDP growth rate. See Chapter 2 Appendix for the source for the projections of GDP and population. Transportation projections were provided by Kyung-Kyoon Lee, director of the Global Strategy Unit, Global Green Growth Institute, Republic of Korea. The agricultural values are based on other AIM Enduse work.

Table 1D Service Demands in Mongolia, 2020 and 2030

Sector		Indicator	Unit	Base Year 2008	Target Year 2020	Target Year 2030
Industry						
	Iron and Steel	Production	tons ('000)	157	2100	2100
	Cement	Production	tons ('000)	169	1250	1250
	Other	Change in GDP	2008 = 100	100	166	239
Residential		No. of Households	'000	678	759	834
Commercial		Number of Employees	persons ('000)	282	335	375
Transportation						
	Passenger	Traffic Volume	million per km	3,607	6,800	8,700
	Freight	Traffic Volume	million tons per km	9,051	23,010	46,515
Agriculture						
	Livestock	Number of Livestock	head ('000)	43,774	36,865	36,865
	Crops	Cultivation Area	hectares ('000)	178	181	182

GDP = gross domestic product.

Sources: The industrial production and agricultural projections were provided by Jargal Dorjpurev, Director of Energy, Environment and Consulting Services, Ulaanbaatar, Mongolia. The GDP and population projections for 2020 and 2030 are estimated by the AIM Enduse Model using historical growth rates.

not adopt new technologies unless the payback period is very short, i.e., the discount rate which they apply is very high. The same tends to be true for most vehicles including cars as well as light and heavy trucks. As an alternative, the low discount rate (LDR) scenario examines the implications of applying a uniform and relatively low discount rate to all decisions.

Table 2 Discount Rates by Sector and Scenario (%)

Discount Rate	Power Plant	Industry	Residential and Commercial	Transportation		Non-Energy
				Vehicles	Rail/Ship/Air	
HDR (high discount rate, short payback period)	10	10	33	20	10	5
LDR (low discount rate, long payback period)	5	5	5	5	5	5

Source: Asian Development Bank project team.

Lock-in effect

Because of their lifespan and scale, some conventional technologies cannot be replaced easily by advanced, energy-efficient technologies. For example, it will take a long time to replace existing technologies in the power sector because power plants are expected to operate for 30–50 years. As a consequence, any delay in the development or commercialization of efficient technologies will lead to delays in the installation of advanced technologies, resulting in a decrease in the maximum abatement potential at fixed dates in the future. This effect is referred to as "lock-in." McKinsey (2009) analyzed the impact of lock-in on the maximum abatement potential and costs in the PRC. It concluded that a 5-year delay could translate into a 35% decrease in the maximum abatement potential.[6] A 5-year delay in the installation of efficient technologies in the power sector is considered in this study.[7]

Results

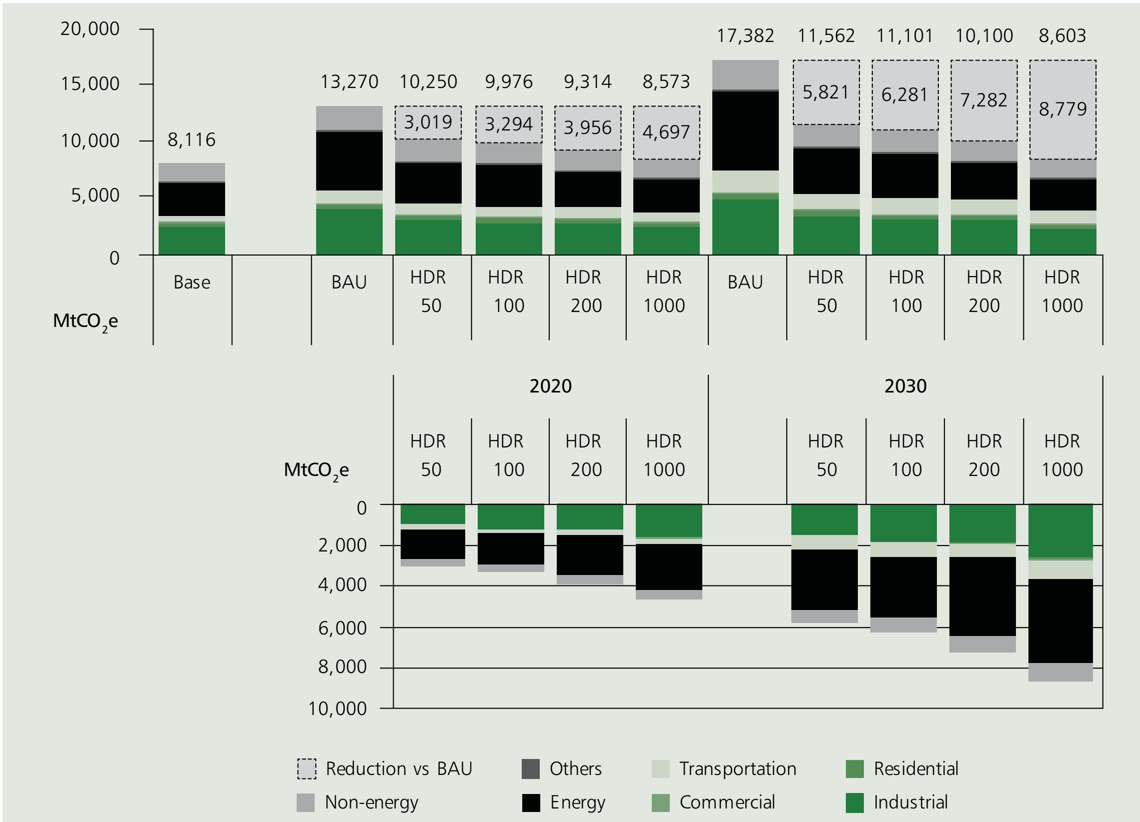
The summary results of the analysis for each country and scenario are shown in Figures 2A and 2B for the PRC, Figures 3A and 3B for Japan, Figures 4A and 4B for the Republic of Korea, and Figures 5A and 5B for Mongolia. The format of the figures is identical. Figure 2A shows emissions and abatement potential in Japan for the HDR scenario. The top left-hand column shows the sector composition of greenhouse gas emissions in the base year (2008), measured in $MtCO_2e$, with a total of 1,298 $MtCO_2e$. The top middle columns (marked BAU, HDR 50, …, HDR 1,000) show the sector composition of total emissions in 2020 under the business-as-usual scenario and under the HDR abatement scenarios with MAC ceilings of \$50 per tCO_2e, \$100 per tCO_2e, \$200 per tCO_2e, and \$1,000 per tCO_2e. Hence, under the business-as-usual scenario, total emissions in 2020 are projected to be 1,443 $MtCO_2e$, which would be reduced to 1,267 $MtCO_2e$ if all abatement options with MAC of \$100 per tCO_2e were implemented. The five columns on the top right-hand side of the figure show the equivalent projections for 2030. The four columns in the bottom middle of the figure show the sector composition of the abatement in greenhouse gas emissions in 2020 that can be achieved with MAC ceilings of \$50 per tCO_2e, \$100 per tCO_2e, \$200 per tCO_2e, and \$1,000 per tCO_2e. The four columns on the bottom right-hand side of the figure are the equivalent levels of abatement in 2030.

Note that the sum of greenhouse gas emissions for a fixed value of the MAC ceiling, e.g., \$100 per tCO_2e, is always lower for the LDR scenario than for the HDR scenario. This is because the discount rate determines the cost of capital that is used in calculating the amortization of capital investment

[6] McKinsey & Company. 2009. *[People's Republic of] China's Green Revolution.*

[7] Lock-in does not mean it is impossible for conventional technologies (e.g., traditional coal-fired power plants) to be replaced before the end of their lifetime by more energy-efficient technologies, but it does increase the cost of adopting alternative technologies with lower emissions. The AIM Enduse model will select the most economic option subject to the ceiling on the MAC.

Figure 2A Emissions and Abatement Potential in the People's Republic of China under the High Discount Rate Scenario



BAU = business-as-usual; HDR = high discount rate, short payback period scenario; $MtCO_2e$ = million tons of carbon dioxide equivalent.

Notes: See the description and definitions in the text.

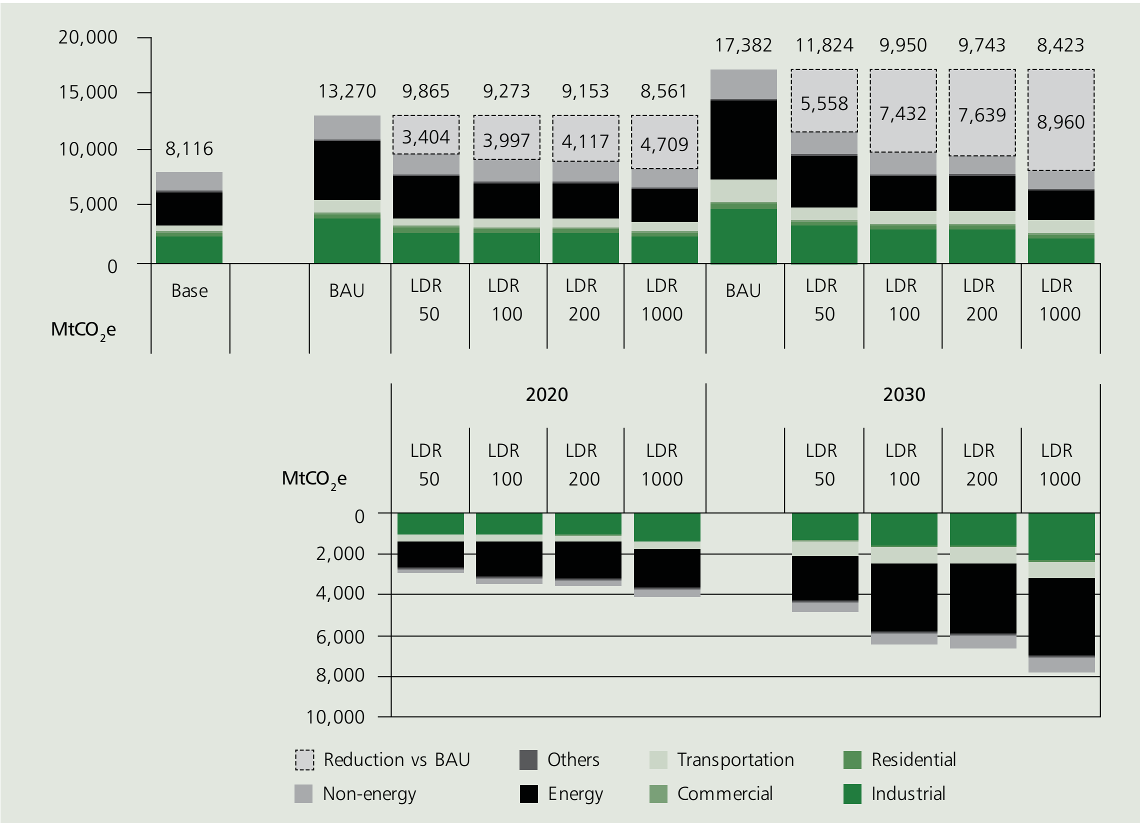
Source: Asian Development Bank project team.

as part of the overall abatement cost associated with each technology. Hence, use of a lower cost of capital means that more technologies will fall under the MAC ceiling, leading to a higher total level of abatement of greenhouse gas emissions.

Without mitigation, greenhouse gas emissions will increase rapidly in most of East Asia up to 2030

Without mitigation efforts, greenhouse gas emissions are expected to increase dramatically in the region. In 2030, under the BAU scenario, total greenhouse gas emissions are projected to increase 70% in the Republic of Korea, 114% in the PRC, and 90% in Mongolia compared to 2008. The projected growth of emissions under the BAU scenario for Japan is much lower (9%) because most of the service demands do not change much compared to 2008. In all four countries the energy sector is projected to make the largest contribution to greenhouse gas emissions (28% in Japan to 41% in the PRC) (Figure 10). In Japan and the PRC, the second-largest source of greenhouse gas emissions is the industry sector, while in the Republic of Korea the second-largest sector for emissions is transport because of the projected future increase in passenger and freight traffic. For Mongolia, agricultural emissions are projected to comprise 29% of greenhouse gas emissions because of the economic importance of agriculture. The vast majority of greenhouse gas emissions are projected to be CO_2: 87% in Japan, 88% in the Republic of Korea, 85% in the PRC, and 74% in Mongolia. Mongolia is an outlier in that 25% of

Figure 2B Emissions and Abatement Potential in the People's Republic of China under the Low Discount Rate Scenario



BAU = business-as-usual; LDR = low discount rate, long payback period scenario; $MtCO_2e$ = million tons of carbon dioxide equivalent.

Notes: See the description and definitions in the text.

Source: Asian Development Bank project team.

the greenhouse gas emissions are projected to be N_2O; this is attributable to agricultural sources such as fertilizer use, manure, and the burning of agricultural residues.

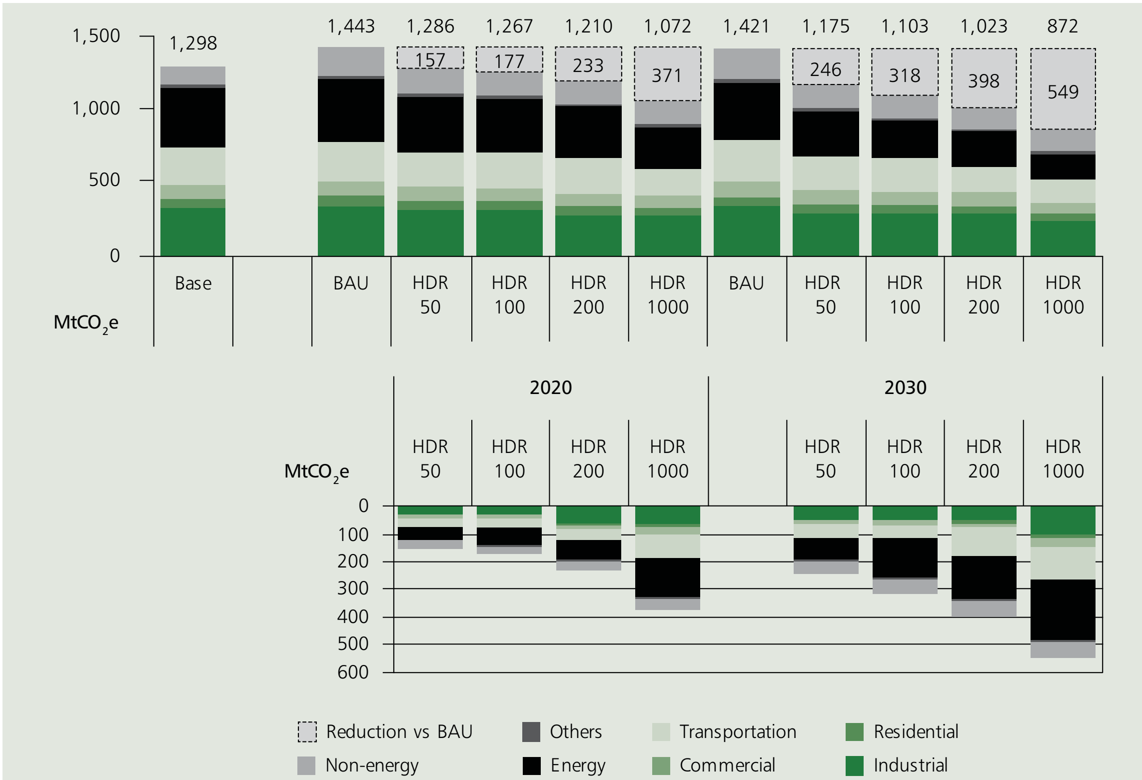
The maximum abatement potential in East Asia in 2030 exceeds the current annual energy-related emissions in the region

There is potential for significant emissions reduction in the region. The HDR scenario with a MAC ceiling of $1,000 per tCO_2e gives an indication of abatement potential up to 2030. The maximum level of abatement for East Asia is 5,300 $MtCO_2e$ in 2020 and 9,700 $MtCO_2e$ in 2030. In the PRC alone, the abatement potential is 4,700 $MtCO_2e$ in 2020 and 8,800 $MtCO_2e$ in 2030, or about 90% of the total for East Asia in each year.

To put these figures into perspective, total energy-related emissions in the four countries were 8,935 $MtCO_2e$ in 2010 (footnote 2). In all four countries in 2030, the energy sector[8] has the largest abatement potential—62% of the total in Mongolia, 48% in the PRC, 40% in Japan, and 37% in

8 In examining abatement potential across sectors, it should be noted that demand-side energy measures are counted in the residential and commercial sector.

Figure 3A Emissions and Abatement Potential in Japan under the High Discount Rate Scenario



BAU = business-as-usual; HDR = high discount rate, short payback period scenario; MtCO$_2$e = million tons of carbon dioxide equivalent.

Notes: See the description and definitions in the text.

Source: Asian Development Bank project team.

the Republic of Korea (Figure 7). The transport sector in the Republic of Korea represents 33% of the abatement potential because of the importance of this sector in the growth of the country's greenhouse gas emissions under the BAU scenario.

A large proportion of the abatement potential is "win–win"

Some of the abatement technologies considered have a negative marginal abatement cost per tCO$_2$e when compared to competing conventional technologies. What this means is that the alternative technology is more efficient and less costly per unit of output even when no weight is attached to any reduction in emissions. Thus, the abatement of greenhouse gas emissions is a "free" good in the sense that it would be appropriate to adopt the technology for economic reasons alone. Taking advantage of such opportunities is said to be a "no regrets" or "win-win" strategy in the sense that it yields both economic and environmental benefits.

Table 6 shows that, for the HDR high discount rate scenario in 2020, 53% of the abatement achievable in Japan with a MAC ceiling of $50 per tCO$_2$e in 2020 has a negative MAC; in the other countries the figures are 66% in the Republic of Korea, 22% in the PRC, and 41% in Mongolia. A higher proportion of abatement potential in Japan and the Republic of Korea can be achieved at a negative MAC because they are advanced economies with high labor costs and there is access to a variety of energy-efficient technologies in the building and transportation sectors. Still, in absolute terms, the opportunity for

Figure 3B Emissions and Abatement Potential in Japan under the Low Discount Rate Scenario

BAU = business-as-usual; LDR = low discount rate, long payback period scenario; $MtCO_2e$ = million tons of carbon dioxide equivalent.

Notes: See the description and definitions in the text.

Source: Asian Development Bank project team.

abatement at negative cost in the PRC is several times that of Japan and the Republic of Korea because its emissions are so much larger. The proportion of the abatement potential at negative cost decreases as the MAC ceiling is increased, simply because raising the ceiling includes more opportunities for abatement at a positive MAC.

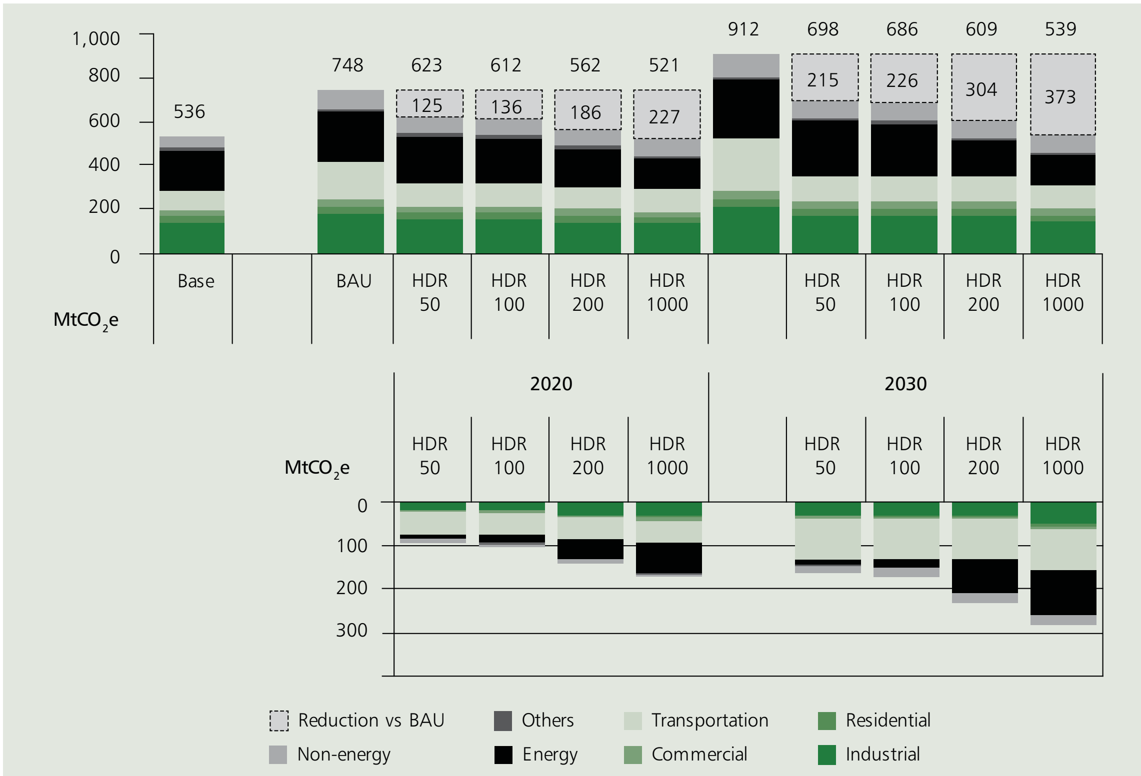
Abatement costs vary considerably across technologies

The marginal abatement cost (MAC) curves provide more detail on the specific technologies selected for a specific value of the MAC ceiling (Box 1). Figures 8A to 11B show the MAC curves in 2030 for a MAC ceiling of \$100 per tCO_2e under the high and low discount scenarios.

Figure 12 identifies the main abatement technologies by cost range for each country. Many of the negative-cost abatement options are energy-efficiency measures, including compact fluorescent lighting in the residential and building sectors; more efficient furnaces and advanced motors in industry; and various types of more efficient passenger car, trucks, and rail transport. Mid-priced abatement options (\$0–\$100 per tCO_2e) include biofuels in transport and more efficient industrial processes (e.g., steel production).

The adoption of emission-reducing technologies in the energy sector generally involves a positive cost of abatement with the notable exception of supercritical coal power generation coupled with carbon capture and storage for the PRC. Mid-priced options in the energy sector include some types of wind

Figure 4A Emissions and Abatement Potential in the Republic of Korea under the High Discount Rate Scenario



BAU = business-as-usual; HDR = high discount rate, short payback period scenario; $MtCO_2e$ = million tons of carbon dioxide equivalent.

Notes: See the description and definitions in the text.

Source: Asian Development Bank project team.

power and, in many cases, natural gas power generation. The latter offers a much greater potential for abatement in the PRC and Mongolia because Japan and the Republic of Korea already generate much higher proportions of their electricity from natural gas. For example, in 2009 Japan generated 27% of its electricity from natural gas and the Republic of Korea 15%, while the PRC generated only 1% and Mongolia none. Renewable energy is quite expensive in East Asia; photovoltaics, hydro power, and wind power with battery storage, for example, have marginal costs greater than \$100 per tCO_2e.

There are two points to note about the abatement potential in Japan and the Republic of Korea. The large abatement potential in the transport sector in the Republic of Korea is due to projected growth in traffic volume (Table 1C). Between 2008 and 2030, the volume of passenger traffic is projected to increase 34% and there are ample opportunities to deploy vehicles that are more efficient. The more advanced economies of Japan and the Republic of Korea have a larger abatement potential in the residential and commercial sectors because of greater opportunities to deploy energy efficiency improvements in areas such as lighting, refrigeration, and heating.

Reducing the discount rate does not alter most of the MAC curves in a major way but it does increase the range of negative-cost options in the residential and commercial sector in Japan.

Figure 4B Emissions and Abatement Potential in the Republic of Korea under the Low Discount Rate Scenario

BAU = business-as-usual; LDR = low discount rate, long payback period scenario; $MtCO_2e$ = million tons of carbon dioxide equivalent.
Notes: See the description and definitions in the text.
Source: Asian Development Bank project team.

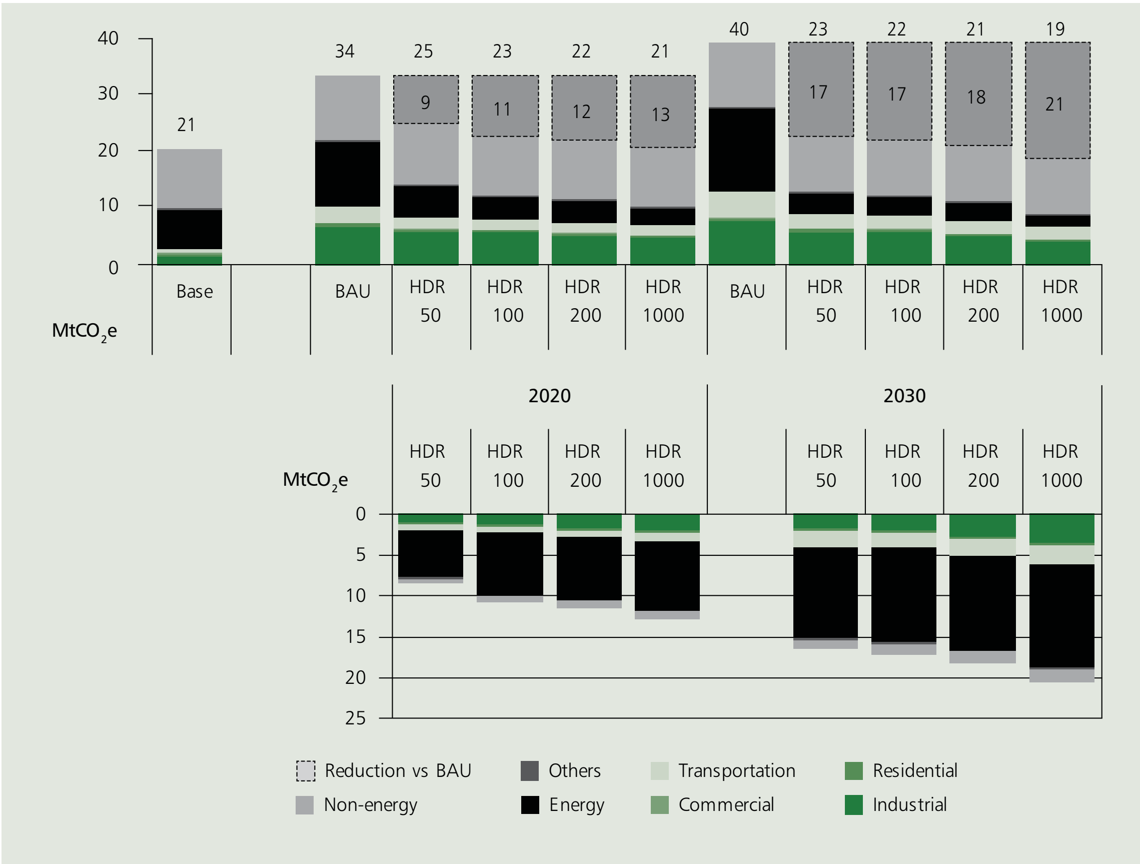
A delay now in implementing mitigation in the power sector in the People's Republic of China and Mongolia reduces the total future abatement potential

MAC curves allow policy makers to make a broad-brush ranking of abatement technologies, but there may be significant constraints on the adoption of the technologies which they identify and on the achievement of emissions abatement at the costs that have been projected.[9] As an illustration, the effective implementation of energy efficiency measures has proved to be notoriously difficult. Regulatory action on product specifications can ensure that energy-saving appliances and equipment are made available but households and firms may simply defer replacement of existing equipment if the alternatives are perceived as expensive or inconvenient.

The lock-in effect created by the existing capital stock is another reason why the abatement potential identified by MAC curves may not be realized in practice or within the time period under consideration.

[9] MAC curves do not generally take account of nonclimate-associated benefits, nonpecuniary costs, synergies between abatement technologies and actions, and the requirements for behavioral or institutional changes. Moreover, the costs reported are typically engineering costs, not the total programmatic costs needed to implement the technology.

Figure 5A Emissions and Abatement Potential in Mongolia under the High Discount Rate Scenario



BAU = business-as-usual; HDR = high discount rate, short payback period scenario; $MtCO_2e$ = million tons of carbon dioxide equivalent.

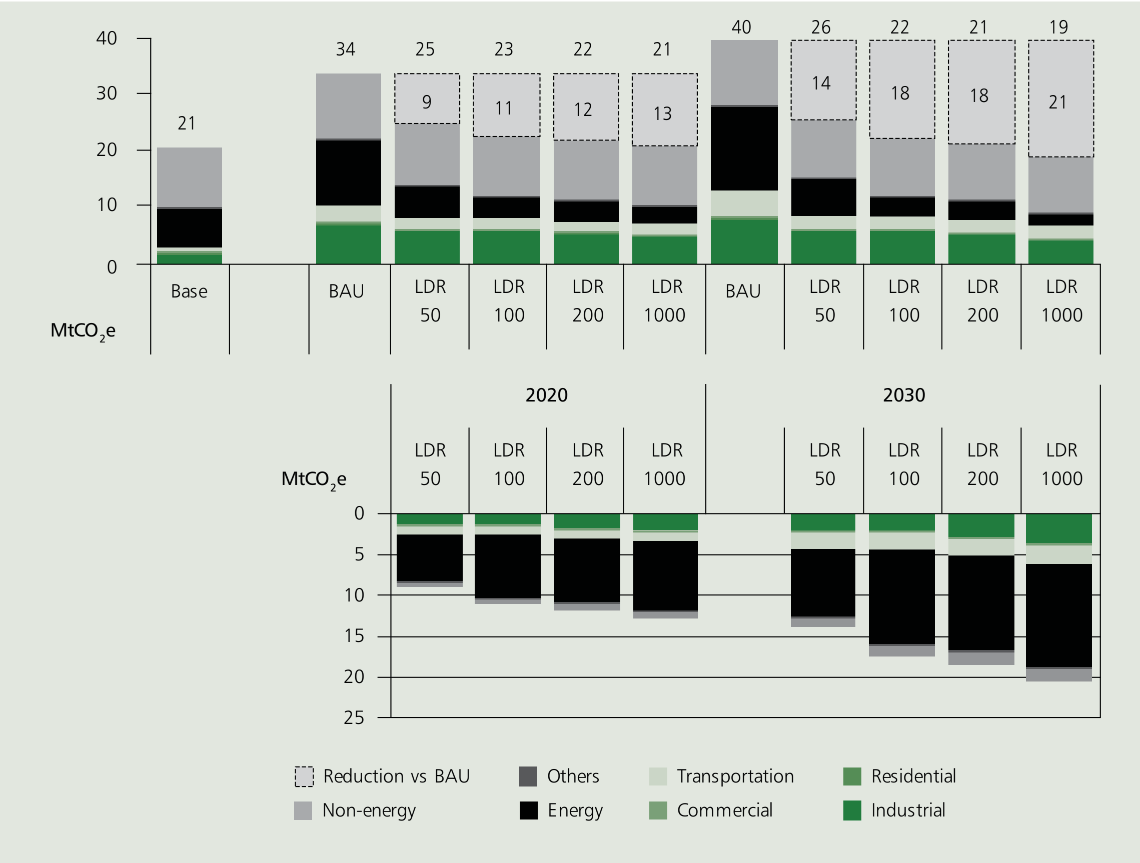
Notes: See the description and definitions in the text.

