Overview

Changing the Climate for Development

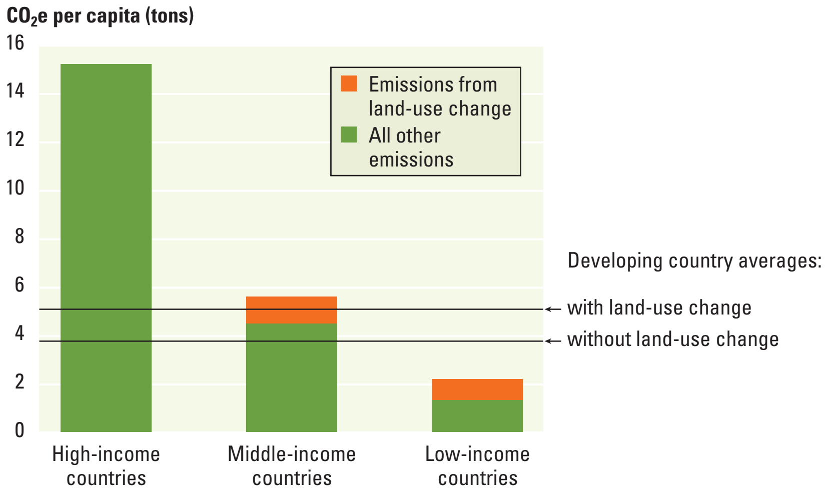
Thirty years ago, half the developing world lived in extreme poverty—today, a quarter.[1] Now, a much smaller share of children are malnourished and at risk of early death. And access to modern infrastructure is much more widespread. Critical to the progress: rapid economic growth driven by technological innovation and institutional reform, particularly in today's middle-income countries, where per capita incomes have doubled. Yet the needs remain enormous, with the number of hungry people having passed the billion mark this year for the first time in history.[2] With so many still in poverty and hunger, growth and poverty alleviation remain the overarching priority for developing countries.

Climate change only makes the challenge more complicated. First, the impacts of a changing climate are already being felt, with more droughts, more floods, more strong storms, and more heat waves—taxing individuals, firms, and governments, drawing resources away from development. Second, continuing climate change, at current rates, will pose increasingly severe challenges to development. By century's end, it could lead to warming of 5°C or more compared with preindustrial times and to a vastly different world from today, with more extreme weather events, many fewer species, and whole island nations submerged. Even our best efforts are unlikely to stabilize temperatures at anything less than 2°C above preindustrial temperatures, warming that will require substantial adaptation.

High-income countries can and must reduce their carbon footprints. They cannot continue to fill up an unfair and unsustainable share of the atmospheric commons. But developing countries—whose average per capita emissions are a third those of high-income countries (figure 1)—need massive expansions in energy, transport, urban systems, and agricultural production. If pursued using traditional technologies and carbon intensities, these much-needed expansions will produce more greenhouse gases and, hence, more climate change. The question, then, is not just how to make development more resilient to climate change. It is how to pursue growth and prosperity without causing "dangerous" climate change.[3]

Climate change policy is not a simple choice between a high-growth, high-carbon world and a low-growth, low-carbon world—a simple question of whether to grow or to preserve the planet. Plenty of inefficiencies drive today's high-carbon intensity.[4] For example, existing technologies and best practices could reduce energy consumption in industry and the power sector by 20–30 percent, shrinking carbon footprints without sacrificing growth.[5] Many mitigation actions—meaning changes to reduce emissions of greenhouse gases—have significant co-benefits in public health, energy security, environmental sustainability, and financial savings. In Africa, for example, mitigation opportunities are linked to more sustainable land and forest management, to cleaner energy (such as geothermal or hydro power), and to the

Figure 1 Unequal footprints: Emissions per capita in low-, middle-, and high-income countries, 2005



Sources: World Bank 2008c; WRI 2008 augmented with land-use change emissions from Houghton 2009.
Note: Greenhouse gas emissions include CO_2, methane (CH_4), nitrous oxide (N_2O), and high-global-warming-potential gases (F-gases). So that they can be aggregated, they are all expressed in terms of CO_2 equivalent (CO_2e), which measures quantities of all gases in terms of the quantity of CO_2 that would cause the same amount of warming. Per capita averages in low- and middle-income countries are calculated both with and without emissions from land-use change. In 2005 emissions from land-use change in high income countries were negligible.