Source: Asian Development Bank project team.

Figures 13A–13D show the impact of a 5-year delay in the adoption of abatement options in the power sector of each country on total emissions in 2020 and 2030 under the HDR scenario. As in the earlier figures, emissions in the base year (2008) are shown as the column on the left-hand side of each block, followed by emissions in 2020 (upper part) or 2030 (lower part) in the BAU scenario. Then, for each value of the MAC ceiling, the levels of greenhouse gas emissions in 2020 or 2030 are shown under the assumptions that abatement options in the power sector are adopted without delay or only after a delay of 5 years. The figures given in the white boxes above the bars show the increase in emissions (i.e., reduction in abatement) due to the delay in adoption of abatement options in the power sector.

In Japan and the Republic of Korea, delaying mitigation in the power sector has a minimal effect because both countries already generate substantial amounts of high-efficiency natural gas thermal power. However, in the PRC and Mongolia the consequences of a 5-year delay are much more significant. The total abatement that can be realized with a MAC ceiling of $100 per tCO_2e is reduced by 10% in 2020 and by 15% in 2030 in the PRC with such a delay. In Mongolia, the equivalent reductions in abatement are 45% in 2020 and 22% in 2030, though the absolute numbers are quite small. For both countries, delay in the adoption of alternative generation technologies locks in reliance upon coal-fired power generation for 30 or more years ahead.

Figure 5B Emissions and Abatement Potential in Mongolia under the Low Discount Rate Scenario



BAU = business-as-usual; LDR = low discount rate, long payback period scenario; $MtCO_2e$ = million tons of carbon dioxide equivalent.

Notes: See the description and definitions in the text.

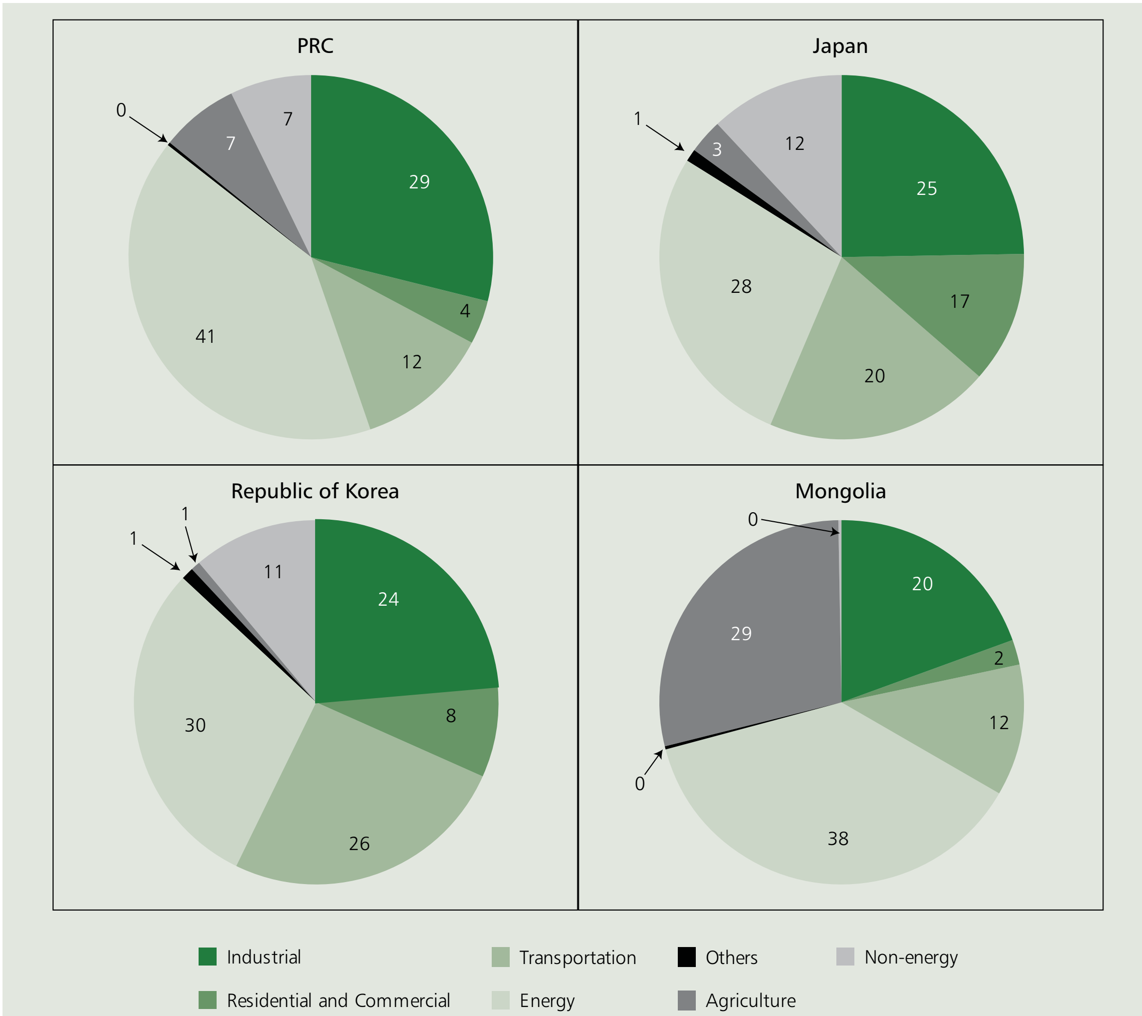
Source: Asian Development Bank project team.

The adoption of abatement options in the People's Republic of China will reduce growth in the country's imports of coal and oil but markedly increase its reliance upon imports of gas

Figures 14 and 15 illustrate how primary energy consumption in the PRC would change if alternative strategies for the abatement of greenhouse gas emissions were adopted. Under the BAU scenario, coal consumption in the PRC will increase 69% from 1,323 million tons of oil equivalent (Mtoe) in 2008 to 2,233 Mtoe in 2020, and by 121% to 2,918 Mtoe in 2030. If all of the abatement options identified for a MAC ceiling of $100 per tCO_2e in the HDR scenario were implemented, the increase in coal consumption would be only 11% by 2020 and 36% by 2030. Coal would account for 49% of the country's energy consumption in 2020 and 43% in 2030, rather than 64% in 2020 and 57% in 2030 under the BAU scenario. Growth in oil consumption would also be curbed by this strategy so that oil would only constitute 12% of the PRC's energy consumption in 2020 and 10% in 2030, instead of 17% in 2020 and 18% in 2030 under the BAU scenario.

Slower growth in coal and oil consumption translates into lower levels of imports. The PRC has the second-largest coal reserves in the world, but it became a net importer of coal in 2009. While imports

Figure 6 Sector Composition of Greenhouse Gas Emissions under Business-as-Usual Scenario, 2030 (%)



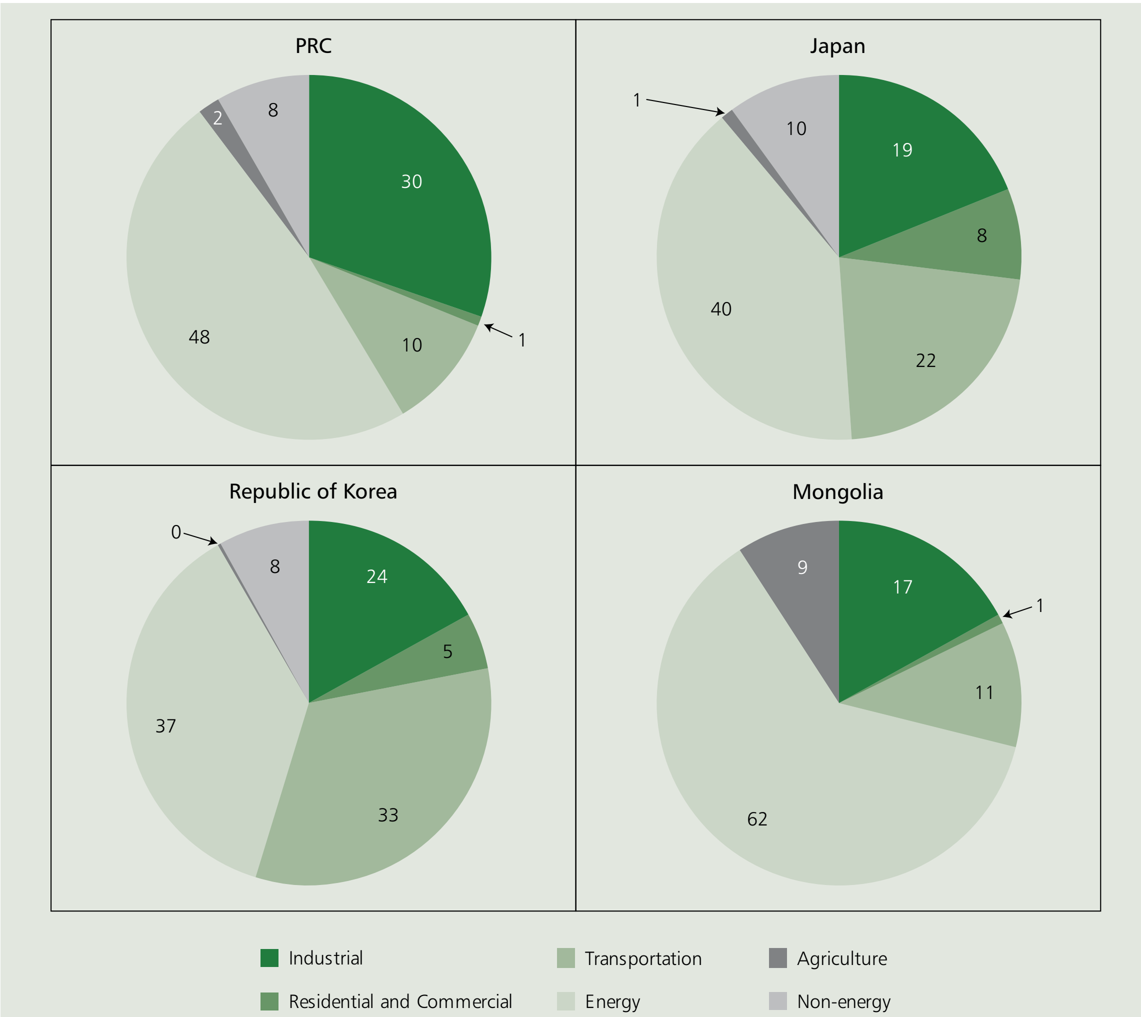
Source: Asian Development Bank project team.

only satisfied 4% of domestic primary demand in 2009, the PRC has become the world's second-largest coal importer after Japan, with total imports of 126 million tons of coal equivalent (Mtce) in 2010. International Energy Agency projections suggest that domestic production of coal in the PRC will increase by 0.9% per year up to 2035. In 2030, the PRC is expected to produce 2,710 Mtce of coal, far short of coal consumption in 2030 under the BAU scenario, so abatement of greenhouse gas emissions will reduce the country's dependence on imported coal. Similarly, the abatement strategy will reduce the PRC's dependence on imports of oil. Currently it imports more than half of the oil it consumes, and oil production is projected to decline 2.2% per year from 2010 to 2035.[10]

On the other hand, all of the abatement strategies lead to a shift in consumption from coal to natural gas. With a MAC ceiling of $100 per tCO_2e in the HDR scenario, the share of natural gas in the PRC's primary energy consumption would increase from about 2% in 2008 to 15% in 2020 and 25% in 2030.

10 International Energy Agency. *World Energy Outlook 2011*. Paris.

Figure 7 Sector Composition of Maximum Abatement Potential, 2030 (%)



Note: Results for the High Discount Rate Scenario in 2030 with $1,000 per tCO_2e MAC ceiling.
Source: Asian Development Bank project team.

The PRC is projected to produce about 252 billion cubic meters (or about 212 Mtoe[11]) of natural gas in 2030, which is far short of the domestic demand projected under any of the abatement scenarios. In effect, abatement will simply change the nature of the PRC's dependence on energy imports.

There are significant barriers to implementing negative-cost abatement technologies

The MAC curves presented above raise an obvious question: if negative-cost abatement options make economic sense, even in the absence of any greenhouse gas reduction, why aren't they more widely adopted? The answer is important in understanding the barriers that may delay or derail the adoption of abatement options.

[11] 1 Mtoe = 1.19 billion cubic meters of natural gas for the PRC. International Energy Agency.

Table 3 Proportion of Abatement Potential Achievable at a Negative Marginal Abatement Cost (%)

Scenario	Year and MAC Ceiling[a]	Japan	Republic of Korea	PRC	Mongolia
HDR	2020, $50	53	66	22	41
	2020, $100	47	54	14	14
	2020, $200	27	35	15	8
	2020, $1,000	17	27	12	7
	2030, $50	52	71	29	17
	2030, $100	40	66	21	13
	2030, $200	32	49	22	9
	2030, $1,000	18	36	17	8
LDR	2020, $50	79	72	32	43
	2020, $100	73	68	32	20
	2020, $200	59	54	31	15
	2020, $1,000	51	40	14	13
	2030, $50	68	68	41	42
	2030, $100	64	68	25	20
	2030, $200	64	63	24	16
	2030, $1,000	45	41	19	14

HDR = high discount rate, LDR = low discount rate, MAC = marginal abatement cost, PRC = People's Republic of China.

[a] MAC ceilings are in $ per ton of CO_2e.

Source: Asian Development Bank project team.

Box 1 How to Read a Marginal Abatement Cost (MAC) Curve

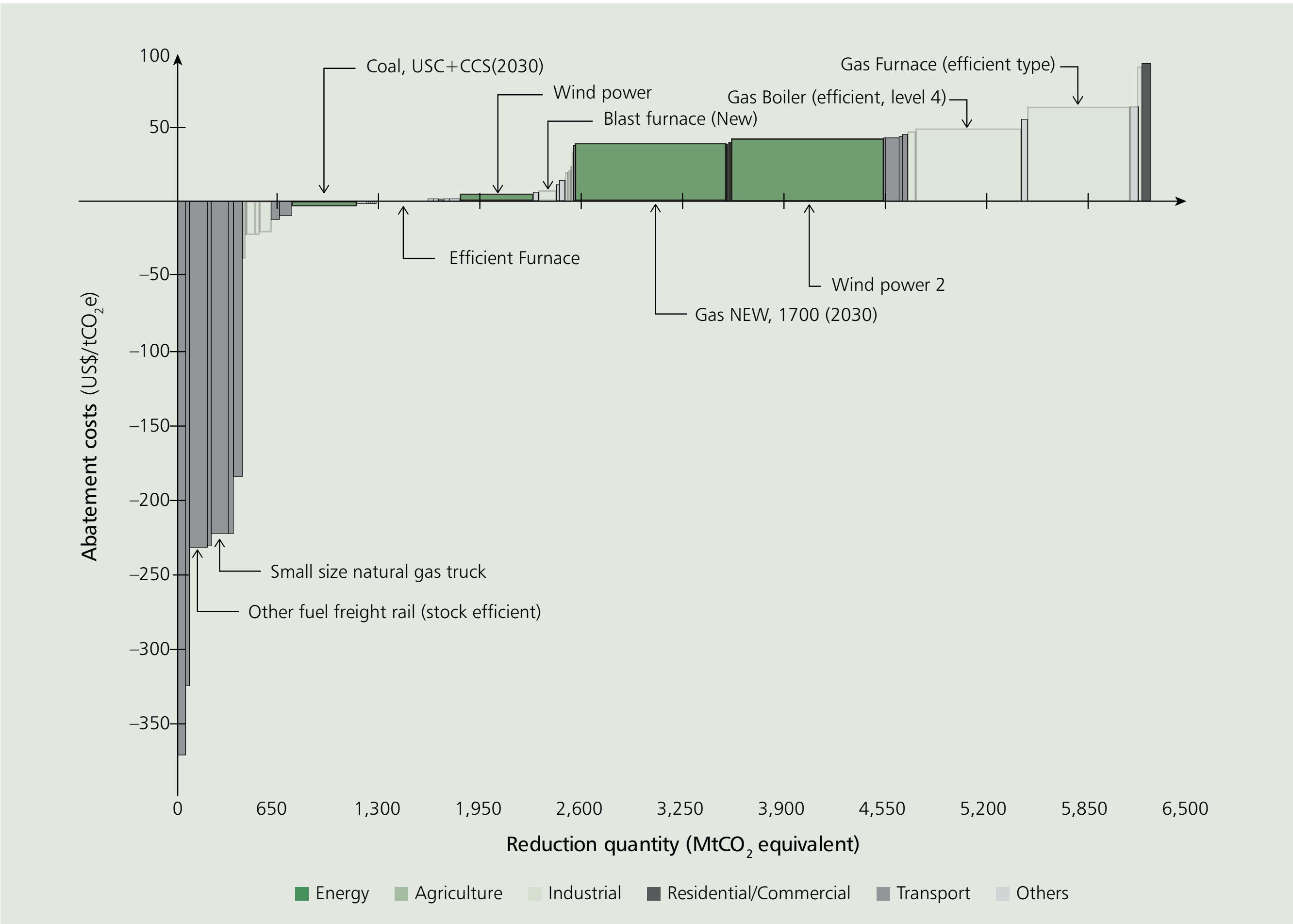
MAC curves are used by climate change analysts and decision makers as a tool to compare the cost-effectiveness of abatement options. The term "marginal cost" refers to the cost of reducing total greenhouse gas emissions by one additional unit. MAC curves can be displayed as histograms, where the abatement technologies are represented as bars and are organized in increasing order of abatement cost starting with the lowest cost options on the left-hand side and extending to the highest cost options included in the analysis.

Figures 8A to 11B illustrate the MAC curves for abatement potential up to a MAC ceiling of $100 per ton of carbon dioxide equivalent (tCO_2e) for each country under the high discount rate (HDR) and low discount rate (LDR) scenarios. The **width of each bar** indicates the abatement potential (in tCO_2e) of that technology. The **height of each bar** indicates the marginal abatement cost (dollars per tCO_2e). This is the net incremental cost of the abatement technology with regard to some conventional technology, divided by the reduction in emissions (tCO_2e) that results from adopting the alternate abatement technology of action.

The abatement cost covers both the capital cost of the technology amortized over its lifetime, and any operating and maintenance costs. Going from left to right, the technologies become more expensive. Some abatement technologies have a negative cost, which means that these technologies are more economic over their life than existing technologies, even without consideration of their contribution to reducing greenhouse gas emissions. The vertical axis extends from the lowest abatement cost to a maximum of $100 per tCO_2e, the ceiling on the abatement cost for the analysis. The horizontal axis extends from zero to the maximum abatement potential given the MAC ceiling.

Details of the full range of technologies incorporated into the model for consideration in constructing the MAC curves are given in Appendixes A and B. The color of each bar corresponds to the sector in which the technology is deployed. The 10 combinations of technology and sector which offer the greatest abatement potential for the scenario are labeled in each figure.

Figure 8A Marginal Abatement Cost Curve for the People's Republic of China for the High Discount Rate Scenario, 2030 (MAC ceiling of $100 per tCO_2e)



Gas NEW = Natural gas advanced combined cycle power plant, MAC = marginal abatement cost, tCO_2e = ton of carbon dioxide equivalent, USC + CCS = ultra supercritical plus carbon capture and storage.

Note: See Box 1 for details of how to interpret the curve.

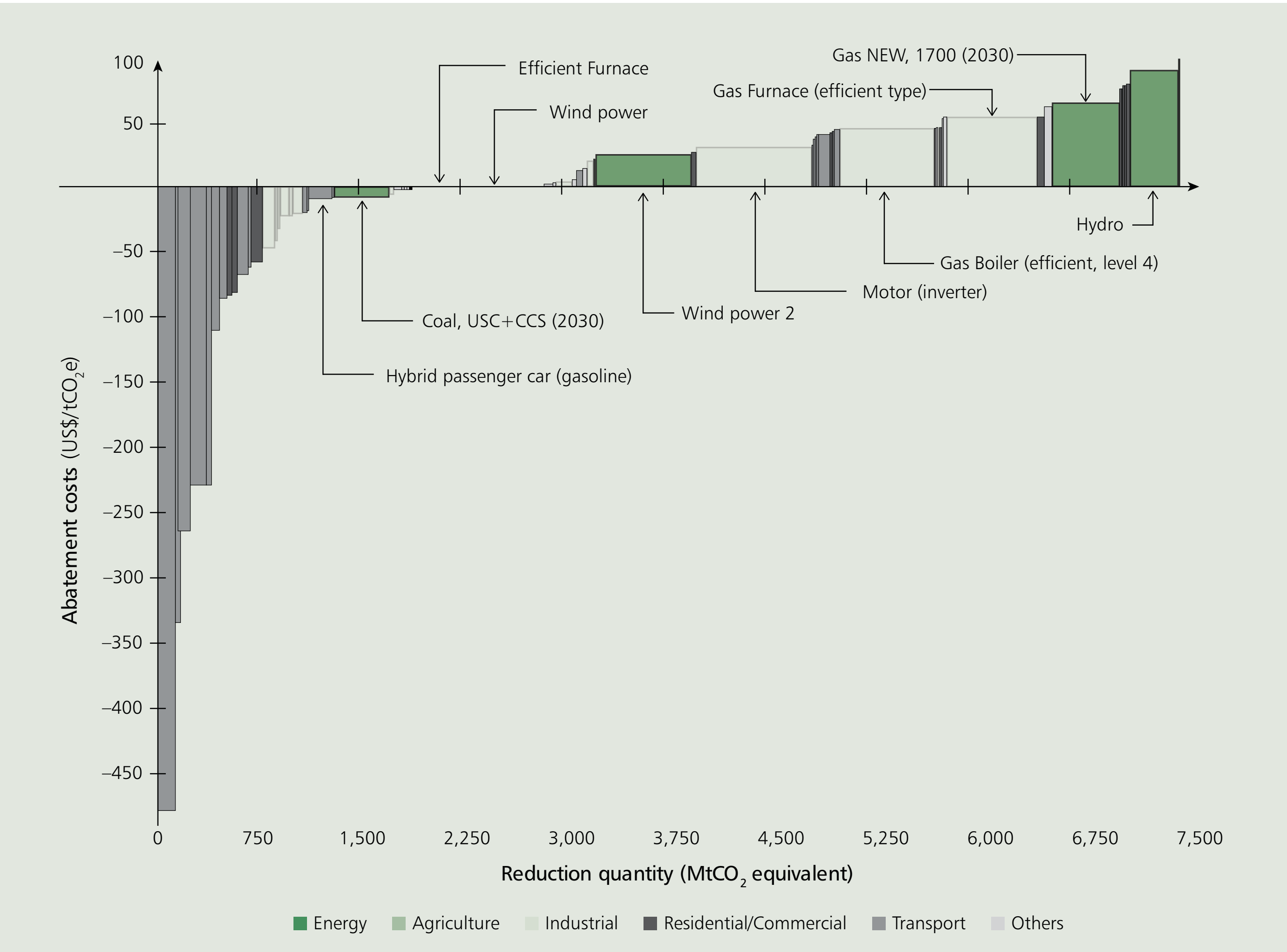
Source: Asian Development Bank project team.

Many of the negative-cost options are energy efficiency measures. Investment in energy efficiency may involve initial costs that are significantly greater than conventional technologies, which may be especially important if access to credit or investment funds is rationed. Other barriers include uninformed investors with little familiarity with energy efficient products; risk exposure; and the "principal agent" or "split incentive" problem, where one agent, such as a builder, bears the cost of installing equipment, while another, such as an owner or tenant, benefits from the lower electricity bills (Figure 16).[12]

In the PRC and Mongolia, some of the more important negative-cost options, such as more efficient coal furnaces, are in the industry sector. Direct or indirect subsidies for fossil fuel consumption can

[12] International Energy Agency. 2011. *25 Energy Efficiency Policy Recommendations: 2011 Update*. Paris; Sarkar, A. and J. Singh. 2010. Financing Energy Efficiency in Developing Countries—Lessons Learned and Remaining Challenges. *Energy Policy* 38: 5,560–71.

Figure 8B Marginal Abatement Cost Curve for the People's Republic of China for the Low Discount Rate Scenario, 2030 (MAC ceiling of \$100 per tCO_2e)



Gas NEW = Natural gas advanced combined cycle power plant, MAC = marginal abatement cost, tCO_2e = ton of carbon dioxide equivalent, USC + CCS = ultra supercritical plus carbon capture and storage.

Note: See Box 1 for details of how to interpret the curve.

Source: Asian Development Bank project team.

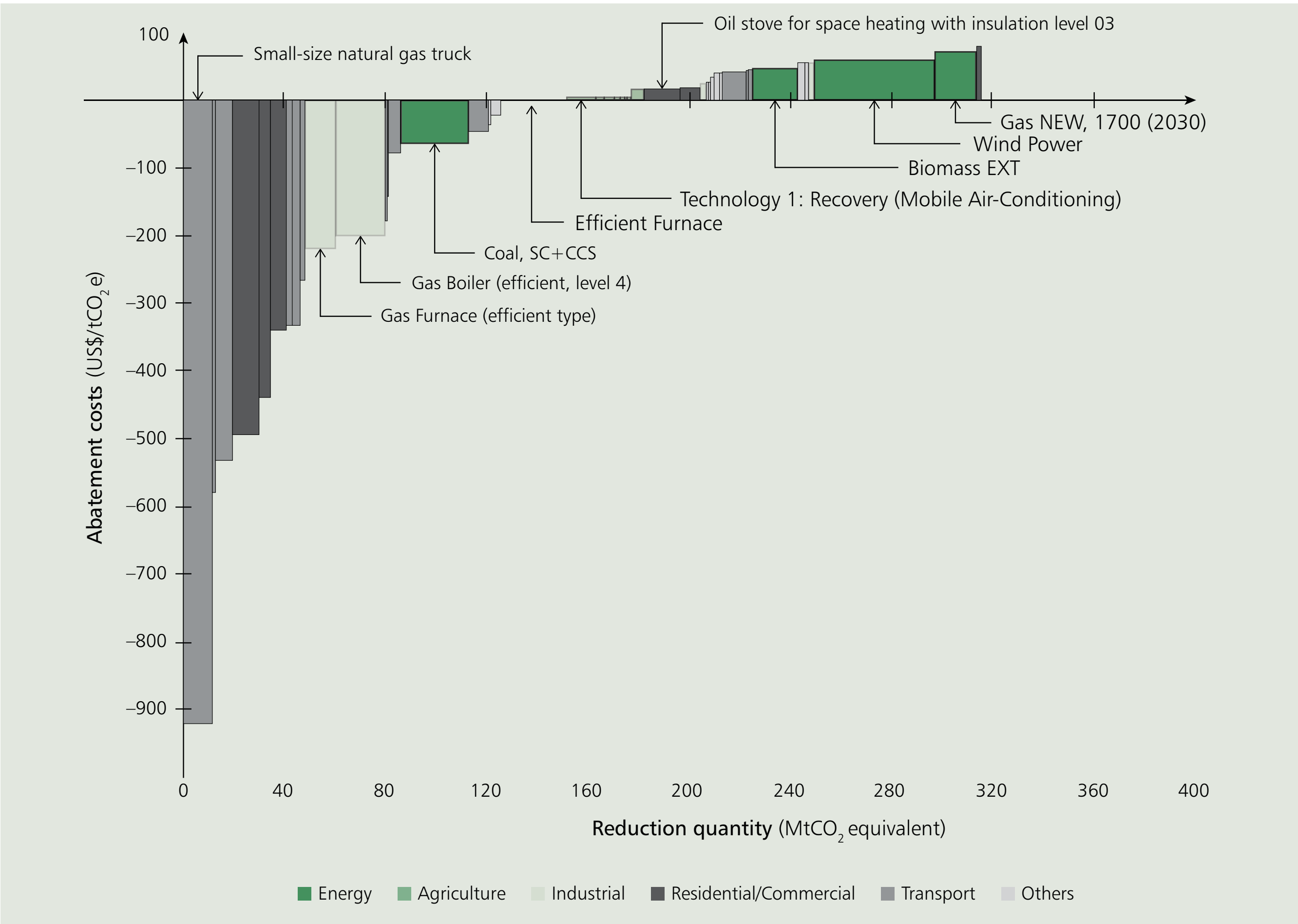
distort the long-term value of these technologies. In 2010, the PRC had the world's fourth-largest fossil fuel subsidies in the world at more than \$20 billion.[13]

Overall, those negative-cost technologies would benefit from financing to address the higher initial capital costs combined with regulation, such as minimum standards and labeling. The International Energy Agency has recommended 25 policy actions for energy efficiency (Table 4).

Japan's Top Runner Program is one example of an effective energy efficiency standards program. Begun in 1998, the program now covers 23 product categories, such as home appliances and motor vehicles. While many countries have introduced minimum efficiency performance standards, the most energy-efficient product on the market in Japan is the basis for the target standard. Producers must

[13] International Energy Agency. *World Energy Outlook 2011*. Paris.

Figure 9A Marginal Abatement Cost Curve for Japan for the High Discount Rate Scenario, 2030 (MAC ceiling of $100 per tCO_2e)



Biomass EXT = Existing biomass combustion for power generation, Gas NEW = Natural gas advanced combined cycle power plant, MAC = marginal abatement cost, SC + CCS = supercritical plus carbon capture and storage, tCO_2e = ton of carbon dioxide equivalent.

Note: See Box 1 for details of how to interpret the curve.

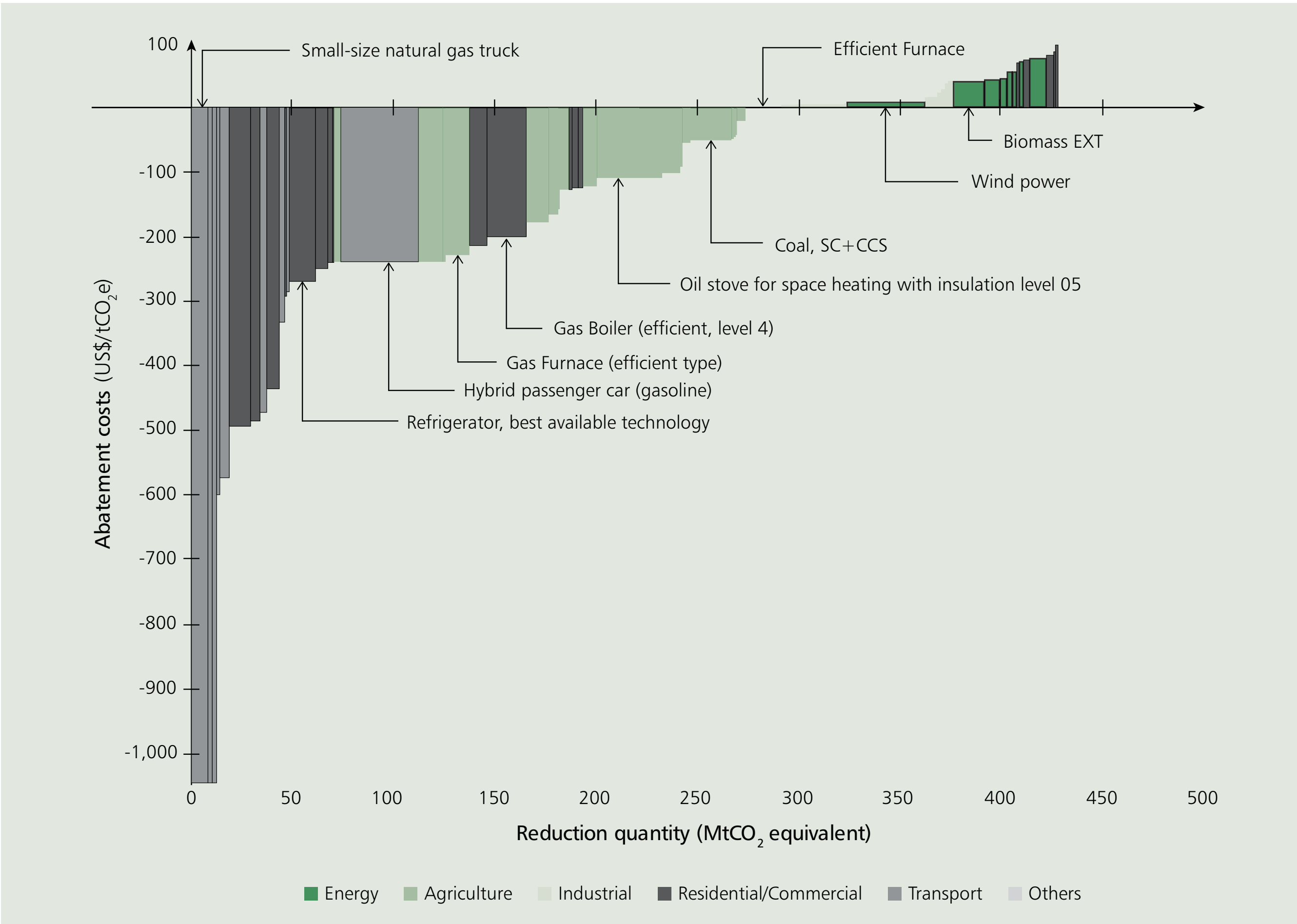
Source: Asian Development Bank project team.

ensure that the weighted-average energy efficiency of their products meets the standard in the target year. To date, no enforcement actions have been taken, as targets have been systematically met or exceeded. According to some estimates, the Top Runner Program has reduced energy consumption by 5% in road transport and by 8% in the residential sector.[14]

While changing a country's pattern of energy consumption and efficiency is a long-term undertaking, recent events in Japan after the Fukushima Daichi nuclear disaster show how quickly behavior in a country can change in response to a crisis (Box 2).

14 Kawamata, K. 2011. *Japan Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report). Manila.

Figure 9B Marginal Abatement Cost Curve for Japan for the Low Discount Rate Scenario, 2030 (MAC ceiling of $100 per tCO_2e)



Biomass EXT = Existing biomass combustion for power generation, MAC = marginal abatement cost, SC + CCS = supercritical plus carbon capture and storage, tCO_2e = ton of carbon dioxide equivalent.

Note: See Box 1 for details of how to interpret the curve.

Source: Asian Development Bank project team.

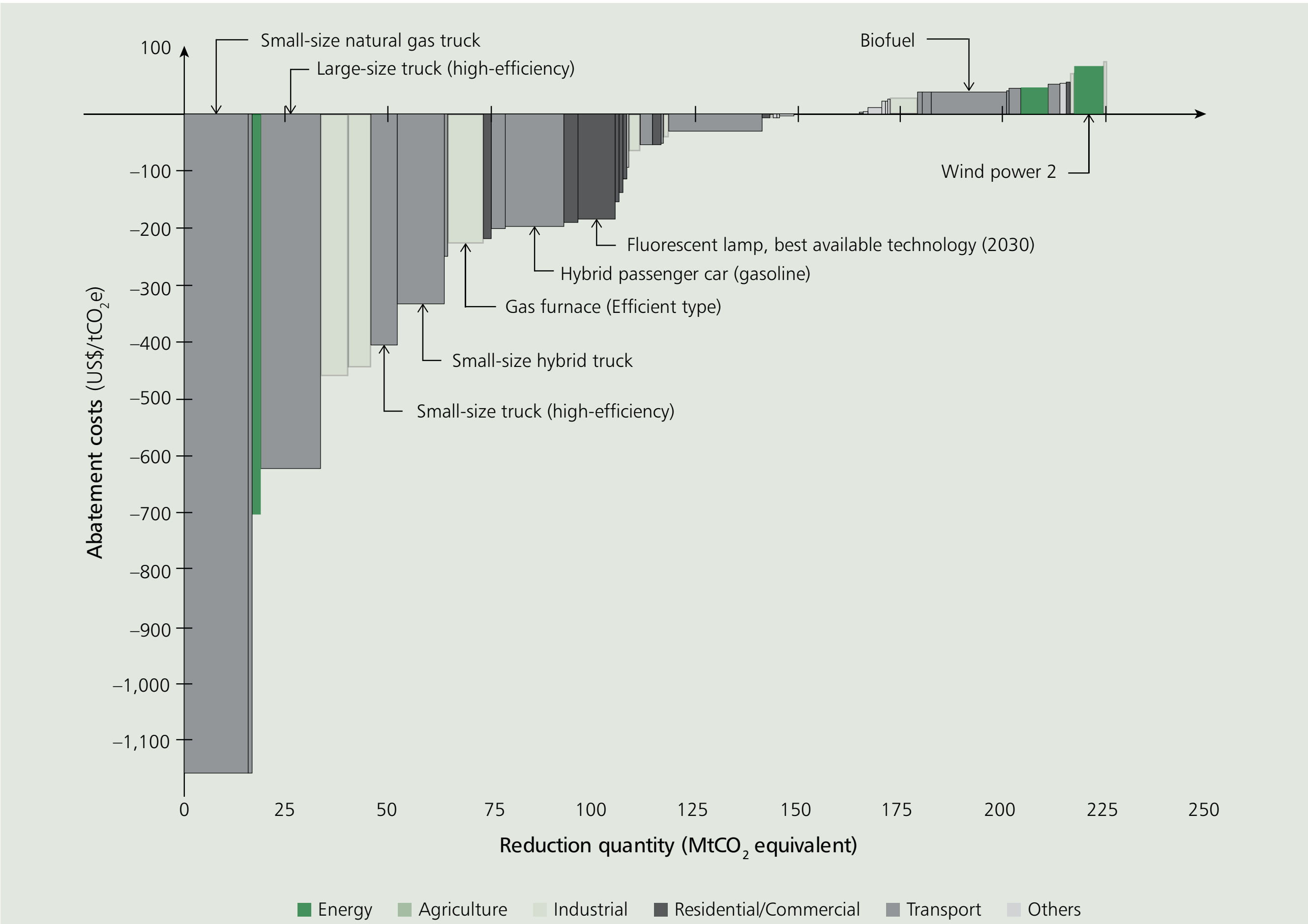
The MAC curves suggest that abatement costs rise sharply above $100 per ton of carbon dioxide equivalent

The MAC curve analysis allows the countries in the region to prioritize abatement technologies and tailor different policies based on costs. The technologies with moderate abatement costs less than $100 per tCO_2e are at the edge of competitiveness. Financial measures such as subsidies or implementation of a carbon tax or carbon markets would support their adoption and dissemination. However, it is unlikely that carbon markets in East Asia will promote deployment before 2030 of technologies that have marginal costs greater than $100 per tCO_2e. For example, the price of 1 tCO_2e for the European Union's emission trading scheme (EU Allowance Unit) was €30 ($47) in 2008, but now the price is persistently under €10.[15] The Australian carbon pricing mechanism was fixed at $23 per ton in 2012–2013.[16]

15 As of August 2013. http://www.bloomberg.com/markets/

16 http://www.cleanenergyregulator.gov.au/Carbon-Pricing-Mechanism/Pages/default.aspx

Figure 10A Marginal Abatement Cost Curve for the Republic of Korea for the High Discount Rate Scenario, 2030 (MAC ceiling of $100 per tCO_2e)



MAC = marginal abatement cost, tCO_2e = ton of carbon dioxide equivalent.

Note: See Box 1 for details of how to interpret the curve.

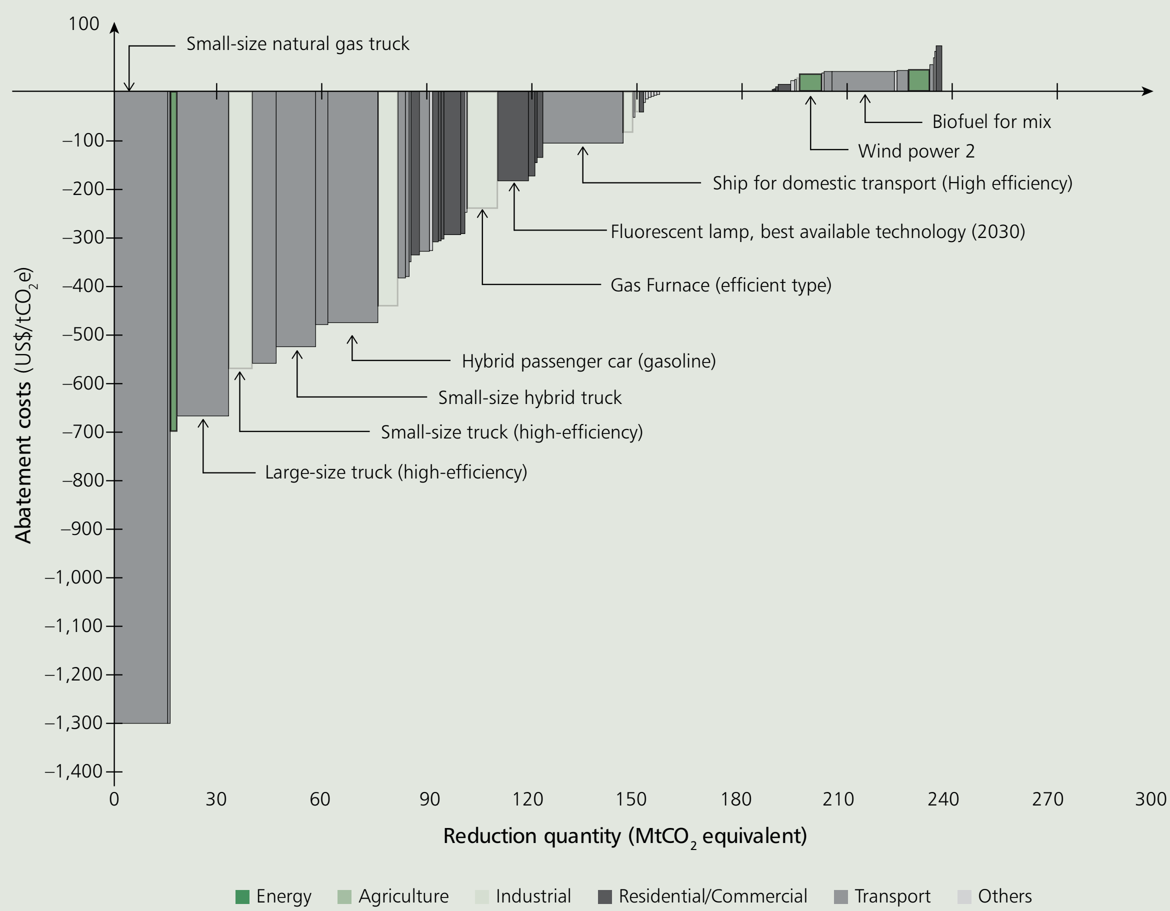
Source: Asian Development Bank project team.

If countries decide that they wish to set targets for reducing greenhouse gas emissions that go further than the abatement options that are or will be competitive with a MAC ceiling of $100 per tCO_2e, the MAC curves indicate that marginal abatement costs start to rise quite sharply, at least up to 2030. Relying upon carbon pricing to promote the adoption of expensive abatement options will involve a heavy penalty for many industries and may be difficult to sustain. Hence, targeted policies that are designed to promote the development and commercialization of new abatement options and low-carbon technologies may be more effective than reliance upon carbon pricing alone.

Mitigation in the People's Republic of China and Mongolia has important health co-benefits

The marginal abatement cost (MAC) curves presented in this chapter only consider the capital and operating costs of technologies, not externalities such as health costs. The World Health Organization has estimated that around 300,000 premature deaths occur in the PRC annually because of outdoor

Figure 10B Marginal Abatement Cost Curve for the Republic of Korea for the Low Discount Rate Scenario, 2030 (MAC ceiling of \$100 per tCO_2e)



MAC = marginal abatement cost, tCO_2e = ton of carbon dioxide equivalent.

Note: See Box 1 for details of how to interpret the curve.

Source: Asian Development Bank project team.

urban air pollution.[17] In 2003, the health damages associated with particulate matter (PM_{10})[18] in the PRC (the costs of chronic bronchitis, premature mortality, and respiratory and cardiovascular hospital admissions) was calculated to be 3.8% of GDP.[19] For Beijing, the costs of mortality and morbidity due to PM_{10} have been estimated at between \$1.7 billion and \$3.7 billion annually, accounting for about 6.6% of Beijing's GDP each year.[20] It should be noted that the PRC has made some progress in combating air pollution over the past decade; PM_{10} concentrations country-wide fell 29% from 2000

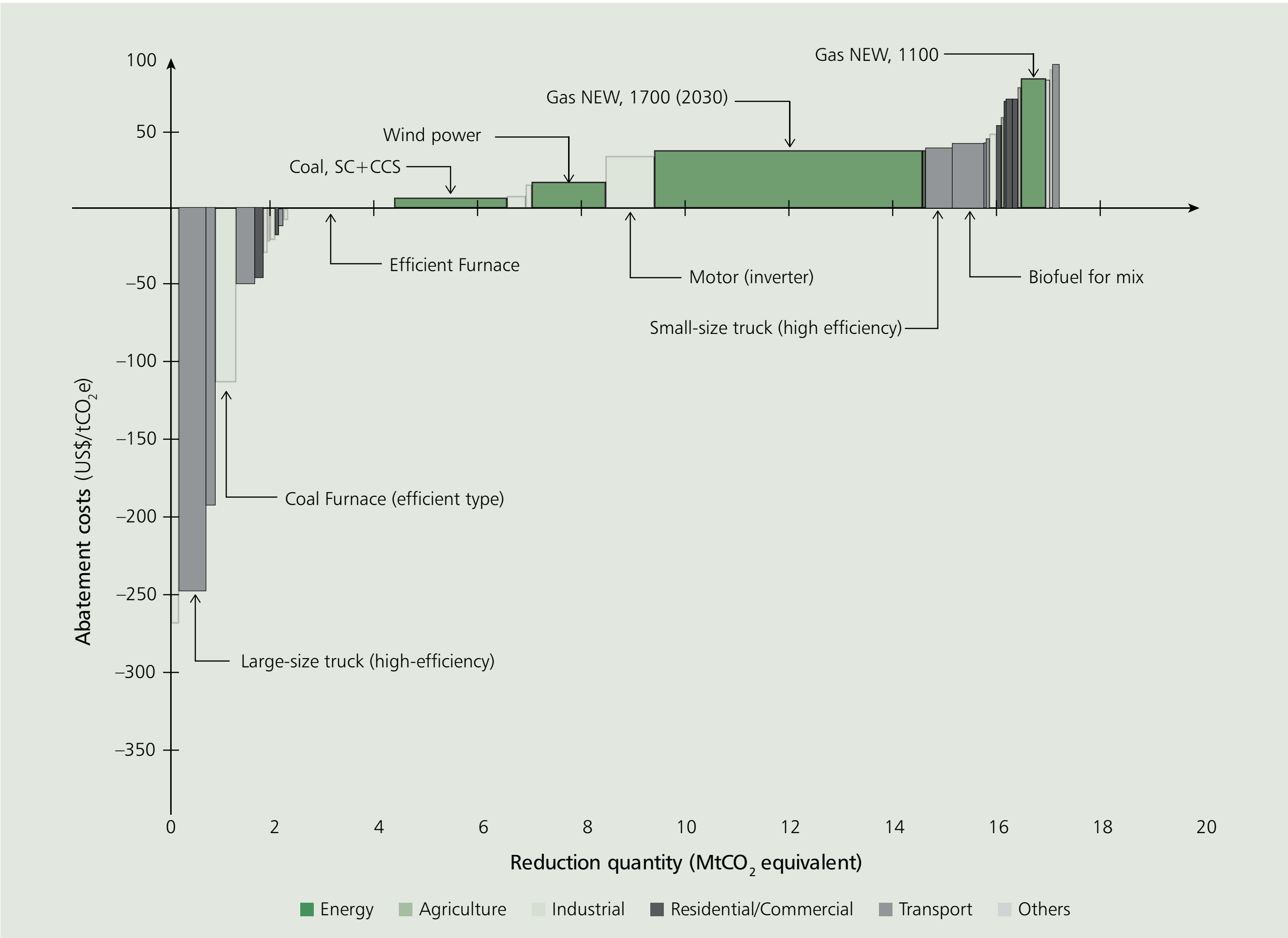
[17] Cohen, A. R. et al. Urban Air Pollution. 2004. In *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors* Vol. 2. Edited by Ezzati, M. et al. Geneva: World Health Organization.

[18] PM_{10} is the concentration of particulates less than 10 microns in size. Source: World Bank World Development Indicators.

[19] Assuming a statistical value of life of CNY1 million and using the willingness-to-pay approach. World Bank. 2007. *Cost of Pollution in [the People's Republic of] China: Economic Estimates of Physical Damages*. Washington, DC.

[20] Zhang, M., Y. Song, and X. Cai. 2007. A Health-Based Assessment of Particulate Air Pollution in Urban Areas of Beijing in 2000–2004. *Science of the Total Environment* 376: 100–108.

Figure 11A Marginal Abatement Cost Curve for Mongolia for the High Discount Rate Scenario, 2030 (MAC ceiling of $100 per tCO_2e)



Gas NEW = Natural gas advanced combined cycle power plant, MAC = marginal abatement cost, SC + CCS = supercritical plus carbon capture and storage, tCO_2e = ton of carbon dioxide equivalent.

Note: See Box 1 for details of how to interpret the curve.

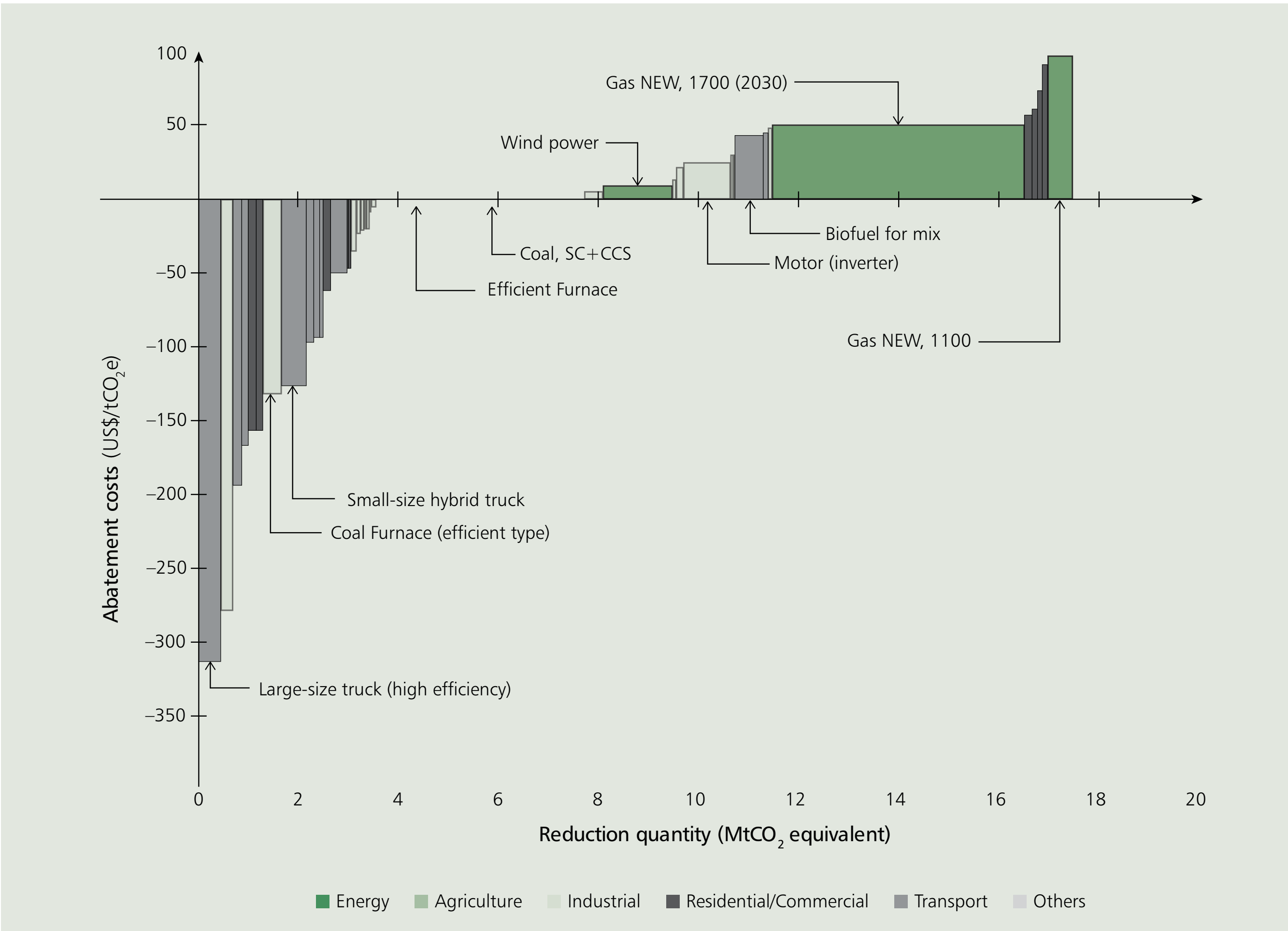
Source: Asian Development Bank project team.

to 2008.[21] However, Beijing continues to have extreme pollution "episodes." In mid-January 2013, for example, monitoring stations of the Beijing Municipal Environmental Monitoring Center showed $PM_{2.5}$ concentrations of over 900 micrograms per cubic meter at some locations, far beyond the thresholds that are considered acceptable according to international guidelines.[22] Thus, for the first time in its history, the city had to adopt its emergency response plan for extreme air pollution and issue an orange-level haze warning. Box 3 discusses the extent to which policies designed to address problems

[21] World Bank World Development Indicators, http://databank.worldbank.org/. Accessed 29 January 2012.

[22] The WHO recommends a guideline of 25 micrograms per cubic meter ($\mu g/m^3$) for $PM_{2.5}$ averaged over a 24-hour period and proposes an interim target of 75 $\mu g/m^3$ that is associated with a 5% increase in short-term mortality. WHO 2006. *Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide: Global Update 2005.* Geneva: World Health Organization. The US National Ambient Air Quality Standards, last revised in December 2012, set a primary standard for the level of $PM_{2.5}$ averaged over a 24-hour period of 35 $\mu g/m^3$ that should not be exceeded on more than 7 days per year averaged over 3 years (78 FR 3086 January 15, 2013).

Figure 11B Marginal Abatement Cost Curve for Mongolia for the Low Discount Rate Scenario, 2030 (MAC ceiling of $100 per tCO_2e)



Gas NEW = Natural gas advanced combined cycle power plant, MAC = marginal abatement cost, SC + CCS = supercritical plus carbon capture and storage, tCO_2e = ton of carbon dioxide equivalent.

Note: See Box 1 for details of how to interpret the curve.

Source: Asian Development Bank project team.

of urban air quality overlap with measures to reduce CO_2 emissions. While some policies, particularly switching from coal to gas, can make a substantial contribution to both objectives, there are important differences in time scale which need to be considered when developing short and longer term plans.

If the health benefits of mitigation technologies were factored into their costs, many of them would be even more competitive with conventional, more polluting technologies. One study in Shanxi province evaluated various coal-related abatement options: coal washing and briquetting, modified boiler design, boiler replacement, improved boiler management, and cogeneration of heat and electricity.[23] Three of the measures had positive abatement costs, but when the local health benefits of reduced particulate matter are included, all of the measures had net economic benefits.[24] Surveying a suite

23 Of these, the AIM Enduse model database includes modified boiler design, replacement, and improved boiler management.

24 Aunana, K. et al. 2004. Co-benefits of Climate Policy—Lessons Learned from a Study in Shanxi, [the PRC]. *Energy Policy* 32: 567–81.

Figure 12 Grouping of Abatement Options by Cost Range, High Discount Rate Scenario in 2030 (MAC ceiling of $1,000 per tCO_2e)

	Japan	Republic of Korea	PRC	Mongolia
High	[E] Photovoltaic, hydro [I] Boiler (renewable) [T] Hybrid car (diesel, gas) [RC] Gas/coal stove/coal boiler (space heating)	[E] Photovoltaic, wind power 3 [I] Boiler (renewable) [RC] Gas/coal stove/coal boiler (space heating)	[E] Hydro, wind power 3, wind + storage [I] Boiler (renewable) [T] Hybrid car (gas, diesel)/bus, efficient gas car [RC] AC, biomass/coal stove/coal boiler (space heating)	[E] Hydro, wind + storage [I] Boiler (renewable) [T] Hybrid truck/car (gas, diesel)/bus, efficient gas car [RC] AC, biomass/coal stove/coal boiler (space heating)
$100				
Mid	[E] Biomass, wind power, Gas (NEW, 1,700) [I] Efficient gas furnace [T] Biofuels	[E] Biomass, wind power 2, coal (SC + CCS) [I] More efficient steel processes [T] Biofuels, hybrid bus	[E] Gas, (NEW, 1,700), wind power 2 [I] More efficient steel processes [T] Biofuels	[E] Coal (SC + CC), wind power, gas (NEW, 1,700) [I] More efficient steel processes [T] Biofuels [RC] Gas stove (space heating)
$0				
Low	[E] Coal (SC + CCS) [I] Efficient gas furnace, advanced motors [T] Efficient truck/ bus, natural gas truck, efficient rail [RC] CFL, FL lighting	[I] Efficient gas furnace [T] Efficient truck, hybrid truck/ car (gas, diesel, efficient rail) [RC] CFL, FL lighting	[E] Coal (USC + CCS) [I] Advanced motors [T] Natural gas trucks, efficient trucks, efficient rail [RC] CFL, FL lighting	[I] Advanced motors [T] Efficient/electric rail, efficient trucks [RC] CFL, FL lighting

AC = air conditioning, CCS = carbon capture and storage, CFL = compact fluorescent lighting, E = Energy, FL = fluorescent lighting, I = Industry, MAC = Marginal Abatement Cost, PRC = People's Republic of China, RC = Residential and Commercial Buildings, SC = supercritical, T = Transport, tCO2e = ton of carbon dioxide equivalent, USC = ultra-supercritical. .

Note: See Appendix B for details of technologies.