creation of sustainable urban transport systems. So the mitigation agenda in Africa is likely to be compatible with furthering development.[6] This is also the case for Latin America.[7]

Nor do greater wealth and prosperity inherently produce more greenhouse gases, even if they have gone hand in hand in the past. Particular patterns of consumption and production do. Even excluding oil producers, per capita emissions in high-income countries vary by a factor of four, from 7 tons of carbon dioxide equivalent (CO_2e)[8] per capita in Switzerland to 27 in Australia and Luxembourg.[9]

And dependence on fossil fuel can hardly be considered unavoidable given the inadequacy of the efforts to find alternatives. While global subsidies to petroleum products amount to some $150 billion annually, public spending on energy research, development, and deployment (RD&D) has hovered around $10 billion for decades, apart from a brief spike following the oil crisis. That represents 4 percent of overall public RD&D. Private spending on energy RD&D, at $40 billion to $60 billion a year, amounts to 0.5 percent of private revenues—a fraction of what innovative industries such as telecom (8 percent) or pharmaceuticals (15 percent) invest in RD&D.[10]

A switch to a low-carbon world through technological innovation and complementary institutional reforms has to start with immediate and aggressive action by high-income countries to shrink their unsustainable carbon footprints. That would free some space in the atmospheric commons (figure 2). More important, a credible commitment by high-income countries to drastically reduce their emissions would stimulate the needed RD&D of new technologies and processes in energy, transport, industry, and agriculture. And large and predictable demand for alternative technologies will reduce their price and help make them competitive with fossil fuels. Only with new technologies at competitive prices can climate change be curtailed without sacrificing growth.

There is scope for developing countries to shift to lower-carbon trajectories without compromising development, but this varies across countries and will depend on the extent of financial and technical assistance from high-income countries. Such assistance would be equitable (and in line with the 1992 United Nations Framework Convention on Climate Change, or UNFCCC): high-income countries, with one-sixth of the world's population, are responsible for nearly two-thirds of the greenhouse gases in the atmosphere (figure 3). It would also be efficient: the savings from helping to finance early mitigation in developing countries—for example, through infrastructure and housing construction over the next decades—are so large that they produce clear economic benefits for all.[11] But designing, let alone implementing, an international agreement that involves substantial, stable, and predictable resource transfers is no trivial matter.

Developing countries, particularly the poorest and most exposed, will also need assistance in adapting to the changing climate. They already suffer the most from extreme weather events (see chapter 2). And even relatively modest additional warming will require big adjustments to the way development policy is designed and implemented, to the way people live and make a living, and to the dangers and the opportunities they face.

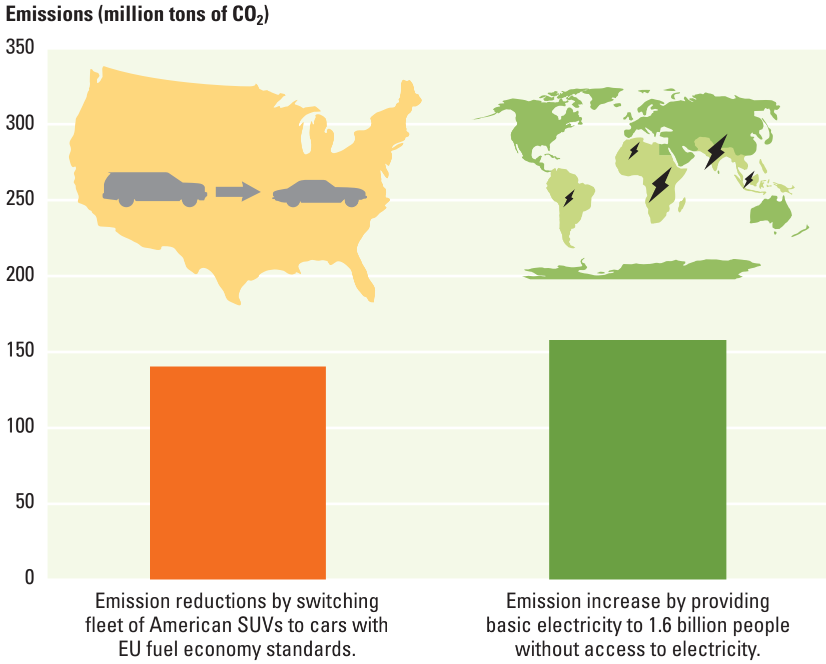
The current financial crisis cannot be an excuse to put climate on the back burner. On average, a financial crisis lasts less than two years and results in a 3 percent loss in gross domestic product (GDP) that is later offset by more than 20 percent growth over eight years of recovery and prosperity.[12] So for all the harm they cause, financial crises come and go. Not so with the growing threat imposed by a changing climate. Why?

Because time is not on our side. The impacts of greenhouse gases released into the atmosphere will be felt for decades, even millennia,[13] making the return to a "safe" level very difficult. This inertia in the climate system severely limits the possibility of making up for modest efforts today with accelerated mitigation in the future.[14] Delays also increase the costs as impacts worsen, and cheap mitigation options disappear as economies become locked into high-carbon infrastructure and lifestyles—more inertia.

Immediate action is needed to keep warming as close as possible to 2°C. That amount of warming is not desirable, but it is likely to be the best we can do. There isn't a consensus in the economic profession that this is the economic optimum. There is, however, a growing consensus in policy and scientific circles that aiming for 2°C warming is the responsible thing to do.[15] This Report endorses such a position. From the perspective of development, warming much above 2°C is simply unacceptable. But stabilizing at 2°C will require major shifts in lifestyle, a veritable energy revolution, and a transformation in how we manage land and forests. And substantial adaptation would still be needed. Coping with climate change will require all the innovation and ingenuity that the human race is capable of.

Inertia, equity, and ingenuity are three themes that permeate this Report. Inertia is the defining characteristic of the climate challenge—the reason we need to act now. Equity is the key to an effective global deal, to the trust needed to find an efficient resolution to this tragedy of the commons—the reason we need to act together. And ingenuity is the only possible answer to a problem that

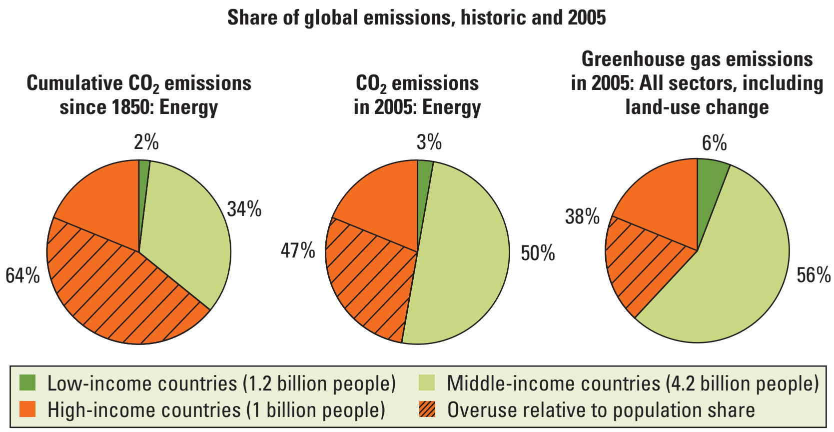
Figure 2 Rebalancing act: Switching from SUVs to fuel-efficient passenger cars in the U.S. alone would nearly offset the emissions generated in providing electricity to 1.6 billion more people



Source: WDR team calculations based on BTS 2008.

Note: Estimates are based on 40 million SUVs (sports utility vehicles) in the United States traveling a total of 480 billion miles (assuming 12,000 miles a car) a year. With average fuel efficiency of 18 miles a gallon, the SUV fleet consumes 27 billion gallons of gasoline annually with emissions of 2,421 grams of carbon a gallon. Switching to fuel-efficient cars with the average fuel efficiency of new passenger cars sold in the European Union (45 miles a gallon; see ICCT 2007) results in a reduction of 142 million tons of CO_2 (39 million tons of carbon) annually. Electricity consumption of poor households in developing countries is estimated at 170 kilowatt-hours a person-year and electricity is assumed to be provided at the current world average carbon intensity of 160 grams of carbon a kilowatt-hour, equivalent to 160 million tons of CO_2 (44 million tons of carbon). The size of the electricity symbol in the global map corresponds to the number of people without access to electricity.