Source: Asian Development Bank project team.

of studies, Vennemo et al. (2006) estimate that 34–161 lives are saved for each million tons of CO_2 reduced in the PRC energy sector.[25] In Shanghai, measures to reduce PM_{10} could reduce premature deaths by 9,870–23,100.[26]

The health co-benefits of mitigation are not limited to the PRC. In Ulaanbaatar, Mongolia the PM_{10} concentration during winter is estimated to be 3–6 times higher than the levels recommended in Europe and North America, and 10–20 times higher than the World Health Organization's recommended standards.[27]

A carbon trading system covering East Asia could make mitigation more cost-effective

Most of the potential for abatement in East Asia is in the PRC. If all technologies with abatement costs of less than $100 per tCO_2e under the HDR scenario are considered, over 90% of the emissions reduction potential in the region in 2030 is in the PRC. What is particularly important is that the potential for reducing emissions at abatement costs of between $0 and $100 per tCO_2e in the PRC in 2030 is about 19 times the potential in this range for Japan and the Republic of Korea combined. It would be much more cost-effective for Japan and the Republic of Korea to offset their national

[25] The range is the 15% to 85% confidence interval. Vennemo, H. et al. 2006. Domestic Environmental Benefits of [the People's Republic of] China's Energy-Related CDM Potential. *Climatic Change* 75: 215–39.

[26] Chen, C. Et al. 2007. Low-Carbon Energy Policy and Ambient Air Pollution in Shanghai, [the PRC]: A Health-Based Economic Assessment. *Science of the Total Environment* 373: 13–21.

[27] Kamata, T. et al. 2010. *Mongolia: Enhancing Policies and Practices for Ger Area Development in Ulaanbaatar.* Washington, DC: World Bank.

Figure 13A Impact of 5-Year Delay for the Power Sector in the People's Republic of China (greenhouse gas emissions in $MtCO_2e$)

$MtCO_2e$ = million tons of carbon dioxide equivalent.

Note: See the description and definitions in the text.

Source: Asian Development Bank project team.

emissions by engaging in mitigation in the PRC. A regional carbon market could provide a framework for this in East Asia. However, to date, no country in the region has a country-wide mandatory cap-and-trade scheme, and there would be many strategic issues related to the design of such a market, including the nature of targets, the sector scope, and the allocation of allowances (Box 4).

Figure 13B Impact of 5-Year Delay for the Power Sector in Japan
(greenhouse gas emissions in $MtCO_2e$)

$MtCO_2e$ = million tons of carbon dioxide equivalent.
Note: See the description and definitions in the text.
Source: Asian Development Bank project team.

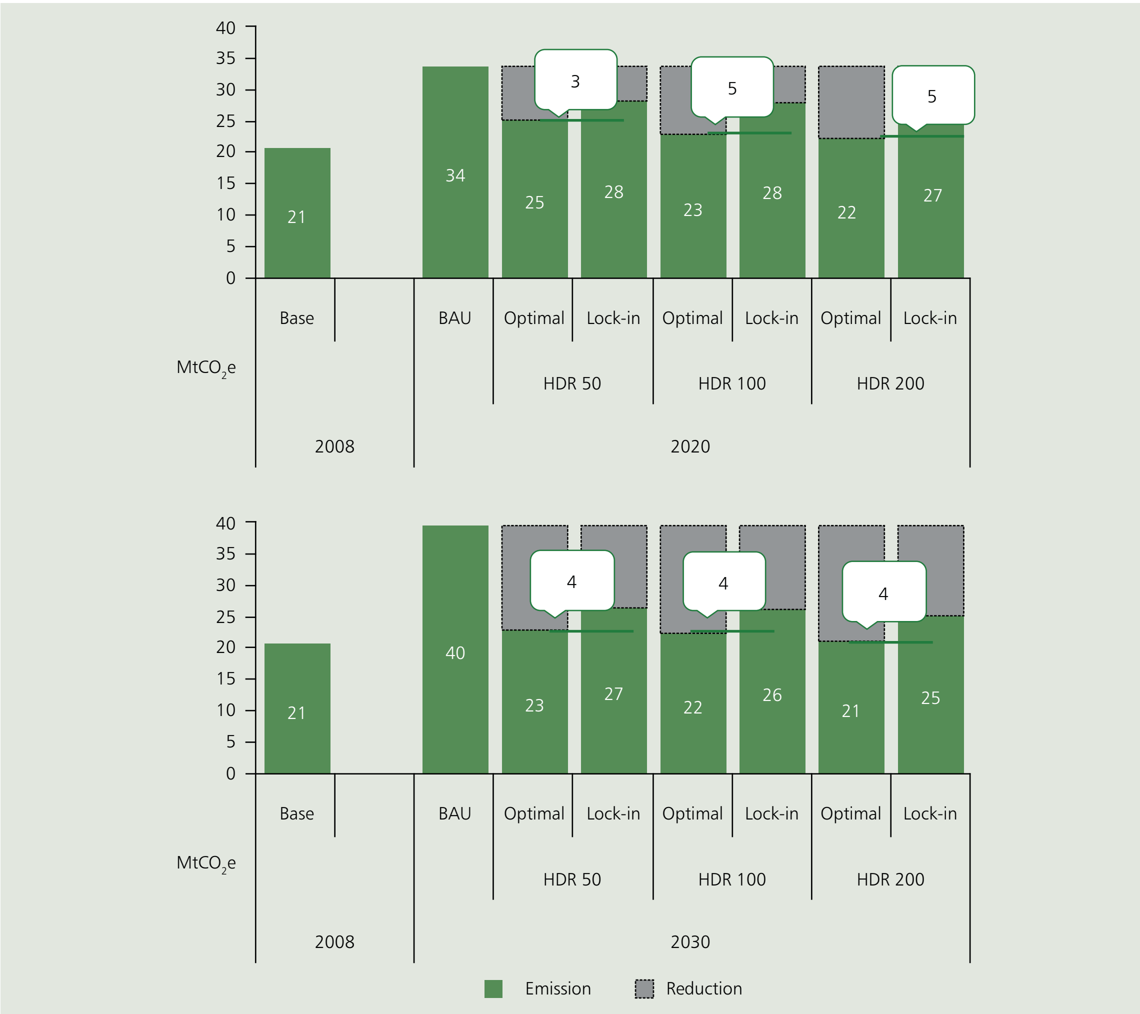
Figure 13C Impact of 5-Year Delay for the Power Sector in the Republic of Korea (greenhouse gas emissions in $MtCO_2e$)

$MtCO_2e$ = million tons of carbon dioxide equivalent.

Note: See the description and definitions in the text.

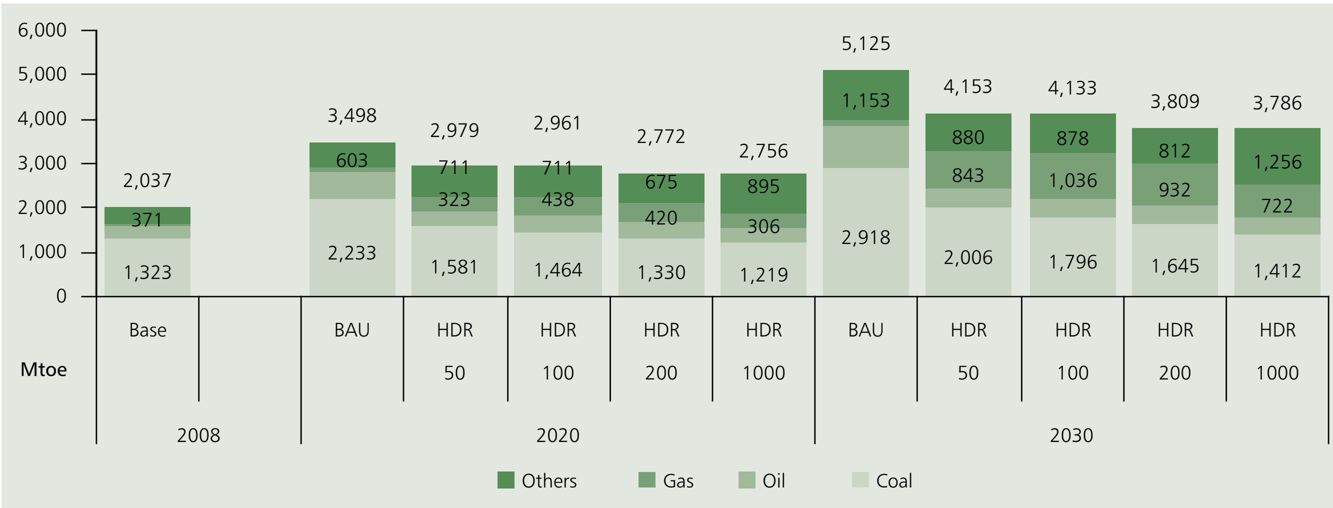
Source: Asian Development Bank project team.

Figure 13D Impact of 5-Year Delay for the Power Sector in Mongolia
(greenhouse gas emissions in $MtCO_2e$)



$MtCO_2e$ = million tons of carbon dioxide equivalent.
Note: See the description and definitions in the text.
Source: Asian Development Bank project team.

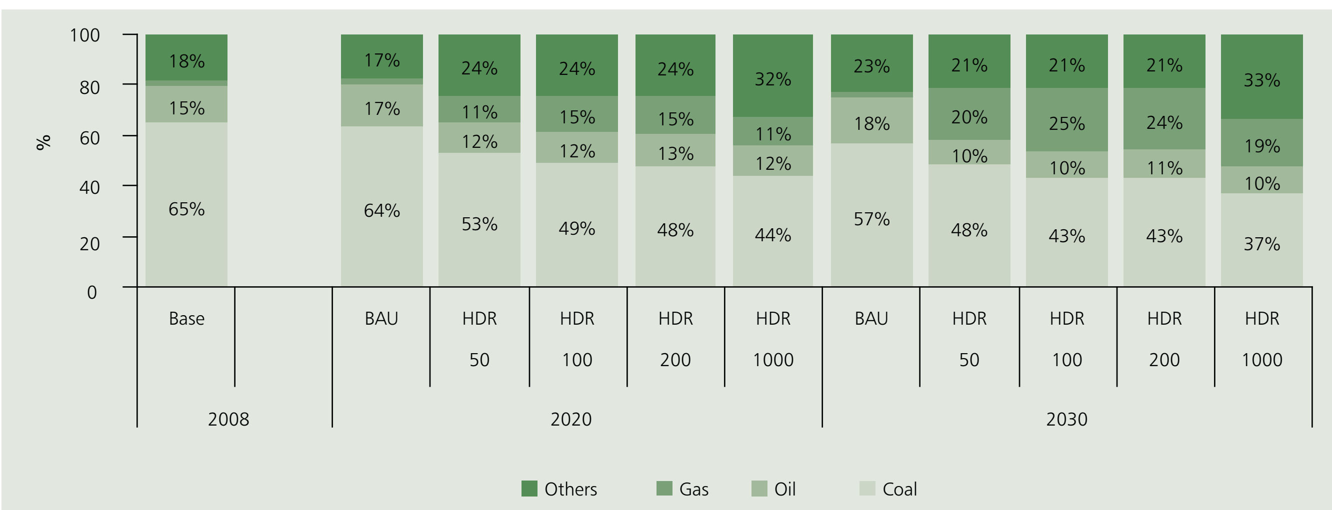
Figure 14 Primary Energy Consumption in the People's Republic of China under Alternative Abatement Strategies (million tons of oil equivalent)



Note: See the description and definitions in the text.

Source: Asian Development Bank project team.

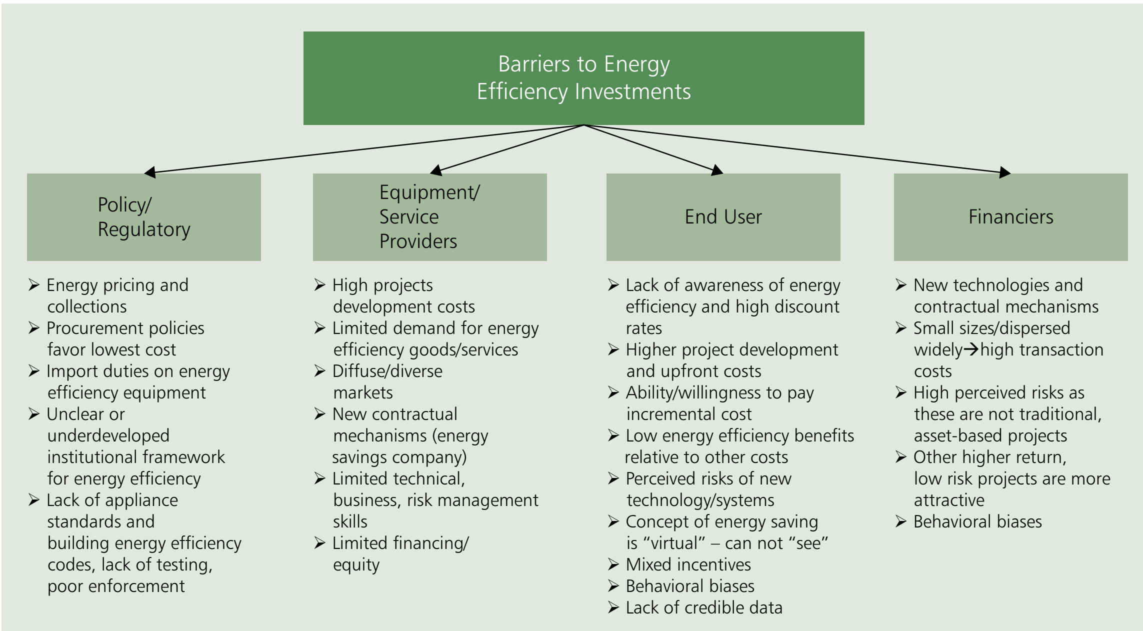
Figure 15 Composition of Primary Energy Consumption in the People's Republic of China (%)



Note: See the description and definitions in the text.

Source: Asian Development Bank project team.

Figure 16 Barriers to Energy Efficiency Investments



Source: Reprinted from Sarkar, A. and J. Singh. 2010. Financing Energy Efficiency in Developing Countries—Lessons Learned and Remaining Challenges. *Energy Policy* 38: 5560–71.

Table 4 Policy Recommendations to Promote Energy Efficiency

Area	Policy Recommendation
Cross-Sector	Institute energy efficiency data collection and indicators
	Strive for competitive energy markets, with appropriate regulation
	Facilitate private investment in energy efficiency by supporting energy efficiency capacity building, standardized measurement and verification protocols, private lending and energy efficiency technology research, development demonstration and deployment
	Monitor, enforce, and evaluate policies and measures
Buildings	Introduce mandatory building energy codes and minimum energy performance standards (MEPS)
	Support and encourage the construction of buildings with zero net energy consumption
	Implement policies to improve the energy efficiency of existing buildings with emphasis on significant improvements to building envelopes and systems during renovations
	Require building energy performance labels or certificates that provide information to owners, buyers, and renters
	Establish policies to improve the energy efficiency performance of critical building components, such as windows and heating and ventilation and cooling systems, to improve the overall energy performance of new and existing buildings
Appliances and Equipment	Introduce mandatory MEPS and labels for appliances and equipment
	Introduce and regularly update test standards and measurement protocols for appliances and equipment
	Introduce market transformation policies for appliances and equipment—such as financial incentives, procurement programs, endorsement schemes, and coordinated international policies—to increase the demand for and trade in of efficient appliances and equipment

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Table 4 *(continued)*

Area	Policy Recommendation
Lighting	Phase out inefficient lighting products as soon as technically feasible and economically viable
	Require and promote improved lighting systems design and management by ensuring that building codes promote the use of natural light and include MEPS for lighting systems
Transport	Introduce mandatory vehicle fuel efficiency standards
	Introduce measures to improve vehicle fuel efficiency, such as vehicle fuel economy labels, vehicle taxes to encourage the purchase of more fuel-efficient vehicles, and infrastructure support and incentive schemes for very low carbon-dioxide-emitting and fuel-efficient vehicles
	Put in place policies to improve the performance of tires, air-conditioning, lighting, and other non-engine components that affect a vehicle's fuel efficiency
	Improve vehicle operational efficiency through eco-driving and other measures
	Enable policies that increase the overall energy efficiency of national, regional, and local transport systems, and promote shifts of passengers and freight to more efficient modes
Industry	Support industry adoption of energy management protocols
	Mandate MEPS for electric motors
	Implement a package of measures to promote energy efficiency in small and medium-sized enterprises (SMEs) that include energy audits, the provision of high-quality and relevant information on proven practice for energy efficiency, and energy performance benchmarking information
	Put in place complementary financial policies that promote energy-efficient investment, such as the removal of energy subsidies, carbon taxes, and tax incentives for energy-efficient investments in industry (in particular in SMEs); risk-sharing or loan guarantees with private financial institutions; and enabling the market for energy performance contracting
Energy Utilities	Support regulatory and other policies (e.g., energy tariffs) to ensure that energy utilities support cost-effective, verifiable end-use energy efficiency improvements

Source: International Energy Agency. 2011. *25 Energy Efficiency Policy Recommendations: 2011 Update*. Paris.

Box 2 The Fukushima Disaster and Japan's Impressive Reduction in Electricity Usage

On 11 March 2011 a powerful earthquake, estimated to have an intensity of 9.0 on the Richter scale, occurred under the ocean 130 kilometers east of Sendai, Japan.[a] The earthquake triggered a massive tsunami that hit the Fukushima Daichi nuclear power station, which sits 10 meters (m) above sea level and was originally designed to withstand a 3.1 m wave; however, the 11 March wave was about 15.0 m. It smashed the plant's seawater intake systems and flooded electrical switching facilities and diesel generators, depriving the reactors of critical coolant.[b] The accident was eventually rated a Level 7, the highest since the Chernobyl accident a quarter of a century earlier.[c] As a result of the damage to the power plants, the Tokyo Electric Power Company (TEPCO), which supplied electricity to 42 million people and 40% of Japan's gross domestic product, lost 40% of its generation capacity.[d]

In the immediate aftermath of the disaster, TEPCO was forced to introduce a system of "rolling blackouts," where power supplies to different areas were periodically suspended. It was estimated that, without conservation measures, the peak summer demand in 2011 would be 60.0 gigawatts (GW); however, it was projected that TEPCO would supply up to 56.2 GW. Thus, the government asked all consumers to reduce electricity usage by 15% from the previous summer. The peak summer demand was actually 49.22 GW—an 18% reduction.[e]

In keeping with this objective, the Ministry of Environment introduced an initiative to reduce electricity consumption by 25% in its offices by implementing seven actions: maintaining indoor temperature at 28° Celsius rather than lower levels, encouraging a "no jacket" dress code in summer ("Super Cool Biz"), improving insulation, maintaining only essential lighting, rotating employee vacation times such that entire office floors are empty at a time, installing energy saving equipment wherever possible, and encouraging energy saving actions such as reducing the use of office refrigerators and suspension of some elevators. In the summer of 2010, the peak summer electricity demand in Ministry of Environment buildings was 228 kilowatts (kW); in 2011 it fell to 110 kW (footnote d).

The longer-term impact on Japan's greenhouse gas emissions, though, is uncertain. In 2011, Japan's nuclear reactors were providing 30% of the country's total power, and the official target was 50% by 2030 (footnote c, p. 378). Fukushima has prompted a review of Japan's power generation policy. In May 2012, the government had shut down all 54 of its nuclear reactors, most taken off-line for "routine maintenance."[f] This suspension of nuclear power increased Japan's bill for oil and gas imports by $100 million per day, resulting in the first trade deficit in three decades. By July 2012, two reactors had been restarted (reactors 3 and 4 at the Oi power plant).[g] Prime Minister Abe announced in March 2013 that the Government of Japan will propose new targets for 2020 at the Conference of Parties 19 (COP19) of the United Nations Framework Convention on Climate Change. The goal of 50% nuclear will almost certainly be abandoned.

The Fukushima episode illustrates how crises can force countries to make dramatic changes in behavior and energy usage, and is a cautionary note on the robustness of future energy and economic projections—extreme events can have large unexpected consequences on energy supply and demand and economic development.

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a US Geological Survey. http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/usc0001xgp.php#details
b *The Economist.* 2011. Piecing together Fukushima. 5 May.
c Yergin, D. 2011. *The Quest: Energy, Security, and Remaking of the Modern World*. New York: Penguin Press, 412.
d Personal communication. Ryuzo Sugimoto, Climate Change Policy Division, Ministry of the Environment, Japan
e Tokyo Electric Power Company. http://www.tepco.co.jp/en/press/corp-com/release/betu11_e/images/110926e13.pdf
f *The Economist.* 2012. Power Politics in Japan: A Silent Majority Speaks. 5 May. http://www.economist.com/node/21554239
g *The Economist.* 2012. Japan's Anti-nuclear Protests: The Heat Rises. 21 July. http://www.economist.com/node/21559364

Box 3 Reducing CO_2 Emissions along with Improving Local Air Quality

The People's Republic of China (PRC) has a major problem with local air quality in much of the rapidly developing parts of the country. Levels of fine particulates in Beijing reached historic peaks in January 2013 and again during the summer. Similar problems affect many cities, including ones that have regarded as being relatively unpolluted in the past. As a consequence, reducing air pollution has become a high priority for the central government. Promoting options for improving air quality and reducing CO_2 emissions has great appeal, but the lesson from other countries is that this may not be easy as some advocates of "win-win" strategies suggest.

Switch from coal to gas. In Europe, especially Central and Eastern Europe, simultaneous reductions in local air pollution and CO_2 emissions involved a structural shift from coal to gas together with a contraction in heavy industrial activities. The environmental improvements came at the cost of substantial social disruption, which would not be contemplated by any government in the PRC. In any case, gas is much more expensive relative to coal in the PRC than was the case in Europe, so that the economic case for shifting to gas is much weaker. Even so, all forecasts suggest that the share of gas in total energy consumption will increase. This shift will be slower if the country has to rely upon expensive imports of liquefied natural gas (LNG) for additional supplies, so that any gradual shift from coal to gas in urban areas will require a major commitment to developing the country's indigenous reserves of shale gas and building the pipelines that will be required to transport gas to cities in the center and north of the country.

The key issue at a macro level is what sectors should receive priority in getting access to limited supplies of gas. From an environmental – and an economic – point of view the goal should be to phase out the use of coal in all small boilers, fireplaces, etc in residential, commercial and industrial uses. It is much more efficient and less polluting to substitute gas for such purposes. Some cities, including Beijing, have explicit targets for reducing coal use within their city limits, but often this involves a large commitment to develop the infrastructure necessary to distribute gas as widely as possible. The experience of towns and cities in Eastern Europe testifies to the improvements in local air quality that have followed such a switch. In the longer term this is a policy that should be adopted and enforced in all urban areas of the country.

The corollary of that strategy is that the use of coal should gradually be restricted to power generation and large industrial activities which have the resources and capacity to install and operate stringent pollution controls. Even combined heat and power (CHP) and district heating plants should be switched to use gas, unless they are linked to large industrial plants. The costs of controlling emissions of particles, SO_2 and NO_x from the combustion of coal are not excessive for large boilers but they are expensive and technically difficult for medium and small boilers. In addition, it is much more difficult to establish an effective regime of monitoring and enforcement for SMEs.

Understanding air pollution. Peak levels of air pollution tend to attract attention, but it is important to understand the distribution of exposure as well as just the peaks. Consider two cities: City A has 2 weeks a year with daily average levels of fine particulates of 500 $\mu g/m^3$ and 50 weeks with daily averages of 25 $\mu g/m^3$, while City B has 52 weeks a year with daily averages of 50 $\mu g/m^3$. Understandably, City A will attract most attention because of spikes in mortality during the periods of peak exposure, but in the longer term the burden of mortality and illness due to air pollution will be significantly higher in City B.

Peak levels of exposure to fine particulates, SO_2 and ozone cause acute distress, especially to the elderly and others in poor health, and should not be ignored. Nonetheless, the real killer is year-round exposure to high or even moderate levels of fine particulates. Policies designed to limit levels of peak exposure may or may not have a significant impact on long term exposure, so that strategies for air quality management must be based on consideration of both issues.

Geography, history and meteorology all play a part in shaping the distribution of exposure and the composition of air pollution. Some cities are vulnerable to temperature inversions that trap pollution in air basins, while it is hard to alter patterns of industrial development when polluting industries are poorly located relative to residential and commercial areas of a city. The differences in air quality between 3 megacities in Latin America – Buenos Aires, Mexico City and Sao Paulo – reflect such factors as well as differences in policy.

Patterns of exposure to fine particulates depend upon the relative contributions of direct emissions of particulates (usually carbon) and the formation of secondary particulates in the atmosphere (usually sulfates and nitrates linked to emissions of SO_2 and NO_x). Secondary particulates tend to be spread more uniformly over a region and may persist longer in the air, whereas directly-emitted particulates tend to be concentrated where there is a high density of low level sources such as coal boilers, wood heating and diesel vehicles.

There is very little that can be done in the short run to reduce peak levels of exposure due to secondary particulates, so that emergency measures tend to focus on lowering direct emissions of particulates from heating and other boilers, vehicles and sometimes industrial operations. On the other hand, reducing longer term exposure to secondary particulates involves a focus on removing emissions of SO_2 and NO_x from the power sector, heavy industry, vehicles and small scale heating. Both emergency and

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Box 3 *(continued)*

longer term measures to manage air quality may sometimes increase fuel consumption and cannot be relied upon to decrease emissions of CO_2 by significant amounts.

Large vs small sources. Any strategy to reduce CO_2 emissions in the near future must focus on reducing the amount of coal that is burned. In contrast, it is how and where coal is burned that matters for local air quality. The distinction between large and small sources is crucial because high performance particle filters should be standard for all power plants and large boilers, while scrubbers (flue gas desulfurization) and low NO_x burners are becoming standard on new plants and can be retrofitted to older plants. Even more sophisticated technologies including coal gasification can be used to minimize emissions of local pollutants, but at best they have only a limited impact on emissions of CO_2.

One advantage of ensuring that coal use is concentrated in large plants is that this will facilitate the adoption of carbon capture and storage (CCS) in the longer term. The example of flue gas desulfurization suggests that there are likely to be large economies of scale in installing and operating CCS infrastructure, especially if this is to be retrofitted to existing plants. At the same time, coal-fired power plants should be moved away from urban areas when this is possible, partly because this will reduce the damage associated with their impact on local air quality and partly because this will ensure that space is available to install CCS plant if and when the technology becomes economic.

Controlling emissions from small sources is much more difficult. Even when control technologies exist, it is often difficult or impossible to retrofit existing installations. Maintenance is critical for new installations, so effective control depends upon a widespread commitment to reduce emissions as much as possible. Developing a regulatory framework and associated systems of monitoring and enforcement has taken decades in rich countries. Experience in Europe suggests that any strategy of reducing emissions from small sources in urban areas – residential, commercial and industrial – will rely heavily on the promotion of fuel substitution by replacing coal and oil boilers with gas boilers, usually by a mixture of incentives and penalties but with more reliance on incentives at the beginning of the transition.

Vehicles. It is easy to assume that poor air quality may be linked to the rapid growth in traffic, especially in the number and use of cars. The situation is not so simple. Air quality was notably poor in many cities around the world when traffic levels were much lower than today. The PRC adopted the equivalent of Euro 1, 2 and 3 emission standards for passenger cars less than 8 years after the EU and before the recent growth in car numbers. The average age of the car fleet is younger than for most rich countries, so the average level of emissions per kilometer should be lower than in the EU. The only qualification is that maintenance standards may be poorer, while the monitoring and enforcement of emissions performance of the vehicle fleet may be weaker. Even so, it is unlikely that car emissions are the major contributor to poor urban air quality.

The application of the equivalent of Euro 4 emission standards in 2013 and the gradual introduction of Euro 5 standards in the more polluted cities should ensure that the average level of emissions of hydrocarbons and NO_x per vehicle or per kilometer will fall in future. There is a risk that the growth in the car fleet and the total number of vehicle-kilometers driven will outstrip the improvement in emissions performance. Measures to restrict the ownership and use of cars would be politically unpalatable. Hence, effective action to strengthen the regime for inspection and enforcement of emission standards for older vehicles, perhaps along the lines of the system in Japan, might be a better option.

Commercial vehicles, including buses, fuelled by diesel are more important than petrol-fuelled cars. As a general rule, the pollution from heavy duty diesel engines used in trucks and buses is much worse than that from petrol engines, largely because of black smoke which has a large component of fine particulates. Engines which are poorly maintained and operate in stop-start traffic can emit large amounts of black smoke unless they are fitted with effective particulate filters. Since heavy commercial vehicles operate for more kilometers per year and have longer operating lives than cars, older vehicles that do not comply with current emission standards are often a serious source of pollution. To address this, many cities around the world have adopted rules that ban or penalize diesel vehicles without particulate filters in order to oblige operators to scrap or retrofit older vehicles. Similar provisions could be applied in all urban areas in the PRC.

It is unclear to what extent the secondary particulates that form a substantial portion of fine particulates in Beijing and other cities in the PRC are derived from emissions of SO_2 and NO_x from vehicles. Emissions of SO_2 can be reduced by imposing stringent limits on the sulfur content of diesel fuel, kerosene and similar petroleum products used in cities. Much of the diesel fuel used in the PRC has a sulfur content of 350 ppm as compared with a maximum of 50 ppm specified by EU standards since 2006 and a level of 10 ppm for ultra-low sulfur fuels which are gradually being introduced. One reason for adopting a much lower cap on the sulfur content of fuel is to ensure that the equipment which is required to comply with more stringent vehicle emission standards – in particular, Euro 4 and 5 – functions reliably. On the other hand, large investments are required to retrofit petroleum refineries to install the desulfurization equipment necessary to produce low or ultra-low sulfur fuels. This is what has delayed the adoption of more stringent fuel standards in the PRC up to now.

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Box 3 *(continued)*

Economic incentives. Both analysis and experience suggest that tradable emission permits can be effective in addressing problems of regional air quality but are less suitable for the management of urban air quality. In contrast, pollution charges that are differentiated by location or by existing air quality have proved to be effective tools for improving local air pollution in Poland and other countries in Central and Eastern Europe. In such cases the results have been achieved by stimulating large sources to control their emissions, so the benefits of using incentives rather than emission standards have not been established.