Figure 3 High-income countries have historically contributed a disproportionate share of global emissions and still do



Sources: DOE 2009; World Bank 2008c; WRI 2008 augmented with land-use change emissions from Houghton 2009.

Note: The data cover over 200 countries for more recent years. Data are not available for all countries in the 19th century, but all major emitters of the era are included. Carbon dioxide (CO_2) emissions from energy include all fossil-fuel burning, gas flaring, and cement production. Greenhouse gas emissions include CO_2, methane (CH_4), nitrous oxide (N_2O), and high-global-warming-potential gases (F-gases). Sectors include energy and industrial processes, agriculture, land-use change (from Houghton 2009), and waste. Overuse of the atmospheric commons relative to population share is based on deviations from equal per capita emissions; in 2005 high-income countries constituted 16 percent of global population; since 1850, on average, today's high-income countries constituted about 20 percent of global population.

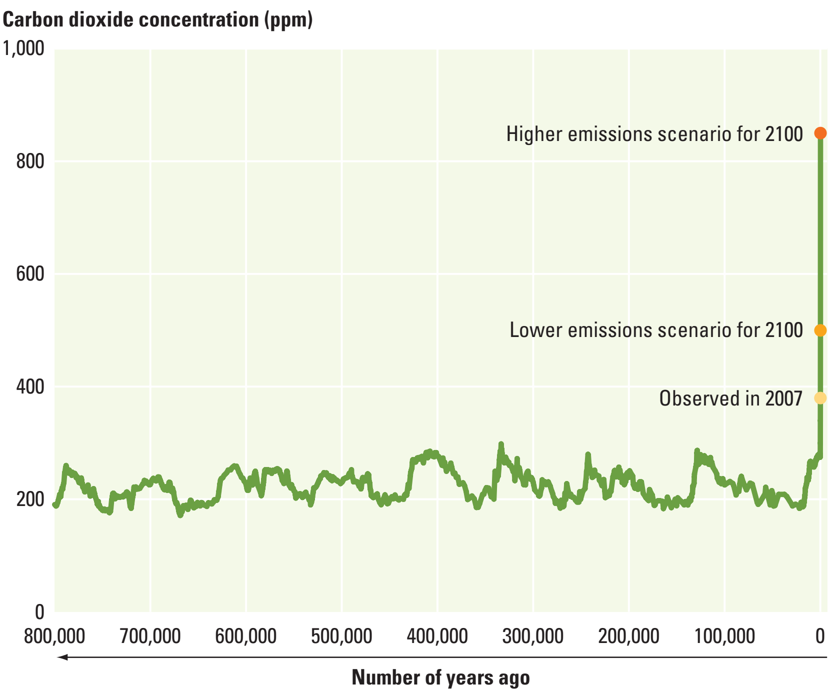
is politically and scientifically complex—the quality that could enable us to act differently than we have in the past. Act now, act together, act differently—those are the steps that can put a climate-smart world within our reach. But first it requires believing there is a case for action.

The case for action

The average temperature on Earth has already warmed by close to 1°C since the beginning of the industrial period. In the words of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), a consensus document produced by over 2,000 scientists representing every country in the United Nations: "Warming of the climate system is unequivocal."[16] Global atmospheric concentrations of CO_2, the most important greenhouse gas, ranged between 200 and 300 parts per million (ppm) for 800,000 years, but shot up to about 387 ppm over the past 150 years (figure 4), mainly because of the burning of fossil fuels and, to a lesser extent, agriculture and changing land use. A decade after the Kyoto Protocol set limits on international carbon emissions, as developed countries enter the first period of rigorous accounting of their emissions, greenhouse gases in the atmosphere are still increasing. Worse, they are increasing at an accelerating rate.[17]

The effects of climate change are already visible in higher average air and ocean temperatures, widespread melting of snow and ice, and rising sea levels. Cold days, cold nights, and frosts have become less frequent while heat waves are more common. Globally, precipitation has increased even as Australia, Central Asia, the Mediterranean basin, the Sahel, the western United States, and many other regions have seen more frequent and more intense droughts. Heavy rainfall and floods have become more common, and the damage from—and probably the intensity of—storms and tropical cyclones have increased.

Figure 4 Off the charts with CO_2



Source: Lüthi and others 2008.

Note: Analysis of air bubbles trapped in an Antarctic ice core extending back 800,000 years documents the Earth's changing CO_2 concentration. Over this long period, natural factors have caused the atmospheric CO_2 concentration to vary within a range of about 170 to 300 parts per million (ppm). Temperature-related data make clear that these variations have played a central role in determining the global climate. As a result of human activities, the present CO_2 concentration of about 387 ppm is about 30 percent above its highest level over at least the last 800,000 years. In the absence of strong control measures, emissions projected for this century would result in a CO_2 concentration roughly two to three times the highest level experienced in the past 800,000 or more years, as depicted in the two projected emissions scenarios for 2100.

Climate change threatens all, but particularly developing countries

Unmitigated climate change poses grave threats to all. The more than 5°C warming it could cause this century[18] amounts to the difference between today's climate and the last ice age, when glaciers reached central Europe and the doorstep of New York City. That change occurred over millennia; human-induced climate change is occurring on a one-century time scale giving societies and ecosystems little time to adapt to the rapid pace. Such a drastic temperature shift would cause large dislocations in ecosystems fundamental to human societies and economies—such as the possible dieback of the Amazon rain forest, complete loss of glaciers in the Andes and the Himalayas, and rapid ocean acidification leading to disruption of marine ecosystems and death of coral reefs. The speed and magnitude of change could wipe out more than 50 percent of species. Sea levels could rise by one meter this century,[19] threatening 60 million people and more than $200 billion in assets in developing countries alone.[20] Agricultural productivity would likely decline throughout the world, particularly in the tropics, even with dramatic changes in farming practices. And over 3 million additional people could die from malnutrition each year.[21]

Even 2°C warming above preindustrial temperatures would result in new weather patterns with global consequences. Increased weather variability, more frequent and intense extreme events, and greater exposure to coastal storm surges would lead to a much higher risk of catastrophic and irreversible impacts. Between 100 million and 400 million more people could be at risk of hunger.[22] And 1 billion to 2 billion more people may no longer have enough water to meet their consumption, hygiene, and food needs.[23]

Developing countries are more exposed and less resilient to climate hazards. These consequences will fall disproportionately on developing countries. Warming of 2°C could result in a 4 to 5 percent permanent reduction in annual per capita consumption in Africa and South Asia,[24] as opposed to minimal losses in high-income countries and an average reduction in world consumption equivalent to about 1 percent of global GDP.[25] These losses would be driven by impacts in agriculture, a sector important to the economies of both Africa and South Asia (map 1).

It is estimated that developing countries will bear most of the costs of the damages—some 75–80 percent.[26] Several factors explain this (box 1). Developing countries are particularly reliant on ecosystem services and natural capital for production in climate-sensitive sectors. Much of their population lives in physically exposed locations and economically precarious