Other economic instruments such as differential fuel taxes are generally implemented at a regional or a national level and are not suitable for the achieving rapid improvements in local air quality. This applies to incentives that are designed to stimulate the adoption of energy-saving technologies including product standards, green investment incentives, etc. These have a long term pay-off and can even have perverse effects by extending the life of current plant and equipment by increasing the cost of replacing it. To counteract this effect, various countries have implemented "cash for clunkers" schemes designed to accelerate the scrapping of old vehicles with high emissions. Eligibility for such incentives can be restricted to vehicles that are registered within restricted areas with poor air quality.

The implementation of carefully designed incentives should play a key role in any long term strategy to reduce CO_2 emissions. These will discourage the use of fossil fuels and adoption of technologies that are cleaner and more energy-efficient. However, they are unlikely to make a substantial contribution to addressing current problems of urban air quality. There will be long term benefits to human health as a consequence of a gradual reduction in average levels of exposure to fine particulates, both associated with direct emissions and due to the creation of secondary particulates in the atmosphere. However, designing a system of incentives to achieve a rapid improvement in air quality in the most polluted areas will require a rather different approach.

Summary. The effective management of urban air pollution requires a detailed understanding of the processes that lead to poor air quality as well as of the potential options for controlling both emissions and exposure. The idea that there is a substantial overlap between measures designed to improve local air quality and those which reduce CO_2 emissions rest on two elements: (a) the substitution of gas for coal on a large scale, and to a lesser extent (b) the adoption of cleaner, energy-saving technologies. Both of these elements have been important in, for example, Eastern and Central Europe and can play a role in the PRC. However, they operate over the longer term and are constrained by the amount and cost of natural gas which can be supplied to cities.

In the short and medium term, policies designed to improve urban air quality will focus on the adoption of emission controls for large sources and diesel vehicles together with restrictions on the use of coal in small boilers. Such measures will have a limited impact on total emissions of CO_2, because the goal is to alter the way in which coal and other fossil fuels are used rather than to achieve an immediate reduction in the use of such fuels.

The consequence is that policies to improve air quality and reduce CO_2 emissions operate over different time scales. Reducing local air pollution is an immediate priority and will require the implementation of strategies that offer the prospect of lower emissions and exposure well before 2020. Tackling the level and growth of CO_2 emissions is likely to take much longer, partly depending on the availability of ample supplies of gas and partly on the gradual adoption of greener technologies including, for example, carbon capture. Such options will reinforce progress in improving local air quality but they are unlikely to be the main driver of such improvements over the next decade.

Box 4 Carbon Markets in East Asia

Japan

According to the terms of the Kyoto Protocol, Japan committed to reducing greenhouse gas emissions by 6% compared to 1990 levels during 2008–2012. By 2007, with emissions 9% higher than the 1990 baseline, it was clear that this goal would be hard to achieve.[a] As part of a broader strategy of trading in carbon credits (which included the purchase of credits in the Czech Republic, Ukraine, and Latvia), the Ministry of Environment launched a voluntary emissions trading scheme in 2005—the Japan Voluntary Emissions Trading Scheme (J-VETS).[b] Now in its fourth phase, as of November 2010, 359 companies were registered as participants in the scheme.[c] In May 2010, the lower house of the Japanese parliament passed the Bill for the Basic Act on Global Warming Countermeasures which advocated the introduction of a domestic emissions trading scheme (ETS) (footnote c, slide 15). In June 2010, Japan's New Growth Strategy mentioned the ETS as something which "should be implemented" in fiscal year 2011. But, as of May 2013, no notable progress had been made in making the scheme operational. However, the Tokyo Metropolitan Government, which launched a city-specific voluntary emissions reduction scheme in 2002, created a mandatory trading program in 2008.[d] The scheme covers close to 1,500 public and private facilities and aims to reduce emissions by 25% below 2000 levels by 2020. The penalty for noncompliance is a fine of ¥500,000. In addition, the Tokyo Metropolitan Government follows a "name and shame" policy, publishing the details of violators on its website and in newspapers.

Republic of Korea

The Republic of Korea publicized the draft plan for an ETS in April 2011. The plan envisages an ETS coming into effect on 1 January 2015, covering 300 of the country's largest companies (including the powerful *chaebol* [conglomerates]), which together account for about 60% of the country's total greenhouse gas emissions.[e] The objective of the ETS is to reduce emissions by 30% relative to 2000 by 2020. In May 2012, the country passed legislation creating the national ETS.[f]

People's Republic of China

The Government of the People's Republic of China (PRC) proposed starting an ETS during the 12th Five-Year Plan (2011–2015). Given the complexities and potential economic impacts of emission trading, the National Development and Reform Commission decided, in November 2011, to pilot seven programs in selected sectors and regions, starting with provinces and cities designated as low-carbon economic development zones. The selected municipalities were Beijing, Shanghai, Tianjin, and Chongqing; the selected city of Shenzhen; and the selected provinces of Guangdong, and Hubei. The five cities/municipalities and two provinces were asked to submit detailed implementation plans for carbon trading schemes for approval by the State Council by the end of 2012.[g]

The emission targets vary across the pilot areas. The province of Guangdong, which has estimated emissions of about 465 million tons of carbon dioxide equivalent ($MtCO_2e$), compared to 397 $MtCO_2e$ in France, was told by the central government to cut the amount of carbon emitted per unit of gross domestic product by 19.5% from 2005 levels by the end of 2015.[h] Other regions have been given relatively lower targets: Chongqing and Hubei have been told to reduce emissions by 17% compared to 2005 levels over the same period.[i] On 18 June 2013, Shenzhen became the first pilot ETS in the country, covering 635 companies, whose aim is to achieve a 30% cut in emissions per unit of output.[j] From 2011–2015, along with the pilot carbon markets, there will be a national cap on energy consumption. The next phase is to turn this energy cap into a national emissions target over the period of 2016–2020, with a fully-fledged national ETS in 2021–2025.[k]

There are many strategic issues that need to be decided:

- Should the ETS be based on intensity-based targets (i.e., emissions per unit of economic activity) or absolute targets? Although the intensity-based target is consistent with the stated pledge of the PRC for emission reduction, the monitoring and verification requirements are more complex for intensity-based ETSs.
- How should the ETS interact with other administrative policies aimed at reducing carbon and energy intensity, such as energy conservation performance targets for key enterprises, phasing out obsolete technologies and industrial capacities, and fiscal incentives and penalties for inefficient industries?
- What should be the sector scope of the ETS?
- How stringent should the emission targets be and should they be national or regional in scope? Varying the stringency of emissions requirements across the country could lead to "carbon leakage."
- Should the system allow flexible caps or other safety valves, such as the issuance of additional emission allowances if the market price exceeds a predefined level?
- How should the initial allocation of allowances be determined? Should they be grandfathered (i.e. allocated based on historical emissions) or auctioned?

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– Should offsets be permitted? What, if any, should be the links with other carbon markets including voluntary markets? Offsets provide an avenue to link the proposed ETS with voluntary markets, while links with other ETSs would increase the market liquidity and efficiency.

Finally, the PRC is also the leading recipient of projects of the Kyoto Protocol's Clean Development Mechanism (CDM). The CDM allows a country with an emission reduction or emission limitation commitment under the Kyoto Protocol (an Annex B party) to implement an emission reduction project in developing countries, allowing the Annex B party to earn saleable certified emission reduction (CER) credits (each equivalent to 1 ton of CO_2), which can be counted towards meeting Kyoto targets. As of August 2012, 2,271 projects in the PRC had been registered as CDM projects, accounting for 50% of the global total.[l] The accumulated CERs issued are equivalent to 597 $MtCO_2e$ (footnote i). The vast majority of registered projects are in renewable energy, followed by energy savings and efficiency and methane utilization and recovery.[m]

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a See http://www-gio.nies.go.jp/aboutghg/nir/nir-e.html for details of Japan's inventory over time.
b Details in presentation prepared by Office of Market Mechanisms, Climate Change Policy Division, Global Environment Bureau, Ministry of the Environment, Japan. http://www.env.go.jp/en/earth/ets/jvets090319.pdf
c Presentation by Yasuharu Ueda, director of the Office of Market Mechanisms, Ministry of the Environment. Carbon Offsetting Initiatives and Consideration of Emissions Trading in Japan. 4 November 2010. http://www.iges.or.jp/en/cdm/pdf/regional/101104/y_ueda_e.pdf
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h Zhang, D. et. al. 2012. Quantifying Regional Economical Impacts of the CO_2 Intensity Reduction Target Allocation in [the PRC]. Unpublished paper prepared at the Massachusetts Institute of Technology, Joint Program on the Science and Policy of Global Change, Cambridge, MA; Han, Guoyi., et al (see footnote f). The Asian Development Bank is providing technical assistance to one of the pilot carbon-trading markets in Tianjin, known as the TCX, through a $750,000 grant.
i Zhang, D., et. al. (see footnote g).
j *The Economist.* 2013. Carbon Emissions: The Cap Doesn't Fit. 19 June.
k *The Economist.* 2013. [People's Republic of] China and the Environment: The East is Grey. 10 August.
l United Nations Framework Convention on Climate Change. http://cdm.unfccc.int/Statistics/Registration/NumOfRegisteredProjByHostPartiesPieChart.html
m Clean Development Mechanism in [the PRC]. http://cdm.ccchina.gov.cn/english/index.asp. Accessed August 2012.

Appendix 1: Technology Options in the Asia-Pacific Integrated Model Enduse Database

Sector	Category	Technology Options
Power Generation (Energy)	Coal power plant	Efficient coal power plant (supercritical, ultra supercritical, pressurized fluidized bed combustion, integrated gasification combined cycle), carbon capture and storage
	Gas power plant	Efficient gas power plant (combined cycle), advanced combined cycle, carbon capture and storage
	Renewables	Wind power, photovoltaics, biomass power plant
Industry	Steel	Coke oven (coke gas recovery, automatic combustion, coal wet adjustment, coke dry type quenching, coke oven gas latent heat recovery, next generation coke oven), sinter furnace (automatic igniter, cooler waste heat recovery, mainly waste heat recovery, efficient igniter), blast furnace (large blast furnace, blast furnace gas recovery, wet top pressure recovery turbine, dry top pressure recovery turbine, heat recovery of hot blast stove, coal injection, dry top pressure gas recovery), basic oxygen furnace (high-temperature waste gas [LDG] recovery, LDG latent heat recovery), casting and rolling (continuous caster, hot charge rolling, hot direct rolling, efficient heating furnace, heat furnace with regenerative burner, continuous annealing lines), electric furnace (direct current electric furnace, scrap preheat)
	Cement	Mill (tube mill, vertical mill), kiln (wet kiln, semiwet kiln, dry long kiln, dry shaft kiln, suspension preheater, new suspension preheater)
	Other industries	Boiler (efficient boiler [coal, oil, gas], boiler with combustion control [coal, oil, gas], cogeneration [coal, oil, gas], regenerative gas boiler), process heat (efficient industrial furnace [oil, gas]), motors (motors with inverter control, efficient motors)
Residential and Commercial Buildings	Cooling	Efficient air-conditioners (sold average in developed countries in 2005, Top Runner, highest performance)
	Warming	Efficient air-conditioners (sold average in developed countries in 2005, Top Runner, highest performance), thermal insulation (wall insulation, double glazing)
	Hot water	Efficient water heaters (kerosene, liquid petroleum gas [LPG], gas, coal), latent heat recovery water heaters (kerosene, LPG, gas), carbon dioxide refrigerant heat pump water heaters, solar thermal water heaters, electric water heaters
	Cooking	Efficient cooking stoves (kerosene, LPG, gas, coal, electricity), electric induction cookers
	Lighting	Fluorescent of incandescent type, fluorescent with energy saving stabilizer, inverter type fluorescent, Hf inverter type fluorescent, light emitting diode lamps
	Refrigerator	Efficient refrigerators (sold average in developed countries in 2005, Top Runner, highest performance)
	TV	Efficient TVs (sold average in developed countries in 2000, Top Runner, highest performance)
	Others	Efficient other devices
Transport	Passenger car	Efficient gasoline passenger cars (variable valve control, cylinder deactivation, direct injection, engine friction reduction, rolling resistance reduction, aluminum body, lightweight chassis, aluminum block, continuously variable transmission [CVT]), hybrid passenger gasoline cars, plug-in hybrid gasoline cars, efficient diesel passenger cars (engine friction reduction, rolling resistance reduction, direct injection, common-rail, aluminum body, lightweight chassis, aluminum block, CVT), hybrid passenger diesel cars, plug-in hybrid diesel cars, electric passenger cars, fuel-cell passenger cars
	Truck	Efficient small trucks (rolling resistance reduction, engine improvement), efficient large trucks (rolling resistance reduction, engine improvement)
	Passenger bus	Efficient buses (rolling resistance reduction, engine improvement), hybrid buses
	Ship	Efficient ships
	Aircraft	Efficient aircraft (engine improvement, weight reduction, drag reduction)

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Appendix 1 *(continued)*

Sector	Category	Technology Options
	Rail	Efficient trains
	Road transport	Biofuel
Agriculture	Rice cultivation	Water management (midseason drainage, shallow flooding, alternative flooding and drainage), fertilizer management (ammonium sulfate, addition of phosphogypsum), cultivation management (upland rice, direct wet seeding, offseason straw), rice straw compost
	Cropland	Fertilizer management (reduce fertilization, nitrogen inhibitor, spreader maintenance, split fertilization, suboptimal fertilizer application), replacing fertilizer (replacing fertilizer with manure and residue), cultivation management (fertilizer-free zone, optimize distribution geometry, convert fertilizational tillage to no-till), water management (irrigation, drainage)
	Manure management	Anaerobic digestion (centralized plant, farm-scale plant), covered lagoon (farm use, household use), biogas use for cooking and lighting from domestic storage, manure treatment (daily spread of manure, slowing down anaerobic decomposition), fixed-film digester, plug flow digester
	Livestock rumination	Chemical substance management (propionate precursors, probiotics, antibiotics, antimethanogen, methane oxidizers), feed management (improved feed conversion, improved feeding practices, high-fat diet, replace roughage with concentrates), genetic (high genetic merit, improved feed intake and genetics)

Appendix 2: Explanation of Some Technologies in the Marginal Abatement Cost Curves

Technology	Explanation
CFL, FL lighting	Compact fluorescent, fluorescent lighting
Gas NEW, 1700	Natural gas advanced combined cycle power plant
Coal (SC + CCS, USC + CCS)	Supercritical plus carbon capture and storage, ultra supercritical plus carbon capture and storage
Biomass, EXT	Existing biomass combustion for power generation
Wind power 1	The range of utilized capacity factor is more than 30%
Wind power 2	The range of utilized capacity factor between 20% and 30%
Wind power 3	The range of utilized capacity factor is less than 20%
Biofuel	Various sources are considered
Biofuel for mix	The term “mix” is a coding in the technology database
Other Fuel Frg Rail (stock efficient)	“Other fuel freight rail (stock efficient).” This is a conventional diesel train, which was the prevailing type in 2005
Hydro	Large-scale hydro power plant
Wind power + storage	Wind power with storage battery
Photovoltaic 2 + storage	The range of annual averaged insolation is between 2,000 kilowatt-hours per square meter per year (kWh/m^2/yr) and 2,200 kWh/m^2/yr, with storage battery
Photovoltaic 3	The range of annual averaged insolation is between 1,800 kWh/m^2/yr and 2,000 kWh/m^2/yr
Photovoltaic 4	The range of annual averaged insolation is less than 1,800 kWh/m^2/yr
Boiler (renewables)	The use of biomass
Motor (inverter)	Motors with inverter control technology, which reduces electricity consumption by around 30%–40% compared to without inverter controller
Recovery (mobile air-conditioning)	Recovery of refrigeration from “mobile” air-conditioning, which is other than large-scale stationary air-conditioning already installed in a building

Chapter 7

Integrated Assessment Modeling in East Asia

Key Messages

- **Under the business-as-usual (BAU) scenario in which current patterns of development continue, the average losses in East Asia due to climate change could amount to 5.3% of its annual gross domestic product (GDP) by 2100.** There is no winner and Mongolia will be the country most severely affected.
- **Minimizing the losses due to climate change will require a combination of adaptation to changes that are inevitable, plus emissions abatement to slow and eventually reverse the accumulation of greenhouse gases in the atmosphere.**
- **Adaptation can make a substantial contribution to reducing the damage due to climate change but it is not sufficient on its own to reduce the expected cost of climate change to a low level.** Under the BAU scenario, planned adaptation results in residual damages 1.6% of GDP on average in 2100 at an expected cost of 0.4% of GDP over the period.
- **Up until 2020 it is possible to achieve a substantial reduction in carbon dioxide (CO_2) emissions by implementing negative and zero-cost abatement options, but reliance upon a win–win approach will not prevent emissions from increasing substantially from 2020 to 2050.**
- **Alternative paths for reducing emissions can be derived by reference to targets for emissions and the concentration of greenhouse gases, or by setting maximum values for the marginal abatement costs which increase over time.** The first approach is the basis for the Copenhagen–Cancun Convergence (CCC) scenario that aims to stabilize the concentration of CO_2 at 450 parts per million (ppm) and to cap the expected increase in the global mean temperature at about 2.5° Celsius (C). The second approach provides the basis for alternative strategies under which emissions are reduced more gradually.
- **Under the CCC scenario, the gains from regional pooling of emission caps and abatement action are large—up to 25% of the costs of implementation if each country acted separately.** Even with regional pooling, the total and marginal costs of abatement under this scenario involve a rapid increase to 2050 and a slower increase thereafter. This is unlikely to be economically efficient when discounting and intergenerational equity are taken into account.
- **Any policy strategy to address climate change has to combine mitigation and planned adaptation as well as taking into account residual damage costs.** Strictly from the perspective of East Asia, but without discounting, the least-cost strategy would rely upon negative and zero-cost abatement of emissions only, plus planned adaptation to climate conditions in 2100. Under this strategy, the level of CO_2 emissions in 2100 would be similar to that in 2010. However, this strategy would have far-reaching global impacts: global mean temperature would increase by 4° C, with an average sea-level rise of 0.65 meters. As an alternative, the strategy with the second-lowest average cost would involve a gradual reduction in emissions associated with a phased increase in the marginal cost of abatement from $50 per ton of carbon dioxide equivalent (tCO_2) in 2030 to $200 per tCO_2 in 2100.

Introduction

The previous chapters in this report take the climate scenarios as given. There is no feedback from the policies examined to changes in the future climate. This is the classic "small economy in a large world" assumption on which all microeconomics is based. However, East Asia in general, and the People's Republic of China (PRC) specifically, are sufficiently large contributors to total emissions of greenhouse gases that it is useful to consider how the calculus of costs and benefits might be changed once the impact of climate policies on future climate change is taken into account.

The analysis builds upon the examination of adaptation options discussed in Chapters 2 and 3 by allowing adaptation expenditures to mitigate the damage which would otherwise be caused by climate change. Such adaptation does not provide complete protection against the impacts of climate change but it can reduce the damage to a substantial degree. As a consequence, this chapter focuses on the implications of adopting combined strategies that incorporate both mitigation and adaptation rather than relying upon either exclusively.

The level of analysis in this chapter is much higher than the detailed sector investigations presented earlier. It is based on the use of one integrated assessment model—PAGE09.[1] This is the current version of a model which was used in previous Asian Development Bank (ADB) studies of the economics of climate change, as well as for the Stern Review.[2] The contribution of integrated assessment models is that they provide a coherent framework for describing and analyzing the global linkages which underpin both the climate system and economic development.

The estimates of the damage caused by climate change as well as of the costs of mitigation and/or adaptation are based on highly simplified relationships linked to global temperature and emissions. They are intended to provide orders of magnitude but are inevitably sensitive to the assumptions which are built into the analysis. The absolute magnitudes are indicative but they should not be treated as forecasts. What is important is that integrated assessment models provide a framework for comparing alternative strategies for responding to climate change. For example, the differences between economic costs and climate damages for a pure strategy of adaptation versus those for a combination of adaptation and mitigation via a reduction in regional or global greenhouse gas emissions are likely to be more useful than the absolute magnitudes under either strategy on its own.

The parameter values for the key relationships in the integrated assessment model are stochastic, i.e., they are generated as random values from distributions that are intended to reflect the uncertainty about the shape and scale of responses to higher levels of greenhouse gas concentrations and changes in climate conditions. In addition, the PAGE09 model includes a component of the economic damage due to a rise in global temperatures, which rises sharply once a threshold increase in temperature has been passed. This is referred to as the "discontinuity impact" of climate change. It is intended to capture the risk of some large-scale discontinuity in the physical response to climate change, such as the melting of the Greenland ice sheet or the shutdown of the North Atlantic conveyor, which transfers heat from the tropics via ocean currents.

The representation of the discontinuity impact of climate change in the model does not attempt to quantify the consequences of catastrophic climate effects; rather, it is a form of insurance premium set aside to cover the risks of such effects. For this reason, it is not affected by adaptation policies, since the idea is that adaptation focuses on the observable and broadly predictable consequences of climate change, whereas the discontinuity impacts are not something which can be planned for.

1 Hope, C. 2010. *The PAGE09 Model: A Technical Description*. Mimeo. Cambridge, MA: University of Cambridge.
2 Stern, N. 2007. *The Economics of Climate Change: The Stern Review*. Cambridge, MA: Cambridge University Press.

Methodology

The purpose of using an integrated assessment model in this chapter is to provide a long-term perspective of climate change implications in East Asia, while taking into account the possible ranges of uncertainties using a stochastic approach. Integrated assessment models translate projections in greenhouse gas emissions to increases in global mean temperature—and, hence, sea-level rise—which in turn determine region- or country-specific economic damages due to the impacts of climate change subject to adaptation measures. This framework brings together both mitigation and adaptation, allowing for trade-offs between them as well as policy scenarios that incorporate the full range of measures discussed in the previous chapters.

The inertia in the climate system due to the long atmospheric life of greenhouse gases and the need to take a long-term view on climate actions mean that it is essential to look beyond 2050. A time horizon up to 2100 is used for the analysis because the uncertainties associated with socioeconomic projections, technological development, etc. beyond that date are so large that they dominate the results. As in the previous chapters, all values are expressed in constant US dollars at 2005 international prices.

PAGE09 is an updated version of the PAGE2002 integrated assessment model. PAGE2002 was used to value the impacts and calculate the social cost of CO_2 in the 2007 Stern Review and the 2009 ADB review of climate change in Southeast Asia.[3] PAGE09 takes into account updated scientific and economic information, primarily of the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).[4] PAGE09 uses simple equations to simulate the results from more complex specialized scientific and economic models. The base PAGE09 includes eight regions, 10 time periods to the year 2200, and four types of climate impact—sea-level rise, market (e.g., agriculture), nonmarket (e.g., biodiversity), and major discontinuities (e.g., ice sheet collapse). For this chapter, PAGE09 was modified so that the PRC, Japan, the Republic of Korea, and Mongolia are treated as distinct geographical units.

The model estimates impacts through a damage function linking GDP loss with temperature rise. The impacts are driven mainly by three factors: (i) region-specific temperature rise, which is determined by radiative forcing from global greenhouse gas concentration (including CO_2 from energy-related and land-use change and forestry, nitrous oxide [N_2O], methane [CH_4], and sulfur hexaflouride [SF_6]) and regional sulfates; (ii) regional impact parameters which are a function of region-specific geographical characteristics; and (iii) region-specific adaptive capacity which is determined by the level of per capita income. The possibility of future large-scale discontinuity is modeled through a linearly increasing probability of occurring as the global mean temperature rises above a threshold. The BAU scenario of the version used in this chapter is calibrated to the IPCC high-emission A1FI scenario in terms of anthropogenic greenhouse gas emissions, which envisages somewhat higher greenhouse gas emissions from fossil use than the A2 scenario used in the earlier chapter.[5] The path of global emissions of greenhouse gases from 1990 to 2010 has oscillated around the A1FI projections. The rapid growth in CO_2 emissions from the PRC has been particularly important—almost two-thirds of the increase in global emissions of CO_2 between 2000 and 2010 came from the PRC.

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3 The PAGE2002 model is described in detail in Hope, C. 2006. The Marginal Impact of CO_2 from PAGE2002: An Integrated Assessment Model Incorporating the IPCC's Five Reasons for Concern. *Integrated Assessment*, 6, 1, 19–56; and Hope, C. 2008. Optimal Carbon Emissions and the Social Cost of Carbon Over Time Under Uncertainty. *Integrated Assessment*, 8, 1, 107–22. See also ADB. 2009. *The Economics of Climate Change in Southeast Asia: A Regional Review.* Manila.

4 IPCC. 2007. Climate Change 2007. The Physical Science Basis. Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change: IPCC Secretariat Switzerland.

5 Each of the IPCC's scenarios—A1FI, A1T, A1B, A2, etc.—is accompanied by a story line about social and economic development. The underlying projections of population, GDP, and emissions coefficients have not tracked subsequent outcomes closely, so that the scenarios used in PAGE09 are treated as defining alternative paths for future greenhouse gas emissions that are not linked to any specific assumptions about socioeconomic development.

The analysis of abatement costs in the previous chapter examines reductions in CO_2 emissions, and so the analysis in this chapter has a similar focus. The alternative scenarios which are investigated differ only in the extent to which emissions of CO_2 are reduced relative to the BAU scenario. Emissions of all other greenhouse gases are held constant across scenarios. In practice, it may be possible to mitigate the total impact of greenhouse gas emissions at lower cost by, for example, reducing fugitive emissions of methane or tackling emissions of nitrous oxide, but without more detailed data on the relevant abatement costs it is not possible to assess such options.

One consequence of the focus on the abatement of CO_2 emissions is that the calculation of the impacts of, and hence the costs of adaptation to, climate change is separate from the calculation of the costs of abatement. The rate of increase in global mean temperature depends upon the concentration of all greenhouse gases in the atmosphere and is, in turn, a function of the emissions of greenhouse gases expressed in terms of CO_2-equivalent. Hence, the specification of the scenarios presents information on the time paths of (i) total greenhouse gas emissions, and (ii) the contribution of CO_2 emissions to this total. In some scenarios—notably the Copenhagen–Cancun Convergence (CCC) scenario described later in this chapter—the ratio of CO_2 emissions to total greenhouse gas emissions changes substantially over time.

Results

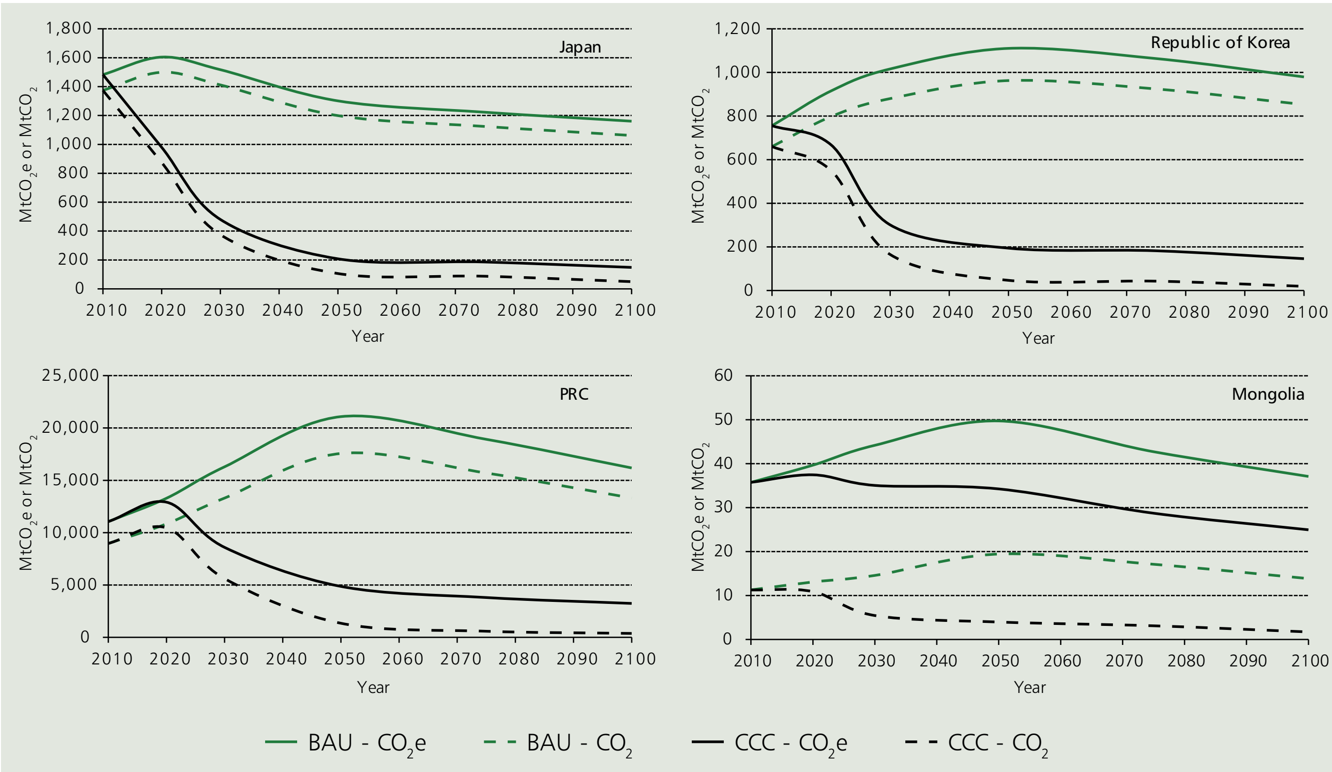
The starting point for the analysis is provided by two scenarios which define the range within which policy choices and actual outcomes may be considered to fall:

- The business-as-usual (BAU) scenario with no adaptation or mitigation efforts that go significantly beyond the current level. Economic and population growth for the countries in East Asia follow the paths given in the Appendix to Chapter 2, while the emissions path follows the A1FI scenario.
- The CCC scenario assumes decoupling of greenhouse gas emissions from BAU economic growth. It is based upon implementation of the pledges made at the Copenhagen United Nations Framework Convention on Climate Change (UNFCCC) Conference in 2009 (up to 2020), combined with a long-term vision that is in line with Cancun agreements, which aims at keeping the increase in global mean temperature below 2° C. In the CCC scenario, per capita emissions for all regions converge to 1 ton of carbon dioxide (tCO_2) per person by 2050 and 0.5 tCO_2 per person by 2100.