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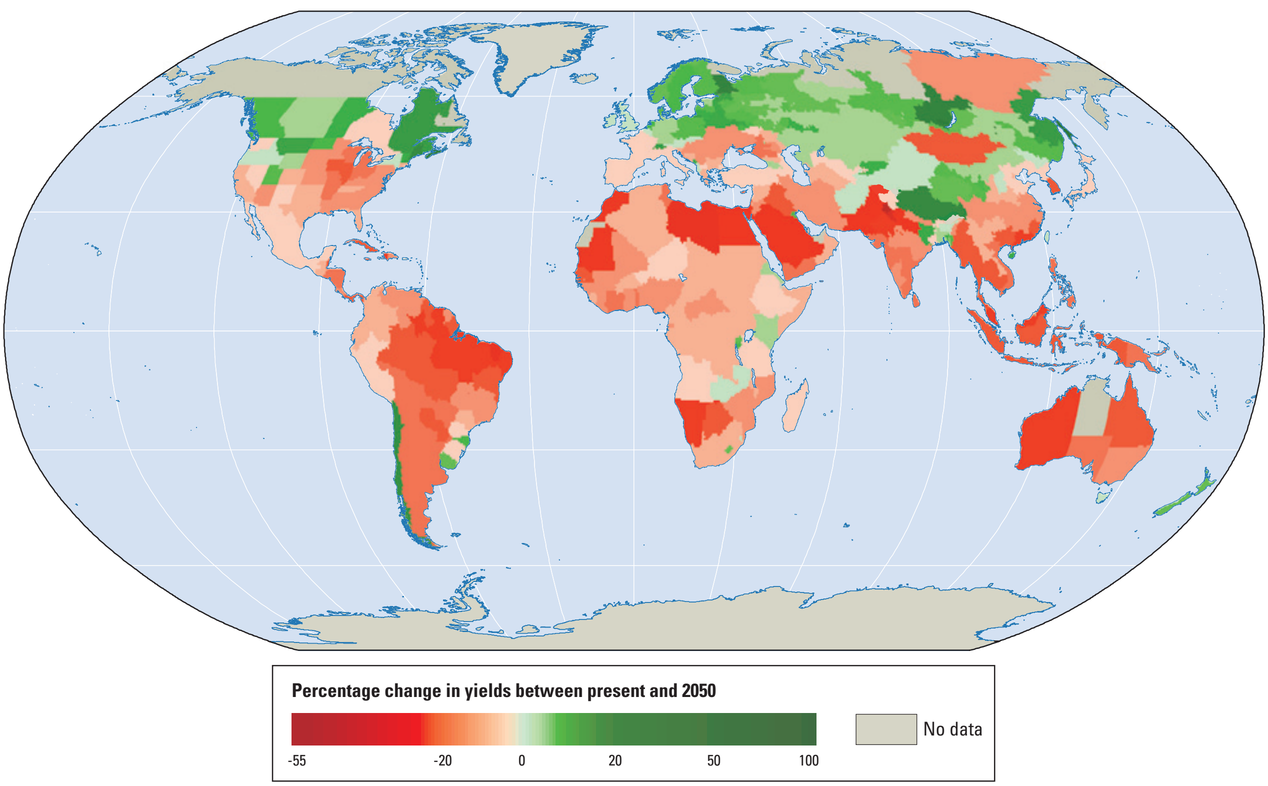
Map 1 Climate change will depress agricultural yields in most countries in 2050, given current agricultural practices and crop varieties



Sources: Müller and others 2009; World Bank 2008c.

Note: The figure shows the projected percentage change in yields of 11 major crops (wheat, rice, maize, millet, field pea, sugar beet, sweet potato, soybean, groundnut, sunflower, and rapeseed) from 2046 to 2055, compared with 1996–2005. The values are the mean of three emission scenarios across five global climate models, assuming no CO_2 fertilization (a possible boost—of uncertain magnitude—to plant growth and water-use efficiency from higher ambient CO_2 concentrations). Large negative yield impacts are projected in many areas that are highly dependent on agriculture.

BOX 1 *All developing regions are vulnerable to the impacts of climate change—for different reasons*

The problems common to developing countries—limited human and financial resources, weak institutions—are critical drivers of their vulnerability. But other factors, attributable to their geography and history, are also significant.

Sub-Saharan Africa suffers from natural fragility (two-thirds of its surface area is desert or dry land) and high exposure to droughts and floods, which are forecast to increase with further climate change. The region's economies are highly dependent on natural resources. Biomass provides 80 percent of the domestic primary energy supply. Rainfed agriculture contributes some 30 percent of GDP and employs about 70 percent of the population. Inadequate infrastructure could hamper adaptation efforts, with limited water storage despite abundant resources. Malaria, already the biggest killer in the region, is spreading to higher, previously safe, altitudes.

In *East Asia and the Pacific* one major driver of vulnerability is the large number of people living along the coast and on low-lying islands—over 130 million people in China, and roughly 40 million, or more than half the entire population, in Vietnam. A second driver is the continued reliance, particularly among the poorer countries, on agriculture. As pressures on land, water, and forest resources increase—as a result of population growth, urbanization, and environmental degradation caused by rapid industrialization—greater variability and extremes will complicate their management. In the Mekong River basin, for example, the rainy season will see more intense precipitation, while the dry season lengthens by two months. A third driver is that the region's economies are highly dependent on marine resources—the value of well-managed coral reefs is $13 billion in Southeast Asia alone—which are already stressed by industrial pollution, coastal development, overfishing, and runoff of agricultural pesticides and nutrients.

Vulnerability to climate change in *Eastern Europe and Central Asia* is driven by a lingering Soviet legacy of environmental mismanagement and the poor state of much of the region's infrastructure. An example: rising temperatures and reduced precipitation in Central Asia will exacerbate the environmental catastrophe of the disappearing Southern Aral Sea (caused by the diversion of water to grow cotton in a desert climate) while sand and salt from the dried-up seabed are blowing onto Central Asia's glaciers, accelerating the melting caused by higher temperature. Poorly constructed, badly maintained, and aging infrastructure and housing—a legacy of both the Soviet era and the transition years—are ill suited to withstand storms, heat waves, or floods.

Latin America and the Caribbean's most critical ecosystems are under threat. First, the tropical glaciers of the Andes are expected to disappear, changing the timing and intensity of water available to several countries, resulting in water stress for at least 77 million people as early as 2020 and threatening hydropower, the source of more than half the electricity in many South American countries. Second, warming and acidifying oceans will result in more frequent bleaching and possible diebacks of coral reefs in the Caribbean, which host nurseries for an estimated 65 percent of all fish species in the basin, provide a natural protection against storm surge, and are a critical tourism asset. Third, damage to the Gulf of Mexico's wetlands will make the coast more vulnerable to more intense and more frequent hurricanes. Fourth, the most disastrous impact could be a dramatic dieback of the Amazon rain forest and a conversion of large areas to savannah, with severe consequences for the region's climate—and possibly the world's.

Water is the major vulnerability in the *Middle East and North Africa,* the world's driest region, where per capita water availability is predicted to halve by 2050 even without the effects of climate change. The region has few attractive options for increasing water storage, since close to 90 percent of its freshwater resources are already stored in reservoirs. The increased water scarcity combined with greater variability will threaten agriculture, which accounts for some 85 percent of the region's water use. Vulnerability is compounded by a heavy concentration of population and economic activity in flood-prone coastal zones and by social and political tensions that resource scarcity could heighten.

South Asia suffers from an already stressed and largely degraded natural resource base resulting from geography coupled with high levels of poverty and population density. Water resources are likely to be affected by climate change, through its effect on the monsoon, which provides 70 percent of annual precipitation in a four-month period, and on the melting of Himalayan glaciers. Rising sea levels are a dire concern in the region, which has long and densely populated coastlines, agricultural plains threatened by saltwater intrusion, and many low-lying islands. In more severe climate-change scenarios, rising seas would submerge much of the Maldives and inundate 18 percent of Bangladesh's land.

Sources: de la Torre, Fajnzylber, and Nash 2008; Fay, Block, and Ebinger 2009; World Bank 2007a; World Bank 2007c; World Bank 2008b; World Bank 2009b.

conditions. And their financial and institutional capacity to adapt is limited. Already policy makers in some developing countries note that more of their development budget is diverted to cope with weather-related emergencies.[27]

High-income countries will also be affected by moderate warming. Indeed, damages per capita are likely to be higher in wealthier countries since they account for 16 percent of world population but would bear 20–25 percent of the global impact costs. But their much greater wealth makes them better able to cope with such impacts. Climate change will wreak havoc everywhere—but it will increase the gulf between developed and developing countries.

Growth is necessary for greater resilience, but is not sufficient. Economic growth is necessary to reduce poverty and is at the heart of increasing resilience to climate change in poor countries. But growth alone is not the answer to a changing climate. Growth is unlikely to be fast enough to help the poorer countries, and it can increase the vulnerability to climate hazards (box 2). Nor is growth usually equitable enough to ensure protection for the poorest and most vulnerable. It does not guarantee that key institutions will function well. And if it is carbon intensive, it will cause further warming.