The trajectories for total greenhouse gas and CO_2 emissions under the two scenarios are shown in Figure 1. The CCC scenario implies a large reduction in emissions from 2020 onwards for the PRC and Mongolia with emissions that are between 10% and 20% of the BAU level by 2050. Allowing for the projections of economic growth in Chapter 1, this scenario would require that emissions per dollar of GDP for the PRC in 2050 should be only 3.5% of their value in 2010, equivalent to a steady annual reduction of 8% per year in emissions intensity over the next 40 years. The necessary reduction in emissions intensity for Mongolia is larger than for the PRC because total GDP is projected to increase by more than 18 times from 2010 to 2050. As a consequence, the emissions intensity would have to fall to 2.2% of its 2010 value, an annual reduction of 9.1% per year. Hence, this scenario may be considered to be at the limits of what climate policies might achieve over the next 40 years.

The results from the scenarios take the form of probabilistic projections of (i) key climate parameters such as the projections of greenhouse gas concentration levels, temperature change, and sea-level rise; and (ii) the economic impacts of climate change, including sector-specific and total (economy-wide) economic losses. Means, standard deviations, and 90% confidence intervals (from the 5th to the 95th

Figure 1 Comparison of Emissions under the Business-as-Usual and Copenhagen–Cancun Convergence Scenarios, 2010–2100 ($MtCO_2$ or $MtCO_2e$)



BAU = business-as-usual, PRC = People's Republic of China, CCC = Copenhagen–Cancun Convergence, CO_2e = carbon dioxide equivalent, $MtCO_2e$ = million tons of CO_2e.

Source: Asian Development Bank project team.

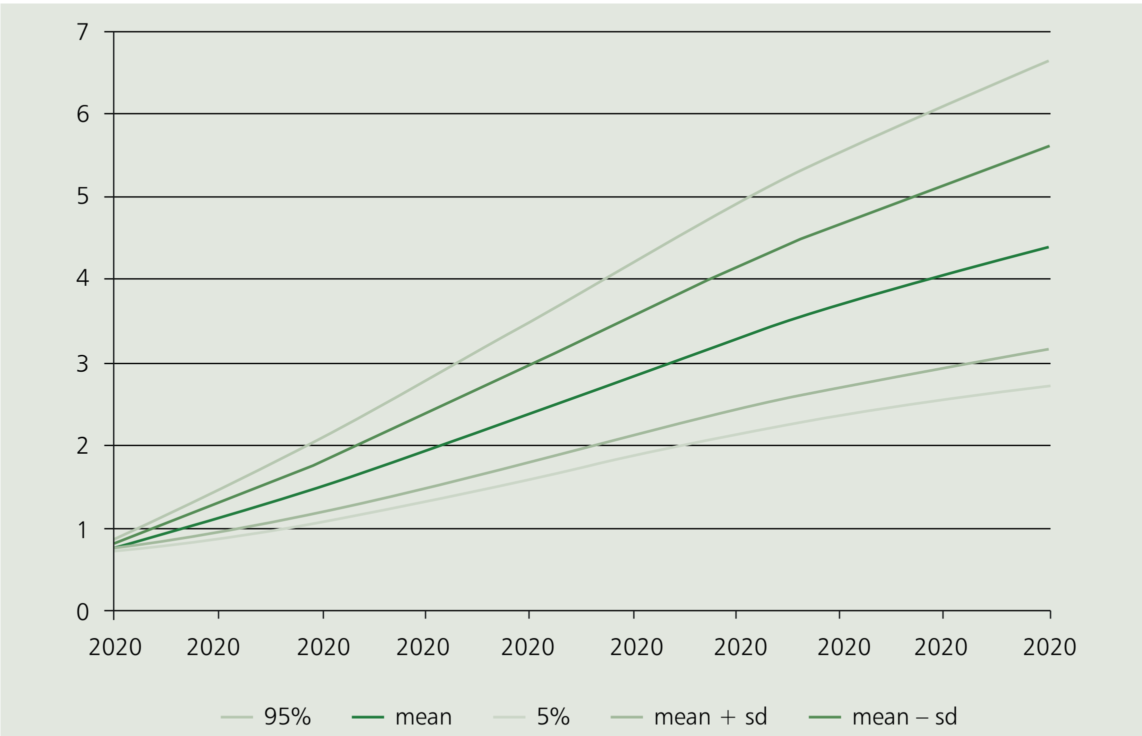
percentile) are computed, though the figures and tables presented below focus on a selected set of key results.

Business-as-usual scenario

The concentration of greenhouse gases will rise under the BAU scenario from approximately 400 parts per million (ppm) today, and will exceed 450 ppm in 2025. The mean concentration reaches 814 ppm in 2100 and continues to rise beyond the end of the 21st century. Figure 2 shows that there is a 50% probability that the increase in the global mean temperature will exceed 2° C by 2040.[6] PAGE09 projects that the mean value of the increase in global temperature will be 4.4° C by 2100, with a rather wide 90% confidence interval from 2.8° C to 6.7° C. The mean projections for the PRC, Japan, and the Republic of Korea using the BAU scenario are 0.4–0.5° C lower than the figures for 2090 shown in Table 5 of Chapter 1, reflecting differences in specification and calibration. However, for Mongolia the mean projection for the BAU scenario is an increase of 5.7° C, which is rather higher than the average over all General Circulation Models (GCMs) shown in Chapter 1. The reason is a combination of latitude

6 Increases in temperature are calibrated differently in PAGE09 from the method used in Chapter 1. The base temperature for the PRC in 2008 is 0.6° C. This is slightly lower than a quadratic interpolation of the temperature projections in Table 5 of Chapter 1, but it corresponds quite closely to use of the average for 1971–1990 as the base period rather than 1961–1990.

Figure 2 **Increase in Global Mean Temperature for the Business-as-Usual Scenario, 2010–2100** (° Celsius)



Note: sd = standard deviation

Source: Asian Development Bank project team.

adjustment in PAGE09, and a weaker impact of sulfate cooling as a result of a lower level of industrial emissions, which is not taken into account in the GCMs.

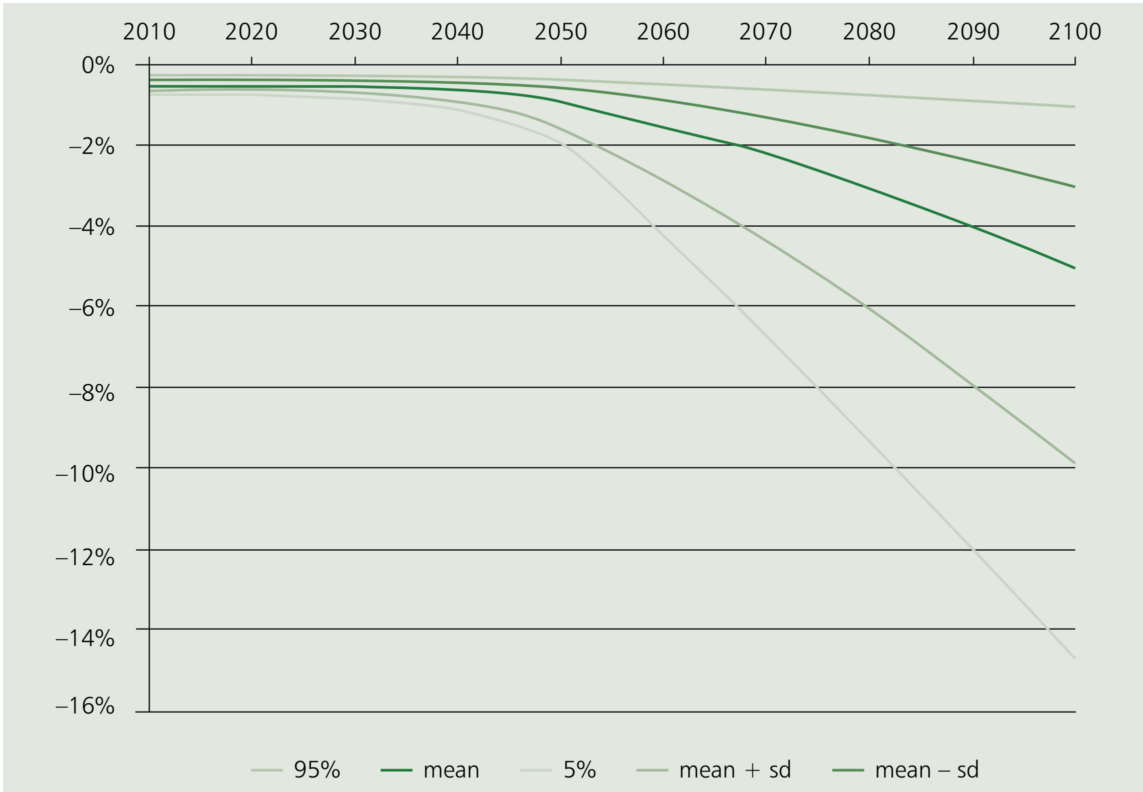
PAGE09 generates a mean increase in global sea level of 70 centimeters (cm) under the BAU scenario by 2100 with a 90% confidence interval of 42–112 cm. The average increase and the range are both slightly smaller than the values used in Chapter 3, which has a medium scenario with a rise of 87 cm and a range of 40–126 cm.

The model projects the losses due to climate change expressed as a percentage of projected GDP to the countries in East Asia using general damage functions for sea-level rise[7] and economic and noneconomic impacts (Figure 3). These losses are small up to 2050 (less than 1% of GDP) but they rise rapidly from 2050 to 2100. By 2100, the average impact of climate change for the region is equivalent to a loss of 5.3% of GDP with a 5% probability that the loss might be 15.0% of GDP.

There are substantial differences in the impact of climate change across countries. Mongolia will be hardest hit with a mean loss of 9.1% of GDP, compared to only 2.4% of GDP for Japan and 3.0% for the Republic of Korea (Figure 4). The 90% confidence interval for losses is also very large for Mongolia, with a 5.0% chance that the loss could be greater than 24.5% of GDP. The reason for the high average level and extreme variability of losses for Mongolia is the combination of a large increase in mean temperature because of its high latitude and the nonlinear specification of the damage functions for

7 The damage caused by sea-level rise in Mongolia is set to zero since the country is landlocked.

Figure 3 Impact of Climate Change under the Business-as-Usual Scenario for East Asia, 2010–2100 (Losses as % of projected GDP)



GDP = gross domestic product.

Note: sd = standard deviation

Source: Asian Development Bank project team.

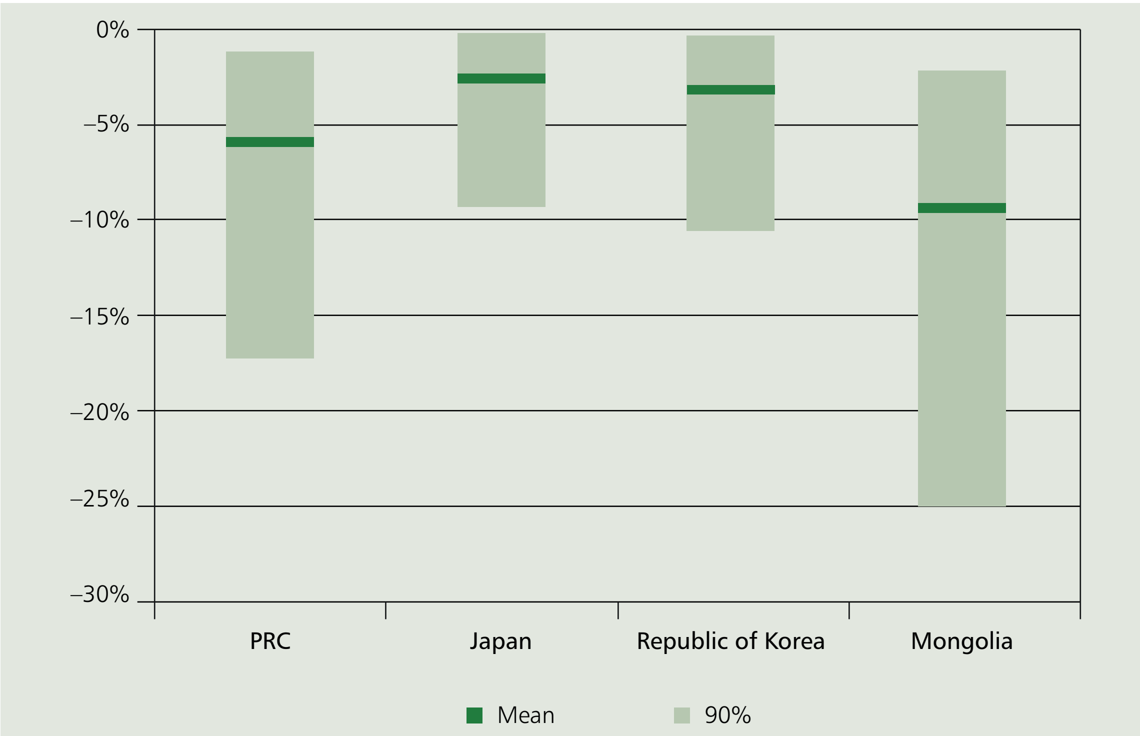
the economic and noneconomic impacts of climate change. The latitude adjustment in PAGE09 means that, as noted earlier, the difference in the mean increases in temperature up to 2100 for Mongolia and the PRC is 1.4° C for the model rather than 0.5° C for the mean of all GCMs. Economic and noneconomic losses increase with an exponent of up to 3 on the increase in temperature. The combination of these parameters means that the mean economic and noneconomic losses as percentages of projected GDP in Mongolia are more than 80% higher than the equivalent losses for the PRC and the difference is much larger for the top end of the probability distributions.

Copenhagen–Cancun Convergence scenario

The global climate under the CCC scenario would look very different to that under the BAU scenario. In the CCC case, the concentration of greenhouse gases in the atmosphere would peak at 455 ppm in 2050 and then drop to 440 ppm in 2100. The increase in the global mean temperature would reach 2° C around 2055—about 15 years later than under the BAU scenario (Figure 5). The rate of increase in the global mean temperature would gradually slow down. In 2100, the mean value of the global temperature would be about 2° C lower than under the BAU scenario, and the 95th percentile would be 2.9° C lower.

Figure 6 compares the mean values of the impact of climate change in 2100 by country for the BAU and CCC scenarios. If the increase in the global mean temperature is kept below 2.5° C, the total losses

Figure 4 Impact of Climate Change under the Business-as-Usual Scenario, 2100
(Losses as % of projected GDP)



GDP = gross domestic product, PRC = People's Republic of China.

Source: Asian Development Bank project team.

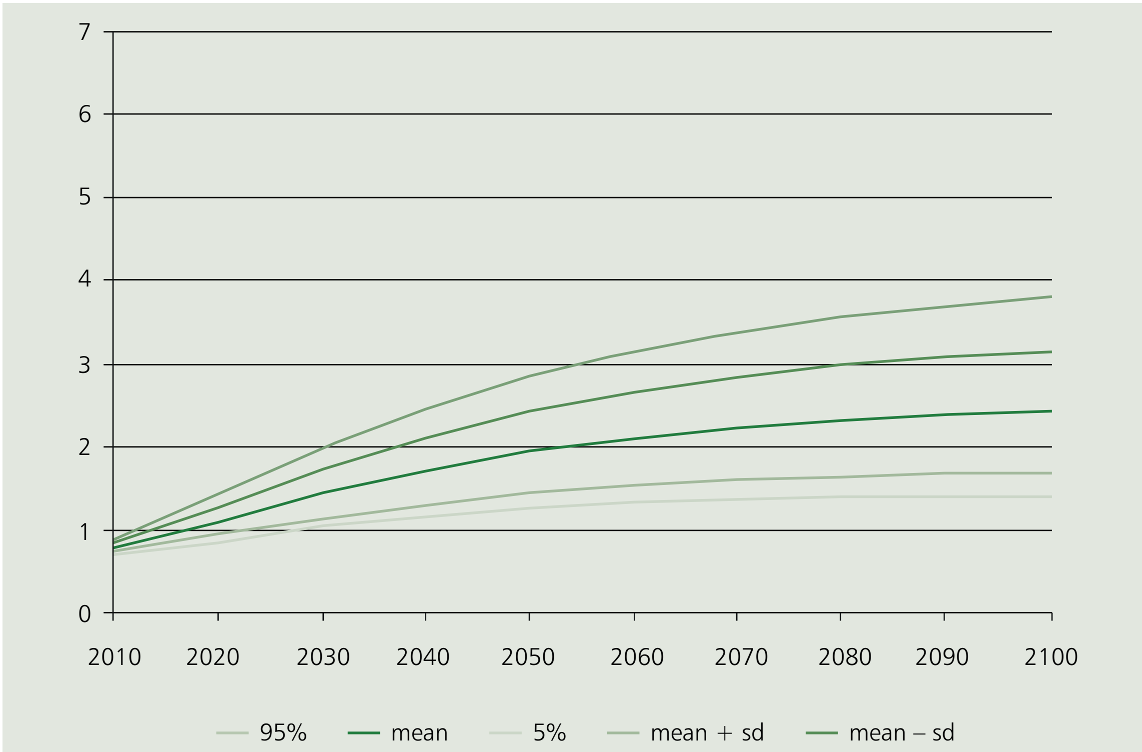
for East Asia will be about 1% of projected GDP. The largest beneficiary would be Mongolia, for which the mean value of the losses due to climate change would fall by 6.7% of projected GDP. Even so, it would remain the country in the region that is worst affected by climate change.

Abatement costs for the Copenhagen–Cancun Convergence scenario

Achieving the reductions in emissions envisaged in the CCC scenario would be a very large challenge. In Chapter 6 a set of marginal abatement cost (MAC) curves were derived for each country for 2020 and 2030 using detailed sector information. The results of this analysis were integrated with the PAGE09 MAC module. This uses a stochastic approach to project the impact of learning and scale effects, knowledge spillover and technical progress driven by mitigation targets on the MAC curves derived in Chapter 6, which are based on data about the technologies available in 2008. The projections assume that the location and curvature of the cost curves change over time at rates based on historical patterns of technical progress.[8] The time sequence of MAC curves generated by this procedure for the PRC is shown in Figure 7. From 2020 to 2050 the amount of zero-cost abatement gradually increases while the marginal costs increase less steeply as the level of abatement increases. After 2050 the difficulty of abating emissions tends to increase because the uncontrolled level of emissions is falling (Figure 1) because of shifts in the composition of economic activity and the technologies in use. Similar time sequences of marginal abatement costs have been constructed for the other countries in East Asia.

[8] Alberth S. and Hope C. 2007. Climate Modeling with Endogenous Technical Change: Stochastic Learning and Optimal Greenhouse Gas Abatement in the PAGE2002 Model. *Energy Policy*, 35, 1,795–807.

Figure 5 Increase in Global Mean Temperature under the Copenhagen–Cancun Convergence Scenario, 2010–2100 (° Celsius)



Note: sd = standard deviation.

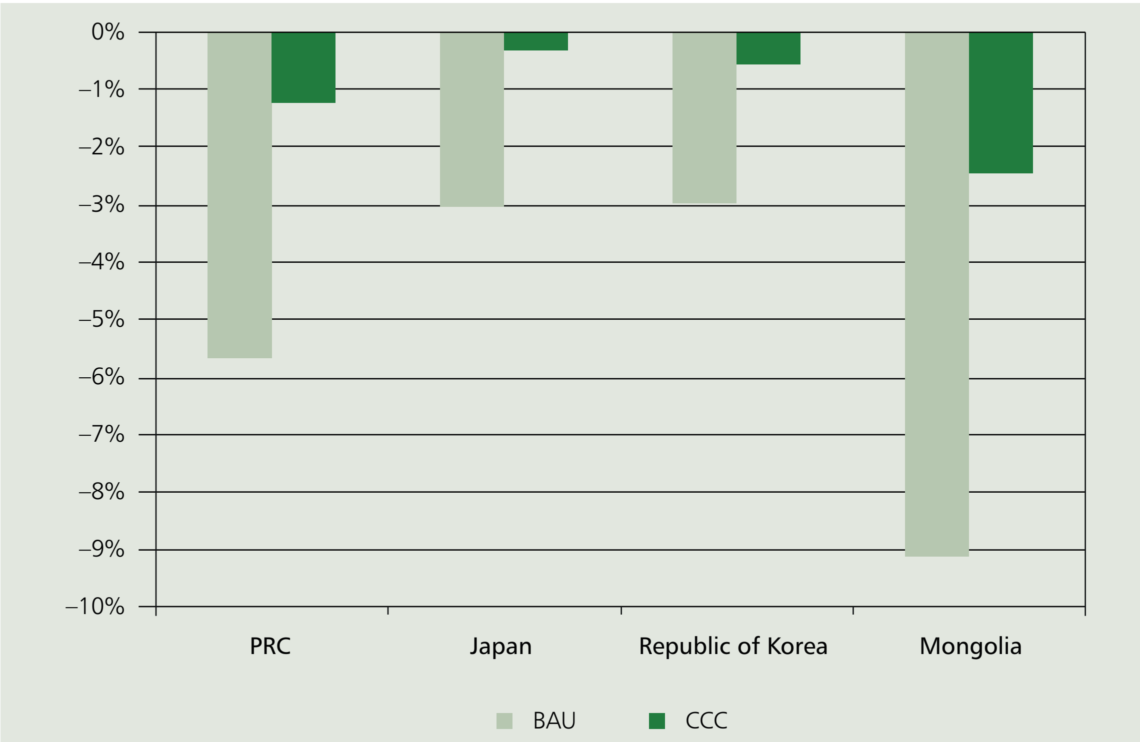
Source: Asian Development Bank project team.

Section B of Table 7 shows estimates of the marginal costs of abatement at constant prices by country and period associated with the CO_2 emissions reductions for the CCC scenario relative to the BAU scenario detailed in Section A of the table. The reduction targets are quite small in 2020 for the PRC and Mongolia, so they can be covered by measures that have negative cost (i.e., which save money in other respects). However, from 2030 onwards the targets are increasingly expensive to meet. Estimated costs which exceed $500 per tCO_2 are only indicators of orders of magnitude since the MAC curves provide very limited information above this level. It is clear that meeting the CCC targets for reducing CO_2 emissions will have a high marginal cost after 2020 in Japan and the Republic of Korea and after 2050 in the PRC.

One option for reducing the marginal cost of abatement would be to pool emissions and emission reduction targets within East Asia through some form of emission trading arrangement. The results of assuming that emission reductions are achieved by applying a uniform marginal cost of abatement across the region (referred to as the "East Asia Pool") are shown in the final two columns of Table 1. The large differences in marginal abatement costs by country for each time period indicate that there would be significant potential benefits from the adoption of emission trading. The marginal cost of abatement would still be high after 2050, but enabling Japan and the Republic of Korea to purchase abatement credits from, primarily, the PRC would ease the burden of meeting the CCC emission targets for these countries after 2020.

The potential benefits of pooling are illustrated by estimates of the annual costs of abating emissions on a country or a pooled basis shown in Section A of Table 2. The annual costs are calculated as the area

Figure 6 Impact of Climate Change under the Business-as-Usual and Copenhagen–Cancun Convergence Scenarios, 2100 (Losses as % of projected GDP)



BAU = business-as-usual scenario, CCC = Copenhagen–Cancun Convergence scenario, GDP = gross domestic product, PRC = People's Republic of China.

Source: Asian Development Bank project team.

under the MAC curves up to the relevant level of abatement for each year.[9] The net gain from pooling is shown the final column of Table 2 and is up to 25% of the unpooled (country by country) total from 2050 onwards. For 2020 and 2030 the pooled costs are negative, meaning that opportunities for reducing emissions in ways that would be economic without consideration of climate change are greater than the aggregate targets for reducing emissions. However, negotiating a mechanism that takes advantage of such opportunities will not be easy since it will involve very large transfers from Japan and the Republic of Korea to the PRC, especially in 2030.

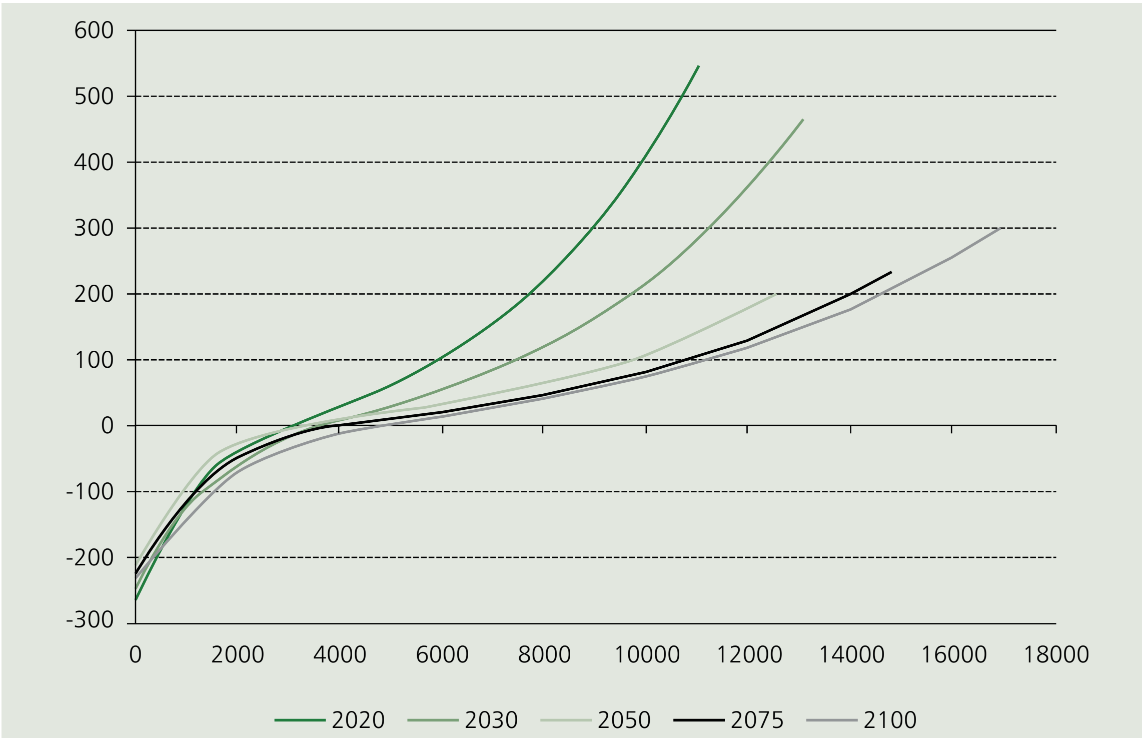
The relative burden of abatement under the CCC scenario varies widely across countries and over time, as illustrated in Section B of Table 2. For the PRC, the annual cost of abatement is negative until after 2030, whereas for Japan it is 3.7% of GDP in 2030 and for the Republic of Korea it is 8.6% in the same year. The annual burden of abatement increases gradually over time for the PRC, whereas for the Republic of Korea it falls after 2030 but remains above 6% of GDP until the end of the century.

Alternative policy scenarios

The large increase in the marginal cost of abatement from 2020 to 2030 shown in Table 1 is inefficient and probably infeasible as an economic strategy. The marginal climate damage caused by the emission of 1 $MtCO_2e$ in 2020 is more or less identical to that caused by the same amount of emissions in 2030, because of the lengthy residence time of CO_2 in the atmosphere. Applying the standard Hotelling rule

9 The estimation of annual costs is carried by linear interpolation, i.e., treating each segment of the MAC curve as if it is linear.

Figure 7 Time Sequence of Marginal Abatement Cost Curves under the Copenhagen–Cancun Convergence Scenario for the People's Republic of China
(Marginal cost of abatement in \$/tCO_2 versus aggregate abatement in MtCO_2)



MtCO_2 = million tons of carbon dioxide, tCO_2 = tons of carbon dioxide.
Source: Asian Development Bank project team.

Table 1 Marginal Cost of Abatement for Copenhagen–Cancun Convergence Emissions Relative to the Business-as-Usual Scenario

Year	PRC	Japan	Rep. of Korea	Mongolia	East Asia Pool
A. Reduction in emissions relative to BAU for CCC scenario (%)					
2020	3	42	31	17	9
2030	58	73	81	63	61
2050	92	91	95	80	92
2075	96	92	95	82	96
2100	97	95	98	88	97
B. MAC for emission abatement (\$ per tCO_2 at constant prices)					
2020	(169)	93	15	(20)	(130)
2030	79	892	806	38	100
2050	192	549	778	71	347
2075	832	617	855	71	772
2100	2,674	754	930	65	1,192

( ) = negative, BAU = business-as-usual scenario, CCC = Copenhagen–Cancun Convergence scenario, MAC = marginal abatement cost, PRC = People's Republic of China, tCO_2 = ton of carbon dioxide.
Source: Asian Development Bank project team.

Table 2 Annual Costs of Abatement for Copenhagen–Cancun Convergence Emissions Relative to the Business-as-Usual Scenario

Year	PRC	Japan	Rep. of Korea	Mongolia	East Asia Pool	Saving due to East Asia Pool
A. Annual costs in $ billion at constant prices						
2020	(67.6)	(42.2)	(21.3)	(0.2)	(201.0)	69.7
2030	(206.6)	192.6	161.2	(0.3)	(186.9)	333.7
2050	429.6	64.0	196.2	(0.2)	545.3	144.3
2075	666.4	89.1	222.4	(0.2)	962.3	15.4
2100	1,310.2	141.0	241.4	(0.1)	1,275.3	417.2
B. Annual costs as % of current GDP						
2020	0.4	0.9	1.4	1.6	0.8	0.5
2030	0.7	3.7	8.6	1.5	0.5	1.4
2050	0.8	0.9	7.3	0.5	0.8	0.4
2075	0.8	1.0	6.5	0.2	1.0	0.0
2100	1.5	1.4	6.5	0.1	1.3	0.4

( ) = negative, GDP = gross domestic product, PRC = People's Republic of China,

Source: Asian Development Bank project team.

for intertemporal efficiency in resource use suggests that the marginal abatement cost in year t should satisfy the condition:

$$MAC_t = (1+d)^{t-2020}\, MAC_{2020} \text{ for } t \geq 2020$$

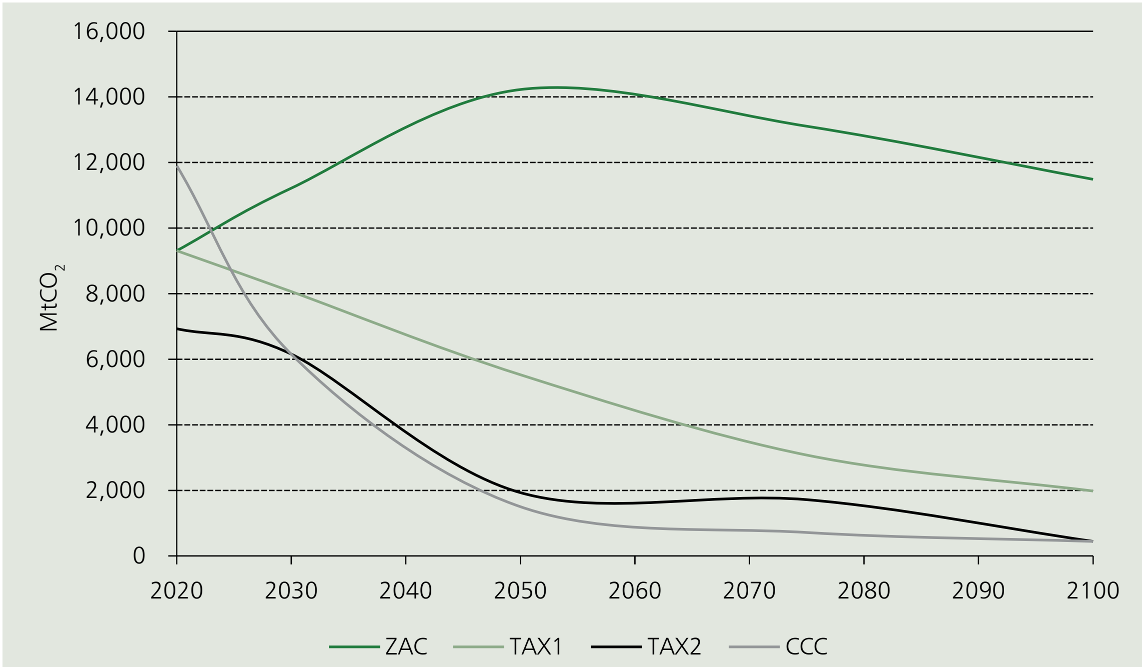
on the assumption that the efficient path starts in 2020 and in which *d* is the appropriate discount rate. Calculating the correct discount rate is complicated when differences between countries in future growth rates are taken into account. However, the PRC accounts for such a large share of total GDP and emissions in East Asia that it is reasonable to use a reasonable discount rate for the PRC in this case. Using the parameters built into the PAGE09 model, the discount rates for the PRC would have a geometric average of 5.6% from 2020 to 2050 and 3.8% from 2020 to 2100. Hence, using the Hotelling rule, a marginal abatement cost of $10 per tCO_2 in 2020 would rise to $51 in 2050 and to $201 in 2100.

While a full analysis of an efficient path over which to reduce emissions would incorporate a broader range of considerations, the basic principle of intertemporal efficiency captured by the Hotelling rule is still relevant. To explore the implications of alternative approaches, three alternative scenarios for reducing emissions have been examined:[10]

- **Scenario ZAC.** The scenario is an alternative to the BAU scenario in which all measures that have a negative or zero cost of abatement are adopted but no further effort to reduce CO_2 emissions is made.
- **Scenario TAX1.** The scenario corresponds to a highly simplified version of a carbon tax which increases over time. It is assumed that all negative- and/or zero-cost measures are adopted by 2020. After that the pooled marginal cost of abatement for all countries in the region

[10] In each case the paths of emissions assumed in the model for the European Union (EU) and the United States (US) are the same as those for Japan, while emissions for Southeast Asia and the rest of the world apply emissions reductions relative to the BAU that correspond to those for the PRC.

Figure 8 **Emissions for East Asia under Alternative Scenarios, 2020–2100** ($MtCO_2$)



$MtCO_2$ = million tons of CO_2.
Source: Asian Development Bank project team.

increases in steps to $50 in 2030, $100 in 2050, and $200 in 2100. The early values are somewhat higher than in the Hotelling path discussed above, representing a commitment to accelerate the reduction in emissions provided that the cost of doing so is not too high.

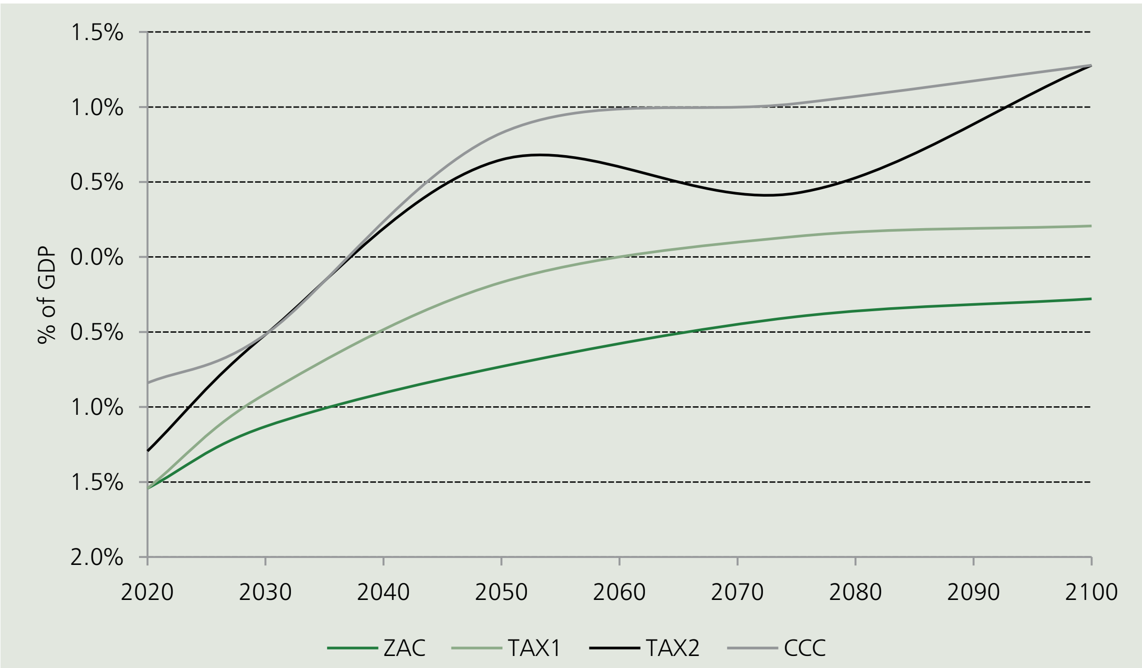
- **Scenario TAX2.** The scenario is close to the CCC scenario in terms of cumulative emissions from the region over 2020 to 2100 but it avoids the sharp increase in the marginal abatement cost in the period between 2030 and 2075. In this case the pooled marginal abatement cost is set at $50 in 2020, $100 in 2030, $200 in 2050, and $1,200 in 2100. The last value matches the MAC for the CCC scenario.

Figures 8 and 9 show the paths of emissions and abatement costs (as a percentage of GDP) for the three alternative scenarios (TAX1, TAX2, and ZAC) compared with the equivalent paths for the CCC scenario. The TAX1 scenario does not achieve as large reductions in emissions as the TAX2 and CCC scenarios but it has a total abatement cost that is negative up to 2050 and no more than 0.2% of GDP after 2050. By 2050, total emissions for East Asia are about half of their level in 2010 under the TAX1 scenario and by 2100 their level is less than 20% of that in 2010. In contrast, relying upon zero cost abatement alone does not prevent a steady increase in emissions after an initial decline up to 2020.

Planned adaptation and residual impacts

The scenarios imply different amounts of climate change relative to the initial climate in the model, so it is necessary to take account of both opportunities for planned adaptation to, and the residual impact of, such change. The results reported in Chapters 2–4 were used to calibrate the model for two broad adaptation strategies based on implementing and maintaining planned adaptation measures based on predicted climate change under the relevant emissions scenario up to either 2050 or 2100.

Figure 9 Abatement Costs for East Asia under Alternative Scenarios, 2020–2100 (% of GDP)



CCC = Copenhagen–Cancun Convergence, GDP = gross domestic product.

Note: TAX1, TAX2, and ZAC are alternative scenarios.

Source: Asian Development Bank project team.

The average values of, and the 90% confidence ranges for, the costs of planned adaptation from 2010 to 2100 are calculated for each scenario and adaptation strategy. The results are expressed as dollar values averaged over the period and as percentages of GDP. In addition, the residual damage after adaptation is estimated for 2100 to take account of the fact that planned adaptation cannot address all of the effects of climate change, such as the discontinuity impact, i.e., the risk of some uncertain but potentially catastrophic change.

The main results of the analysis of the two adaptation strategies for each emission scenario are shown in Table 3. The second column in the table gives the values of the key climate variables used in estimating adaptation costs. The average cost of adapting to the predicted climate for 2050 varies from 0.1% to 0.2% of GDP. These estimates are of a similar order of magnitude to the more detailed results reported above, though the specification of adaptation costs is greatly simplified in the PAGE09 model. Adopting a strategy of adapting to the 2100 climate adds 50%–85% to the average cost of adaptation. With some mitigation, such as for the TAX1 emissions scenario, the average cost of planned adaptation is about 0.3% of GDP with a 90% confidence range from 0.1% to 0.5% of GDP.

The cost of residual damage in 2100 after adaptation varies from 0.1% of GDP for the combination of planned adaptation to 2100 and the CCC emissions scenario to 2.3% of GDP for adaptation to 2050 and the BAU emissions scenario. It is clear that planned adaptation can substantially reduce the impact of climate change since the losses due to climate change for East Asia were estimated at 5.3% of GDP under the BAU scenario with no adaptation. This can be reduced to 1.6% of GDP with no change in emissions by adopting a strategy of planned adaptation to the predicted climate in 2100.

Table 3 Annual Costs of Planned Adaptation and Residual Damages for East Asia

Emission Scenario	Adaptation Targets	Average Annual Cost of Planned Adaptation		90% Confidence Range for Cost of Planned Adaptation (% GDP)		Residual damage in 2100 (% GDP)
		$ billion	% GDP	Low	High	
A. Adaptation to 2050 climate						
BAU	2.5° C, 0.30 m SLR	76.5	0.22	0.10	0.38	2.3
ZAC	2.3° C, 0.30 m SLR	71.1	0.20	0.09	0.35	1.2
TAX1	2.2° C, 0.30 m SLR	67.5	0.19	0.10	0.34	0.9
TAX2	2.1° C, 0.30 m SLR	64.3	0.18	0.08	0.32	0.6
CCC	1.7° C, 0.26 m SLR	51.4	0.14	0.07	0.26	0.2
B. Adaptation to 2100 climate						
BAU	4.5° C, 0.70 m SLR	140.3	0.41	0.20	0.69	1.6
ZAC	4.0° C, 0.65 m SLR	123.9	0.35	0.17	0.59	0.8
TAX1	3.3° C, 0.60 m SLR	101.6	0.29	0.13	0.48	0.7
TAX2	3.1° C, 0.60 m SLR	97.4	0.27	0.13	0.49	0.4
CCC	2.5° C, 0.55 m SLR	75.7	0.22	0.11	0.35	0.1

BAU = business-as-usual, C = Celsius, CCC = Copenhagen–Cancun Convergence, GDP = gross domestic product, m = meter, SLR = sea-level rise.

Note: TAX1, TAX2, and ZAC are alternative scenarios.

Source: Asian Development Bank project team.

Table 4 combines the estimates of mitigation, adaptation, and residual costs to provide a very approximate estimate of the net losses for East Asia associated with climate change, assuming different policy responses with respect to the mitigation of emissions and adaptation. Since the figures in the table are based on averages over 2010–2100, they assume no discounting, while the residual damage estimates rely upon linear interpolation which may overstate the extent of residual damage in the early part of the period.

The analysis does not take account of costs, in particular residual damage, that arise after 2100, so the results should be regarded as indicative rather than definitive. Even so, it is clear that any good policy response to climate change will require some combination of adaptation and mitigation. Of the options considered, the combination with the lowest overall cost of climate change (less than 0.1% of climate change) is the ZAC emissions scenario, which assumes that all negative- and zero-cost reductions in emissions are implemented, combined with planned adaptation to predicted climate conditions in 2100. The extent of climate change under this combination is substantial, with an average increase in global mean temperature of 4° C and an average sea-level rise of 0.65 meters.

This outcome may be regarded as unacceptable for reasons not incorporated in the model, in which case the strategy with the second-lowest cost of climate change is the TAX1 emissions scenario plus, again, planned adaptation to predicted climate conditions in 2100. As illustrated in Figure 8, this emissions scenario involves a gradual but still large reduction in emissions relative to the ZAC scenario spread over 2020–2100. The net cost of this combination of policies is less than half of the alternatives, which require more rapid reductions in emissions. Even without discounting, the introduction of opportunities for planned adaptation changes the ranking of mitigation policies by lowering the level of residual damage if emissions are not reduced as rapidly as required to meet the 450 ppm target for the concentration of CO_2 in the atmosphere.

The results in Table 4 are heavily influenced by the non-climate benefits that are generated by implementing negative-cost options for reducing emissions. It is arguable that this gives too favorable a view of such abatement options by ignoring the practical difficulties and costs which have so

Table 4 Net Average Annual Costs of Climate Change for East Asia

Emission Scenario	Average annual costs as % of GDP of			
	Mitigation	Adaptation	Residual Damage	Total
A. Adaptation to 2050 climate				
BAU	0.00	0.22	1.15	1.37
ZAC	(0.69)	0.20	0.60	0.11
TAX1	(0.30)	0.19	0.45	0.34
TAX2	0.23	0.18	0.30	0.71
CCC	0.49	0.14	0.10	0.73
B. Adaptation to 2100 climate				
BAU	0.00	0.41	0.80	1.21
ZAC	(0.69)	0.35	0.40	0.06
TAX1	(0.30)	0.29	0.35	0.34
TAX2	0.23	0.27	0.20	0.70
CCC	0.49	0.22	0.05	0.76

( ) = negative, BAU = business-as-usual, CCC = Copenhagen–Cancun Convergence,
Note: TAX1, TAX2, and ZAC are alternative scenarios.
Source: Asian Development Bank project team.

Table 5 Net Annual Costs of Climate Change for East Asia – Alternative Version

Emission Scenario	Average annual costs as % of GDP of			
	Mitigation	Adaptation	Residual Damage	Total
A. Adaptation to 2050 climate				
BAU	0.00	0.22	1.15	1.37
ZAC	0.00	0.20	0.60	0.80
TAX1	0.36	0.19	0.45	1.00
TAX2	0.92	0.18	0.30	1.40
CCC	1.10	0.14	0.10	1.34
B. Adaptation to 2100 climate				
BAU	0.00	0.41	0.80	1.21
ZAC	0.00	0.35	0.40	0.75
TAX1	0.36	0.29	0.35	1.00
TAX2	0.92	0.27	0.20	1.39
CCC	1.10	0.22	0.05	1.37

BAU = business-as-usual, CCC = Copenhagen–Cancun Convergence,
Note: TAX1, TAX2, and ZAC are alternative scenarios.
Source: Asian Development Bank project team.

far ensured that such options have not been implemented. Hence, Table 5 provides an alternative calculation in which abatement options that have a negative cost are assumed to have a zero cost from the perspective of climate policy. In this case, the gap between the net annual costs of the BAU scenario and the alternative emissions scenarios is narrowed. The CCC emissions scenario moves above the TAX2 emissions scenario in the ranking, but it remains the case that the ZAC and the TAX1 scenarios have the lowest and second-lowest net costs of climate change over the full period.

Discussion

The results from this exploration of alternative climate strategies using an integrated assessment model cannot be used to draw simple policy conclusions. The most direct trade-off is that between mitigation on the one hand and adaptation plus residual damage on the other. Looking at East Asia alone, the marginal cost of increased mitigation, e.g., moving from the ZAC scenario to the TAX1 scenario, is considerably greater than the reduction in the costs of adaptation plus residual damage. However, lower emissions in East Asia generate benefits for the rest of the world, while the levels of both adaptation costs and residual damage depend upon actions taken in the rest of the world.

A full analysis of the strategies available to countries in East Asia will depend upon what weight is given to within-region effects versus spillovers in the rest of the world. In addition, it requires information on abatement and adaptation costs in the rest of the world that go beyond the scope of a regional study.

There are, however, two general conclusions that emerge from the analysis.

- Regional pooling of emission reductions within East Asia, for example via a trading system, could offer opportunities to result in substantial savings in the overall cost of attaining overall emission targets.
- Climate policies should consider opportunities for a coherent overall framework, and the costs of adaptation and mitigation within it. The benefits of mitigation are long term and global, whereas the benefits of adaptation are more immediate and local. Neither should be neglected, especially when resources for addressing climate change are constrained and trade-offs between alternatives have to be made. Because of the complexity of the issues raised in developing strategies that balance adaptation and mitigation, it is important for countries and international agencies to develop the tools required for evaluating combined policies in advance rather than making judgments on the basis of incomplete evidence.

Chapter 8

Climate Policy in East Asia

Key Messages

- **Countries in East Asia have adopted and are implementing ambitious policies and programs to address climate change.** Energy intensity is decreasing and climate considerations are playing a central role in the policy discourse in all four countries. Japan and the Republic of Korea have focused on greener growth policies for some time. The latest 5-year plan of the People's Republic of China (PRC) has recognized the need to develop a more sustainable growth path for the world's second-largest economy.
- **Climate change policies and programs in East Asia have some common strengths.** These include the provision of public resources, regulatory policies for renewable energy, use of market mechanisms, emphasis on awareness-raising campaigns, and promotion of low-carbon investments.
- **Market arrangements to price carbon, via either carbon trading or carbon taxes, remain underdeveloped.** The PRC, Japan, and the Republic of Korea have made some initial progress in this regard, but much remains to be done.
- **The scale of funding for research and development and the level of innovation mean that the PRC, Japan, and the Republic of Korea are well-placed to develop new low-carbon technologies.**
- **There are a number of possible areas of regional cooperation, most notably a regional emissions trading scheme.** This would be a "win–win" situation for all the countries.

Introduction

The previous chapters have shown that a different model of economic development is needed for East Asia. This needs to build upon opportunities for "green growth," defined as "growth that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental impacts, and resilient in that it accounts for natural hazards and the role of environmental management and natural capital in preventing physical disasters."[1] Resilient, green growth presents an opportunity to generate new win–win situations for addressing climate change, gaining economic benefits, and reducing poverty.[2] Green sectors could potentially provide new sources of growth, lift the competitiveness of countries through industry upgrading, provide new and quality jobs, generate significant co-benefits (such as better air and water quality, and energy security), and help tap economies of scale from knowledge and technology spillovers across East Asia and beyond. While the concept of green growth is new, there have been recent efforts to develop metrics to assess and monitor countries' progress on green transformation in such areas as: natural asset base; environmental and resource productivity/ intensity; environmental quality of life (e.g. exposure to particulate air pollutants; policy and economic opportunities; and socioeconomic context.[3]

East Asia has adopted and is implementing ambitious policies and programs to promote green growth. Clean energy investments are substantial in the region, but more can be done. The public sector needs to set an appropriate price for carbon—through instruments such as carbon taxes or emission trading—to guide private consumption and stimulate private investment in low-carbon green technologies.

The challenge of rapid urban growth in the PRC is particularly important. From 2007 to 2025, the number of people in the largest (~600) cities in the PRC is expected to grow by 325 million, as the proportion of the population living in urban areas grows from 43% to 61%.[4] Higher incomes and the adoption of urban lifestyles will increase pressures on transport infrastructure and housing, running the risk that inefficient patterns of energy use will be locked in. Realizing the vision to move toward a green economy will require large investments together with the removal of institutional, political, and financial barriers.

Country Policies and Arrangements for Addressing Climate Change

Climate change mitigation and adaptation cover a myriad of disciplines. In all countries, these issues are handled by a range of institutions and ministries. Nevertheless, most countries designate an institution as a climate change focal point, which tends to take responsibility for bringing different policy strands together in a climate-change-specific framework. The following discussion on the institutional structure and policy framework in East Asia focuses on the key policy-making institutions that are responsible for the formulation of climate change frameworks and the integration of climate change policy in each country.[5]

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1 As defined by: World Bank. 2012. *Inclusive Green Growth: The Pathway to Sustainable Development*. Washington, DC. Other international institutions use slightly different definitions of green growth.
2 Asian Development Bank–Asian Development Bank Institute. 2013. *Policies and Practices for Low Carbon Green Growth in Asia.* Tokyo.
3 Green Growth Knowledge Platform. 2013. *Moving towards a Common Approach on Green Growth Indicators*. Paris.
4 McKinsey Global Institute. 2011. Urban World: Mapping the Economic Power of Cities.
5 Except where noted, the information comes from the background country reports.

People's Republic of China

In the PRC, the highest forum for debate on climate change issues is the Standing Committee of the National People's Congress on Positive Response to Climate Change. Administratively, climate change policy is subsumed in the functions of the National Development and Reform Commission, which formed the National Leading Group on Climate Change to coordinate all climate-related policies with line ministries, such as the Ministry of Agriculture and the Ministry of Transport. The PRC is also moving towards empowering local development and reform commissions to deal with responses to climate-induced disasters.

In June 2007, the PRC presented the National Climate Change Program, which set out the policies that the country intended to pursue to address climate change issues, in addition to delineating the PRC's position on issues raised by the international community regarding mitigation of greenhouse gas emissions and promotion of efforts to adapt to the changing climate (Box 1). In 2009, PRC announced that by 2020 CO_2 emission per unit of GDP will be reduced by 40–45%, non-fossil energy will account for about 15% of the total primary energy consumption, the forest area will be increased by 40 million hectares relative to 2005.[6]

During the 11th Five-Year Plan period, the PRC set a target of reducing its energy intensity (energy consumption per unit of GDP) by 20% compared to the 2005 baseline, and it achieved a 19.06% reduction, equivalent to a reduction of 630 Mtce (million tons of coal equivalent) in energy and a reduction in carbon dioxide (CO_2) emissions of 1,550 million tons. Energy efficiency improvements were the major driving force for CO_2 emission reductions (87% of the total), while the reduction in energy intensity was a function of both technological development (69% of the total) and structural adjustment (23%), such as the growth of low energy-consuming and high value-added industries and a concomitant decline in high energy-consuming, low value-added industries. During the period, through policy incentives and financial support, the PRC focused on several technology areas to improve carbon and energy efficiency: higher efficiency coal-fired power plants; energy efficiency improvement in the industry and building sectors; wind and solar energy; and carbon capture, utilization, and storage. [7] During the plan period, the PRC exceeded its target of coal plant retirements by 50%, closing almost 70 gigawatts (GW) of capacity.[8]

New implementation mechanisms over the period included an energy conservation target accountability system, energy performance contracting, and the Nation Renewable Energy Law. The energy conservation target accountability system holds local governments accountable for meeting energy intensity improvement targets set by regional and national government structures and ensures effective implementation of national policies. Energy performance contracting allows contracted private enterprises to pay upfront for, and profit from, energy intensity improvements resulting from energy efficiency measures. The Renewable Energy Law (2006) assigns renewable energy obligations for government agencies, enterprises, and the public, and addresses issues related to grid connection, financing, and cost distribution for renewable power. During this period, the PRC became the world leader in investment for renewable energy and energy efficiency and a major manufacturer of renewable energy technology (Box 2) (footnote 5).

Climate change policy in the PRC took center stage with the finalization of the 12th Five-Year Plan in March 2011.[9] The plan is significant in its commitment to energy efficiency and emissions reduction, and

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6 National Development and Reform Commission. 2012. *Second National Communication on Climate Change of The People's Republic of China*. Beijing.

7 Climate Policy Initiative. 2012. *Annual Review of Low-Carbon Development in [the People's Republic of] China (2011–2012): Chapter Summaries*. Beijing.

8 Climate Policy Initiative. 2013. *The Policy Climate*. San Francisco.

9 Government of the People's Republic of China. 2011. *[People's Republic of] China's Twelfth Five-Year Plan, 2011–2015*. Beijing.

Box 1 Key Objectives of Climate Change Policy in the People's Republic of China

Control of greenhouse gas emissions
Policy instruments:

- "Accelerating the transformation" of patterns of economic growth.
- Energy conservation and efficient utilization of energy resources, to be ensured through reinforced government supervision, but also by bringing new market mechanisms for conservation into full play.
- Expediting research and development and demonstration and deployment of energy conservation technology.
- Optimizing the energy consumption structure by aggressively promoting renewables, promoting nuclear power plant construction, and speeding up utilization of coal bed methane.
- Developing a "circular economy" which utilizes resources more efficiently, and reinforcing industrial policy governing metallurgy, building materials, and the chemical industry.
- Promoting adoption of low-emission and high-yielding varieties of rice, and more-efficient irrigation technology.
- Strengthening research and development of ruminant animal breeds, and reinforcing the management of animal waste and other solid waste, as well as promoting biogas utilization.
- Increasing forest cover to 20%.

Enhancing capacity for climate change adaptation
Policy instruments:

- Adjusting cropping patterns, selecting and breeding stress-resistant seed varieties, restoring grasslands.
- Establishing key ecological protection areas and enhancing ecological restoration.
- Promoting rationalized exploitation and optimized allocation of water resources.
- Afforestation in mangrove forests, monitoring sea-level change, and regulating the ecosystem of marine and coastal zone areas.

Other objectives of the climate change program in the People's Republic of China include enhancing research and development, both to understand the science of climate change and to stay on the frontier of research in energy conservation and management, and raising public awareness of climate change.

Box 2 The People's Republic of China – Global Leader in Energy Efficiency and Renewable Energy

Over the course of the 11th Five-Year Plan period, investment in renewable energy and energy efficiency in the People's Republic of China (PRC) has made the country the global leader in terms of investment. The PRC invested $399 billion in energy efficiency and renewable energy over the 11th Five-Year Plan period. Of that, $142 billion went to improve energy efficiency, with private finance accounting for 83% of that total. The PRC has also been the world leader in gross investment in renewable energy over the period 2009–2011. This increased 51% from 2009 to 2011, totaling $51 billion in 2011. In 2011, 87.7% was devoted to wind power, which reached 62.4 gigawatts (about 25% of world capacity), and solar photovoltaics, which reached 3.1 gigawatts (4.4% of the global market) accumulated installed capacity. The PRC has the most installed wind power capacity in the world. State-owned enterprises are the major developers in both the wind and solar photovoltaics markets in the PRC, accounting for 79.9% of total installed wind power capacity and 61.0% of total installed solar photovoltaics capacity in 2011. In 2012, PRC's renewable energy investment reached $67.7 billion, up 20% over 2011.[a]

This investment has translated into a strong position in terms of manufacturing of renewable energy technology. In 2011, the PRC had four of the world's top-10 wind turbine manufacturers, responsible for 26.7% of global sales. Moreover, nine of the top-15 solar photovoltaics manufacturers were located in the PRC (30% of global sales).[b]

[a] Climate Policy Initiative. 2012. *Annual Review of Low-Carbon Development in [the People's Republic of] China (2011–2012): Chapter Summaries*. Beijing; Climate Policy Initiative 2012. *The Landscape of Climate Finance 2012*. San Francisco.
[b] Renewable Energy Policy Network for the 21st Century Secretariat. 2012. *Renewables 2012 Global Status Report.* Paris.

Table 1 Targets of the 12th Five-Year Plan in the People's Republic of China

Target		2010	2015	Change over 5 years (%)	Forecast or Binding
Farmland reserves (billion *mu*[a])		1.818	1.818	0	binding
Decrease in water consumption per unit of value-added industrial output (%)				30.00	binding
Increase of water efficiency coefficient in agricultural irrigation		0.500	0.530	0.03	forecast
Increase of non-fossil-fuel usage in primary energy consumption (%)		8.300	11.400	3.10	binding
Decrease in energy consumption per unit of GDP (%)				16.00	binding
Decrease in CO_2 emissions per unit of GDP (%)				17.00	binding
Total decrease in emissions of major pollutants (%)	Chemical oxygen demand			8.00	binding
	Sulfur dioxide			8.00	
	Ammonia nitrogen			10.00	
	Nitrous oxides			10.00	
Forest increase	Forest coverage rate (%)	20.360	21.660	1.30	binding

CO_2 = carbon dioxide, GDP = gross domestic product.

Note: A mu is a Chinese unit of measurement (1 mu = 666.67 square meters).

Source: PRC, 12th Five-Year Plan 2011–2015.

is the first such plan to mention climate change as an issue. With regard to energy and environmental protection, the plan has eight targets, seven of which it designates as "binding."[10] The targets include reducing energy intensity (or energy consumption per unit of GDP) by 16% over the plan period, reducing CO_2 intensity (or carbon emissions per unit of GDP) by 17% over the same period, increasing the share of renewables in primary energy consumption to 11.4% from current levels of 8.3%, and reducing and limiting emission of nitrogen oxide and sulfur dioxide (Table 1). In addition, the PRC has expanded its "Top 1000" energy efficiency to the top 10,000 enterprises. This program includes energy audits, retirement of inefficient plants, and reporting and management requirements for energy efficiency (footnote 6).

The 12th Five-Year Plan (footnote 8) also emphasizes climate change adaptation. The main policies and actions include:

- Developing an overall adaptation strategy.
- Enhancing scientific research, observation and impact assessments on climate change.
- Considering climate change in the design of infrastructure.
- Accelerating research and development and deployment of adaptation strategies, especially with regard to extreme events.
- Improving climate change adaptation in key sectors like agriculture, forestry and water resources and in coastal and ecologically vulnerable regions.
- Enhancing monitoring, early warning systems and preparedness for extreme events and natural disasters.

Of note is the PRC's adherence to the UNFCCC principle of "common but differentiated responsibilities," according to which, developed countries are expected to take the lead in reducing greenhouse gas

[10] The plan does not specify what this implies, i.e., who will be held responsible, and in what way, if the target is not met.

emissions and are also encouraged to provide financial and technical support to developing countries to cope with adaptation.

Japan

The lead climate change policy-making body in Japan is the Global Warming Prevention Headquarters, established in 1997 to oversee implementation and promotion of climate change policies. It is headed by the prime minister, and includes the chief cabinet secretary; the minister of the environment; and the minister of economy, trade, and industry as deputy chiefs; the remaining cabinet constitutes the general body of members. Since September 2009, however, and climate change issues have been discussed instead at another cabinet committee, the Ministerial Committee on Global Warming Issues. Members of the committee include the prime minister, the deputy prime minister, the cabinet minister, and other ministers (including ministers for the environment; economy, trade, and industry; foreign affairs; and finance). The committee regulates the actions of the Japanese Ministry of Environment, which was formed in 2001 to regulate all environmental issues. In addition, the Environmental Policy Division, working under the aegis of the Industrial Science, Technology Policy and Environment Bureau of the Ministry of Economy, Trade, and Industry, regulates the environmental standards specified for industry.

In Japan, climate change policy takes the form of a number of targeted initiatives, many of which are aimed at stimulating the economy through "green" measures. The key policy document guiding post-tsunami policy in Japan is the Comprehensive Strategy for the Rebirth of Japan, prepared in July 2012.[11] The strategy, which outlines actions for reviving growth following the Great East Japan Earthquake, advocates extensive redesign of energy and environment policies (Box 3).

The Government of Japan has implemented fiscal stimulus on a large scale, which has included support to energy efficiency programs and development of renewable energy technologies. Between August 2008 and April 2009, the government launched four stimulus packages, worth almost 5% of gross domestic product (GDP),[12] which included funding for energy efficiency labeling for home appliances, subsidies for low-emission vehicles, and support for renovation of buildings. In addition, Japan's New Growth Strategy approved in June 2010 identifies green innovation as one of seven strategic areas which will stimulate growth (footnote 2, 63). Japan has also implemented some innovative measures, such as the Team 25% Campaign (Box 4).

Japan has also successfully launched a series of local initiatives, such as the Sustainable Shiga initiative in 2007 (which aimed to improve water quality in Lake Biwa in Shiga prefecture), Low Carbon Kyoto (where a local research team prepared a road map to achieve "low carbon" status for the city by 2030), Carbon Minus Tokyo (where a similar 10-year plan was prepared by the Tokyo metropolitan government in 2007), and the designation of selected municipalities as "environmental model cities" in 2008 and 2009.

This last initiative was later developed further to visualize Eco Future cities, under which the government aims to institutionalize low-carbon city planning policies in major cities. Thus, under the Eco Future cities program, city planners will make plans to expand the use of renewable energy in cities, institute the use of smart-grid technology and next-generation vehicles, and draft legal frameworks to support such development. The Government of Japan's Basic Strategy for Revitalizing Japan, the blueprint for revival of Japan's economy post-tsunami, includes plans to create 11 such cities.

[11] National Policy Unit. 2012. *Comprehensive Strategy for the Rebirth of Japan - Exploring the frontiers and building a "Country of Co-creation."* Tokyo: Government of Japan.

[12] Kawamata, K. 2011. *Japan Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report). Manila.

Box 3 Energy and Environment Policy Redesign in Japan

From nuclear energy to green energy:

- Increase the share of renewables in the energy mix from 2% at present (excluding hydro power) or 10% (including hydro power) to 25%–30% or higher by 2030.
- Reduce energy consumption by 20% from current levels by 2030.

Measures to be taken by government:

- Reform the power supply system by enhancing the neutrality of power grids and developing a competitive market for power.
- Facilitate the creation and dissemination of new products by reviewing regulations and systems as well as promoting standardization.
- Reinforce power grids to adapt to changes in the energy market.
- Develop gas pipelines.
- Form communities that make efficient use of energy by using information technology.
- Support long-term research and development that creates new technology.
- Undertake public investment to create initial demand for advanced technology.
- Propose detailed energy efficiency measures for the residential sector, which has been overlooked in the past.

The government's Green Growth Strategy, which is part of the Rebirth initiative, envisages the following goals for 2020:

- Create new environment-related markets worth ¥50 trillion or more and new employment of 1.4 million or more in environment.
- Up to 50% of next-generation automobiles in total new car sales.
- Install 2 million ordinary chargers and 5,000 quick chargers for automobiles.
- Japanese companies capture 50% or ¥10 trillion of global storage battery market.
- Establish Japan's position as a leader in infrastructure development, and capture a market in development of climate-resistant infrastructure, worth ¥19.7 trillion.
- Install light-emitting diodes (LEDs) and other highly efficient lighting equipment in all public facilities through promotion of measures utilizing energy service companies and lease contracts.
- Standardize net-zero-energy homes and realize net-zero-energy commercial buildings.
- Renovate existing homes as energy-saving homes (about twofold increase from the current number).
- All new homes meet energy-saving standards.
- Floor space of 10 million square meters of environmentally friendly real estate.

Republic of Korea

As in the case of Japan, the Republic of Korea elevated climate change policy to the highest level by creating the Presidential Commission on Green Growth in 2008. The commission was tasked to draft a fundamental law that would promote low-carbon green growth in the country, and succeeded in drafting the Framework Act on Low Carbon Green Growth, which became law in January 2010. For overall regulation of climate-change-related issues, the key institution in the Republic of Korea is the Ministry of Environment, specifically the Green Environment Policy Office, a suboffice of the Environmental Policy Department. In addition, the department also includes the Climate and Air Quality Management Office, which is responsible for control of air pollution.

The Republic of Korea's climate change policy vision is encapsulated in the National Strategy and Five-Year Implementation Plan (2009–2013), which aims to achieve the goal of the Presidential Commission on Green Growth—i.e., making sure that the Republic of Korea is recognized as one of the top seven green states by 2020.[13] The plan stipulates that the government will set aside an amount equivalent to 2% of GDP for expenditure in the area of climate change and energy efficiency, sustainable transportation, and the development of green technologies every year from 2009 to 2013. The government also issued a

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[13] Lee D.K. and M.K. Lee. 2011. *Republic of Korea Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report).

Box 4 Civil Initiatives to Promote Green Growth in Japan and the Republic of Korea

The Government of Japan launched the Team 25% Campaign in December 2009 to raise public awareness and promote low-carbon lifestyles. The team is headed by the prime minister, followed by the minister for the environment. As of December 2010 there were 412,183 people and 15,130 organizations registered in the campaign. The Team 25% Campaign specifies six challenges and 25 actions for the team members to take in order to reduce emissions. The six challenges are to

(i) adopt an eco-friendly lifestyle,
(ii) purchase energy-saving products,
(iii) choose renewable energy,
(iv) select eco-friendly housing and buildings,
(v) support wider initiatives for carbon dioxide emissions reduction, and
(vi) participate in community-based climate change actions.

These six challenges are further broken down into 25 actions which participants can adopt in their everyday lives. This includes choosing eco-friendly products such as compact fluorescent light bulbs, solar panels, and other products with lower carbon footprints and food mileage; adjusting lifestyles including carpooling; moderate use of air-conditioning; and additional measures such as purchasing carbon offset credits.

A similar program has also been in place in the Republic of Korea since August 2009. The Low-Carbon Green Lifestyle Action Plan aims to reduce 10% of lifestyle-related greenhouse gas emissions and help create a low-carbon lifestyle. The program is centered around awareness raising for households and providing them with information on how to develop a low-carbon lifestyle, adopt eco-friendly food, and reduce energy and water consumption. The program hosts events such as eco-friendly driving contests, encourages the use of public transportation, and promotes walking to promote concepts of eco-friendly transportation. Individual citizens and civil groups are encouraged to initiate low-carbon actions through incentives such as carbon points. As part of the green lifestyle support system, 50,000 "green leaders" will be trained by 2015. The creation of green campuses and green schools will also be encouraged.

The plan builds on earlier initiatives such as the Green Start National Network formed in October 2008 to promote green growth through citizen participation. As of June 2010, around 37 groups—which include the Korean Chamber of Commerce and Industry, Presidential Commission on Sustainable Development, and Korea Federation of Teacher's Associations—had joined the network, along with a majority of the local governments in the Republic of Korea. The Green Start movement also encompasses the WE Green (or women's green) movement and the Green Energy Family movement.

framework Act on Low Carbon Green Growth in 2009, which sets out milestones for the National Green Growth Strategy. In November 2009, the Presidential Committee on Green Growth announced that the government's emission reduction target had been set at a 4% reduction from 2005 levels by 2020 (or a 30% reduction compared to the business-as-usual scenario) (Box 5).

The government has launched a number of initiatives to promote the green economy in the Republic of Korea. A pilot project on mandatory negotiated agreements on energy use was launched covering 38 firms in 2010. These resulted in agreements to reduce energy use by 3.7% compared to the 2007 average by 2012. The country has also introduced mandatory energy efficiency standards and labeling for 23 consumer items, and has encouraged manufacturers to produce appliances that automatically switch to power saving mode when not in use. Car manufacturers in the Republic of Korea are required to meet average fuel economy standards.

The government has also successfully used fiscal policy for mitigation. Revenue from environmental taxes constituted 2.5% of GDP in 2008, surpassing the Organisation for Economic Co-operation and Development (OECD) average of 2%.[14] The share of taxes in energy prices in the country is higher than in North America, although lower than in Europe.

[14] Jones, R. S. and B. Yoo. 2011. Korea's Green Growth Strategy: Mitigating Climate Change and Developing New Growth Engines. *Economics Department Working Papers No. 798*. Paris: OECD.

Box 5 Key Elements of the Republic of Korea's Green Growth Strategy

Objectives:
- Promote synergies between economic growth and environmental protection.
- Improve quality of life and promote a green revolution in everyday lifestyles.
- Contribute to international efforts to combat climate change.

Strategies:
- Mitigate climate change and promote energy independence.
- Create new engines for economic growth.
- Improve the quality of life of the country's people and enhance the Republic of Korea's international standing as a leader in green growth policy.

Policies for Achievement of Strategies:
- Effective mitigation of greenhouse gas emissions: The government is to pursue mitigation strategies in building codes, as well as in transport, industry and afforestation. It will also require reporting on emissions by industry.
- Reduce the use of fossil fuels and the enhance energy independence: The country is to reduce energy intensity to the Organisation for Economic Co-operation and Development (OECD) average, increase the use of renewable energy, and expand nuclear power capacity.
- Strengthen the capacity to adapt to climate change: the Republic of Korea to launch the Four Major Rivers Restoration Project and increase the share of environmentally friendly agricultural products to 18% by 2020.
- Develop green technologies: the Republic of Korea to pursue development of important green technologies, boosting its world market share in the relevant sectors to 8% within 5 years.
- The "greening" of existing industries and promoting green industries: Encourage growth of export-oriented green industry and help small and medium-sized enterprises to "green" their business.
- Encourage the growth of high value-added services.
- Introduce an emissions trading system, provide tax incentives to green industry, and extend public credit guarantees to the same.
- Encourage mass transit and railways.
- Encourage households to make better consumption decisions by initiating carbon footprint labeling on appliances.
- Become more active in international climate change negotiations.

Mongolia

Mongolia established the interagency and intersector National Climate Committee led by the minister for nature, environment, and tourism to coordinate and guide national activities and measures aimed to adapt to climate change and to mitigate greenhouse gas emissions. The committee is mandated to approve the country's climate change policies and programs, evaluate projects, and guide policy interventions. It is also the lead agency responsible for implementing the commitments made under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. The lead ministry for climate change policy implementation is the Ministry of Nature, Environment, and Tourism, while the National Agency for Meteorology, Hydrology, and Environment Monitoring has been designated as the operational organization for climate monitoring and research.

The key climate change policy document in Mongolia is the National Action Plan for Climate Change, prepared in 2000.[15] In addition, the parliament approved the Comprehensive National Development Strategy, anchored on the Millennium Development Goals, in January 2008. The strategy pledged to encourage sustainable development, conserve ecosystems, and promote measures that enable adaptation to climate change. In addition, the National Renewable Energy Program (2005–2020) aims to increase the percentage of renewable energy in total generation to 3%–5% by 2010 and 20%–25% by 2020.

[15] Batbold, J. and N. Enebish. 2011. *Mongolia Country Report on Climate Change and Low Carbon Growth Strategies* (TA 7465 report). Manila.

The Key Pillars of Climate Policy

Use of public resources

Japan has led the way in directing public resources towards programs that provide "win–win" solutions for economic revitalization as well as cost-effective sustainable development. The series of fiscal stimuli since 2008 have directed significant funds towards energy efficiency, renewable energy, and related research and development. The Government of the Republic of Korea estimated that close to $97 billion will be spent on supporting green growth during 2009–2013. The continuous 5-year execution would mean that the country would spend almost $20 billion per annum (2% of annual GDP). In 2009, 16% of government research and development investment was on green technology, and this will be increased to 20% by 2013.

The PRC has also undertaken a number of initiatives to direct public resources towards mitigation. Over the 11th Five-Year Plan period (2006–2011), the central government allocated about CNY14 billion of financial subsidies to the production of 200,000 energy efficient vehicles, a batch of high-efficiency energy-saving motors, and other energy efficient products. In 2009, it started the Venture Capital Investment Scheme for newly emerging industries, initiating 18 venture capital investment funds to support the growth of innovative enterprises in the fields of energy conservation, environmental protection, and development of new energy. In December of the same year, the National People's Congress further specified that the PRC would set up a renewable energy development fund to facilitate a full-amount purchase system for renewable-based power generation and to generate resources for, among other things, scientific and technological research into renewable energy, the formulation of standards, demonstration projects for renewable technology, promotion of renewable energy consumption in rural areas, and the institution of independent power generating systems in remote areas and on islands. Cumulatively, the PRC invested $266.6 billion in new energy and renewable energy during 2006–2010 (Box 1) (footnote 5).

The role of market mechanisms

Japan and the Republic of Korea have taken the lead in innovative use of market mechanisms to promote green technology. Japan's Eco-Point program has recently been extended to housing in the tsunami-affected Tohoku region.[16] In the PRC, the State Council is stressing the increased use of market mechanisms, coupled with government regulation, to promote energy efficiency. The PRC's Generation Rights Trading program assigns tradable quotas to coal-based electricity operators across 23 provinces. Operators who exceed their efficiency targets can trade quotas with those who cannot meet targets, thus creating a market for efficiency quotas. In 2007, this scheme is believed to have saved the equivalent of 6.2 million tons of coal.[17]

Renewable energy

All the countries in East Asia have national regulatory policies for renewable energy. With the exception of the Republic of Korea,[18] all the countries have national feed-in tariffs. The PRC, the Republic of Korea, and Japan have mandated renewable portfolio standards,[19] while the Republic of Korea and

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16 http://www.japantoday.com/category/national/view/japan-starts-eco-point-program-for-housing

17 Asian Development Bank–Asian Development Bank Institute. 2013. *Policies and Practices for Low Carbon Green Growth in Asia*. Tokyo.

18 The Republic of Korea feed-in tariff that was operational throughout 2011 has been replaced by a renewable portfolio standards policy for 2012.

19 A quota renewable portfolio standard is an obligation (mandated and not voluntary) placed by a government on a utility company, group of companies, or consumers to provide or use a predetermined minimum share from renewables of either installed capacity, electricity generated, or electricity sold. As defined by: Renewable Energy Policy Network (REPN) for the 21st Century Secretariat. 2012. *Renewables 2012 Global Status Report.* Paris.

Japan have net metering laws[20] and tradable renewable energy certificate schemes.[21] In the PRC, for example, the renewable portfolio standards and feed-in tariff have resulted in dramatic increases in wind power—the installation capacity increased 40-fold from 2005–2010 (footnote 6). In 2012, both the PRC (with installed capacity of 152 GW) and Japan (with installed capacity of 27 GW) were in the top-10 globally for installed renewable energy capacity and clean energy investment (Box 1), while the Republic of Korea experienced an increase of 61% in investment between 2011–2012.[22]

Emphasis on climate change awareness-raising programs

Japan and the Republic of Korea have also focused on communicating the green economy message at the grassroots level. Programs which aim to reduce greenhouse gas emissions by promoting low-carbon lifestyles include the Team 25 Campaign in Japan (Box 3) and the Low Carbon Green Lifestyle Action Plan in the Republic of Korea. In Mongolia, the European Union is assisting in development of an eco-labeling program.

Mainstreaming climate change in national policy

All four governments in East Asia have effectively mainstreamed climate considerations in overall national economic policy. Japan's fiscal stimulus packages have focused on promoting climate-friendly initiatives, while aiming to revive economic growth. The Republic of Korea's emphasis on green growth encompasses all sectors of the economy and even seeks to influence the energy use habits of citizens. The PRC's 12th Five-Year Plan has brought climate considerations into the forefront of national planning. Lastly, Mongolia's growth model, which rests largely on developing sustainable mining practices and on conserving rangelands, also acknowledges the need to adopt climate-friendly practices for the long term.

Future Developments in Climate Policy

The role of domestic and/or regional carbon markets

A regional carbon market for East Asia comparable to the European Union carbon market does not exist. Domestic carbon markets in East Asia, however, are in the early and promising stages (Chapter 6, Box 4).

In November 2009, the Government of the PRC set a target to reduce CO_2 emissions by 40%–45% per unit of GDP by 2020 based on the 2005 level. The government has also set targets to reduce energy consumption per unit of GDP by 16% and CO_2 intensity by 17% during the 12th Five-Year Plan period (2011–2015). Local governments have set similar energy intensity reduction targets for this same period (i.e., Beijing by 17%, Shanghai by 18%, and Guangdong by 18%). In November 2011, the National Development Reform Commission announced pilot programs for carbon emission trading that were approved by seven municipalities and provinces (Beijing, Chongqing, Guangdong, Hubei, Shanghai, Shenzhen, and Tianjin). These pilot regions for emission trading schemes host a population of 200 million, account for 30% of total GDP, and account for more than 20% of CO_2 emissions.

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20 Net metering, also called "net billing," enables self-generated power used on-site to offset electricity purchases. Any excess power is sold to the grid for a pre-determined price. As defined by REPN (footnote 18).

21 Renewable portfolio standards policy (footnote 18).

22 The Pew Charitable Trusts. 2013. *Who's Winning the Clean Energy Race? 2012 Edition*.

Box 6 Carbon Taxes or Carbon Trading?

Implementation of a carbon tax would be an alternative to a carbon market. Carbon taxes are in theory a cost-effective strategy to reduce greenhouse gas emissions. They serve to monetize the social costs of emissions, and are an effective deterrent for polluters, who otherwise do not need to factor negative externalities into their cost–benefit analyses.

Nevertheless, carbon taxes are resisted in many countries as they can be regressive (since they are typically taxes on transactions and not on production or income). In addition, policy makers are reluctant to impose such taxes for fear that they will discourage entrepreneurship or force enterprises to relocate. The advantages and disadvantages of such taxes have been debated in the literature, and examples of implementation of fiscal measures to control carbon emissions are now available from Europe, Australia, and some states in the United States.

A more detailed study of the possible impacts of such a tax in East Asia is needed.

The priorities of the Government of the PRC in promoting the piloting of emission trading schemes are (i) developing a national guideline on greenhouse gas reporting at the enterprise level as part of measurement, reporting, and verification; (ii) capacity building on regional emission trading schemes for local officials and researchers; (iii) developing trading rules and the scope, allowance allocation, regulatory system, and registry for regional and/or national emission trading schemes; and (iv) developing potential links between regional and national emission trading schemes to enable future trading among regional platforms. The preparation for piloting regional emission trading schemes is ongoing, with the aim to establish a national scheme in 2015.

The emissions trading scheme in the Republic of Korea is not projected to come into effect until 2015 (Chapter 6, Box 4).

As of April 2013, no notable progress had been made on the design of a national emissions trading scheme in Japan.

Support to vulnerable communities

Policies in East Asia tend to focus on technical solutions while not adequately addressing the needs of vulnerable communities, such as nomadic communities in Inner Mongolia Autonomous Region and Mongolia. In both the PRC and Mongolia, there is a need for more social protection to cushion against the livelihood impacts of climate shocks.[23]

Policies for Innovation to Enhance Climate Policies

The People's Republic of China, Japan, and the Republic of Korea rank highly in terms of research and development and innovation

Research and development and innovation are important factors in helping to foster green growth[24] and develop technologies for climate change mitigation and adaptation. The PRC, Japan, and the

[23] World Bank. 2010. Reducing Human Vulnerability: Helping People Help Themselves. In *World Development Report 2010: Development and Climate Change*. Washington, DC.

[24] Growth that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental impacts, and resilient in that it accounts for natural hazards and the role of environmental management and natural capital in preventing physical disasters. World Bank. 2012. *Inclusive Green Growth: The Pathway to Sustainable Development.* Washington, DC.

Republic of Korea are well placed in this regard. In 2010, the PRC spent $179 billion on research and development, ranking it second in the world; Japan spent $141 billion, ranking it third; and the Republic of Korea spent $53 billion, ranking it fourth. In terms of research and development spending as a percentage of GDP, the Republic of Korea is second in the world and Japan fourth (both over 3%), and Japan spent the most worldwide on energy as a percentage of government research and development spending.[25] In 2008, the ratio for the PRC remained relatively low at 1.7% but it has more than doubled from 0.8% in 1999.[26]

In terms of patents, Japan was ranked first in the number of patents per capita in 2010 (footnote 6). From 2000 to 2005, Japan was ranked in the top three globally for the total number of green innovations, based on key greenhouse gas mitigation technologies; the PRC was in 10th place—the only emerging economy represented among the top 10 high-quality innovating countries.[27] In a prospective ranking of innovation for 2009–2013, Japan tops the list, followed by the Republic of Korea, while the innovation index is projected to increase markedly in the PRC.[28]

Opportunities for Regional Cooperation

Develop a regional emissions trading scheme

As discussed in Chapter 7, a regional carbon market which permitted the pooling of CO_2 reduction targets would allow countries to meet their targets at significantly lower cost than acting alone. The PRC has many more inexpensive mitigation options than Japan and the Republic of Korea, and so these countries could reduce their national emissions more cost-effectively by purchasing carbon credits (financing mitigation projects) in the PRC and Mongolia. In turn, they would realize substantial benefits from a combination of technology transfer and the reduction in local air pollution that would be associated with implementation of abatement measures.

Provide technical assistance and finance to Mongolia for adaptation

Technical assistance and finance could be provided to Mongolia for adaptation. Assistance could take a number of forms: climate finance, investment in hydro-meteorological services and early warning systems (EWSs), and technical assistance on arid lands and water management. There is an opportunity to link social protection and climate finance through the extension of index-based livestock insurance. While there is an existing index-based livestock insurance scheme in Mongolia, there is no certainty that this program will continue beyond 2014.

There are some important EWS initiatives in Mongolia. In 2004, an EWS for livestock (Gobi Forage Project) was developed through a project funded by the United States Agency for International Development and the Global Livestock Collaborative Research Support Program, implemented by Mercy Corps. The EWS includes a forage monitoring system which enables real-time assessment of forage conditions, in addition to allowing livestock herders to monitor nutritional conditions of their herds and assess changes in body conditions. As of the end 2010, the Gobi Forage Project covered

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25 Organisation for Economic Co-operation and Development. 2012. Main Science and Technology Indicators Database: 2012/1 edition.

26 United States National Science Foundation. 2012. Science and Technology Indicators: 2010. http://www.nsf.gov/statistics/seind12/c4/c4s8.htm

27 Dutz, M. A., and S. Sharma. 2012. Green Growth, Technology and Innovation. *Policy Research Working Paper 5932.* Washington, DC: World Bank.

28 The Economist Intelligence Unit. 2009. A New Ranking of the World's Most Innovative Countries.

802 forage monitoring sites across all 21 *aimags* (provinces).[29] However, the future of the project is uncertain; a proper institutional framework will be required if it is to continue and be extended.

There is a need to strengthen hydro-meteorological systems in Mongolia.[30] In 2009 there were only 120 operational weather stations. The economic returns from investing in the collection and dissemination of hydro-meteorological information are substantial, with benefit–cost ratios of between 4 and 36 by one estimate.[31]

Create an East Asian climate network

East Asia should, in the short-to-medium term, consider moving towards formulation of a climate network to promote collaborative research and information dissemination on regional climate change. Japan has taken the lead in the formation of a collaborative network on climate change. At the G-8 Environment Ministers Meeting in April 2009, leaders endorsed the establishment of the International Research Network for Low Carbon Society (LCS-RNet). LCS-RNet held its first annual meeting in Italy in October 2009. Ten research institutions from six countries including Japan and the Republic of Korea are participating in this network. However, the network's agenda is fairly diffuse and spread over a wide geographical area.

Other international initiatives in which Japan has played a key role include the Clean Asia Initiative launched in 2008 to promote information sharing and to build mutual support on common environmental issues of the region; and the Asia–Pacific Partnership on Clean Development and Climate, which brings together seven major Asian and Pacific countries in an effort to address increased energy needs and the associated issues of air pollution, energy security, and climate change.[32] As a multilateral and regional public–private partnership between industry and governments, the partnership focuses on the one hand on industry sector cooperation across countries to develop and deploy advanced technologies, and on the other hand on regulatory reform to remove identified barriers to technology development and deployment.

In adaptation, the Asia-Pacific Adaptation Network (APAN) is a regional knowledge sharing and capacity building mechanism launched in October 2009 during the UNFCCC Bangkok Talks as a part of the Global Adaptation Network. The network was built as a response to the call from parties in the UNFCCC negotiation "to promote existing networks for assessment of impacts, vulnerability and adaptation and encourage the establishment of new networks."[33] APAN is facilitated by the Asian Development Bank, the United Nations Environment Programme (UNEP), the Regional Office for Asia and the Pacific, the Asian Institute of Technology/UNEP Regional Resource Centre for Asia and the Pacific, the Institute for Global Environment Strategy, and other partners.

While all of these initiatives have contributed to the development of climate policies in the region, a dedicated network focusing on East Asia and covering the range of issues from mitigation to adaptation and policy advice would be a useful enterprise, inasmuch as it would focus on this specific region and provide a forum for in-depth research. This network could also include development of online knowledge platforms and tools, and would serve as an exchange and knowledgebase for data on

29 Mongolia Livestock Early Warning Systems (LEWS) Project. *Annual Report. 2010*. p. 17. http://www.mercycorps.org
30 Ministry of Environment, Nature and Tourism Mongolia. 2009. *Mongolia Assessment Report on Climate Change 2009.* Ulaanbaatar.
31 Hallegatte, S. 2012. A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation. *World Bank Policy Research Working Paper* 6058. Washington, DC.
32 The countries are Australia, Canada, the PRC, India, Japan, the Republic of Korea, and the United States.
33 UNFCCC Subsidiary Body for Scientific and Technological Advice. 2008. Report on 28th Session of UNFCCC Subsidiary Body for Scientific and Technological Advice, held in Bonn on 4–13 June.

climate trends, greenhouse gas emissions, mitigation and adaptation strategies, and lessons learned and best practices on climate change policy, programs, and technologies.[34]

More accurate and transparent reporting of data

It is important for East Asia to be as transparent as possible on research and data related to climate change. For example, under the UNFCCC process, there are differing reporting regimes and timetables for Annex I parties (mainly developed countries that ratified the Kyoto Protocol), and non-Annex I parties (mainly developing countries). For Annex I countries annual reporting is mandatory, while it is not for non-Annex I countries. Based on these requirements, the knowledge on inventories of emissions differs considerably. Closing this gap would promote the comparability and use of the data that are collected. National data on emissions may be reliable in the PRC, but provincial data on emissions and energy intensity need to be improved. For example, in 2011, provinces reported an average reduction in energy intensity of 3.6%, while the verification process concluded it was more like 2.0% (footnote 7).

Policy change can be sudden

Japan provides a lesson worth noting. On 11 March 2011, a powerful earthquake at Honshu's northeast coast triggered a tsunami that killed more than 15,000 people and the Fukushima nuclear power plant disaster (Box 2 and Chapter 6). The Fukushima episode illustrates how countries can be forced quite suddenly into adopting both short-term adjustments and long-term policy changes. Japan was forced to reconsider its energy mix because of an unforeseeable event, and its people showed how to cope in the short term with a reduced energy supply. But climate change is foreseeable; mitigation is still possible, and adaptation measures can be adopted now. Fukushima illustrates that the societal response can indeed by quick and dramatic.

[34] The World Bank's Climate Change Knowledge Platform could serve as a template. http://sdwebx.worldbank.org/climateportal/index.cfm

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Economics of Climate Change in East Asia

This regional study includes the People's Republic of China, Japan, the Republic of Korea, and Mongolia and examines how strategies for adapting to climate change up to 2050 can be combined with measures to reduce greenhouse gas emissions in East Asia. Besides discussing climate model results for costs of adaptation in infrastructure, coastal protection, and agriculture, the study estimates costs for sector-specific mitigation options and the total abatement potential for 2020 and 2030. Long-term strategies for addressing the impacts of climate change in East Asia are explored with a focus on the linkages between adaptation and mitigation taking account uncertainty about key climate variables. Finally, it discusses opportunities for enhancing the effectiveness of some critical climate change policies such as regional carbon markets.

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