But there is no reason to think that a low-carbon path must necessarily slow economic growth: many environmental regulations were preceded by warnings of massive job losses and industry collapse, few of which materialized.[28] Clearly, however, the transition costs are substantial, notably in developing low-carbon technologies and infrastructure for energy, transport, housing, urbanization, and rural development. Two arguments often heard are that these transition costs are unacceptable given the urgent need for other more immediate investments in poor countries, and that care should be taken not to sacrifice the welfare of poor individuals today for the sake of future, possibly richer, generations. There is validity to these concerns. But the point remains that a strong economic argument can be made for ambitious action on climate change.

BOX 2 Economic growth: Necessary, but not sufficient

Richer countries have more resources to cope with climate impacts, and better educated and healthier populations are inherently more resilient. But the process of growth may exacerbate vulnerability to climate change, as in the ever-increasing extraction of water for farming, industry, and consumption in the drought-prone provinces around Beijing, and as in Indonesia, Madagascar, Thailand, and U.S. Gulf Coast, where protective mangroves have been cleared for tourism and shrimp farms.

Growth is not likely to be fast enough for low-income countries to afford the kind of protection that the rich can afford. Bangladesh and the Netherlands are among the countries most exposed to rising sea levels. Bangladesh is already doing a lot to reduce the vulnerability of its population, with a highly effective community-based early warning system for cyclones and a flood forecasting and response program drawing on local and international expertise. But the scope of possible adaptation is limited by resources—its annual per capita income is $450. Meanwhile, the Netherlands government is planning investments amounting to $100 for every Dutch citizen every year for the next century. And even the Netherlands, with a per capita income 100 times that of Bangladesh, has begun a program of selective relocation away from low-lying areas because continuing protection everywhere is unaffordable.

Sources: WDR team based on Guan and Hubacek (2008); Shalizi (2006); Xia and others (2007); FAO (2007); Barbier and Sathirathai (2004); Deltacommissie (2008); Government of Bangladesh (2008); and Karim and Mimura (2008).

The economics of climate change: Reducing climate risk is affordable

Climate change is costly, whatever the policy chosen. Spending less on mitigation will mean spending more on adaptation and accepting greater damages: the cost of action must be compared with the cost of inaction. But, as discussed in chapter 1, the comparison is complex because of the considerable uncertainty about the technologies that will be available in the future (and their cost), the ability of societies and ecosystems to adapt (and at what price), the extent of damages that higher greenhouse gas concentrations will cause, and the temperatures that might constitute thresholds or tipping points beyond which catastrophic impacts occur (see Science focus). The comparison is also complicated by distributional issues across time (mitigation incurred by one generation produces benefits for many generations to come) and space (some areas are more vulnerable than others, hence more likely to support aggressive global mitigation efforts). And it is further complicated by the question of how to value the loss of life, livelihoods, and nonmarket services such as biodiversity and ecosystem services.

Economists have typically tried to identify the optimal climate policy using cost-benefit analysis. But as box 3 illustrates, the results are sensitive to the particular assumptions about the remaining uncertainties, and to the normative choices made regarding distributional and measurement issues. (A technology optimist, who expects the impact of climate change to be relatively modest and occurring gradually over time, and who heavily discounts what happens in the future, will favor modest action now. And vice versa for a technology pessimist.) So economists continue to disagree on the economically or socially optimal carbon trajectory. But there are some emerging agreements.

In the major models, the benefits of stabilization exceed the costs at 2.5°C warming (though not necessarily at 2°C).[29] And all conclude that business as usual (meaning no mitigation efforts whatsoever) would be disastrous. Advocates of a more gradual reduction in emissions would accept continuing increases in temperatures much above 2°C.They conclude that the optimal target—the one that will produce the lowest total cost (meaning the sum of impact, mitigation, and adaptation costs)—could be well above 3°C.[30] But they do note that the incremental cost of keeping warming around 2°C would be modest, less than half a percent of GDP (see box 3). In other words,

BOX 3 *The cost of "climate insurance"*

Hof, den Elzen, and van Vuuren examine the sensitivity of the optimal climate target to assumptions about the time horizon, climate sensitivity (the amount of warming associated with a doubling of carbon dioxide concentrations from preindustrial levels), mitigation costs, likely damages, and discount rates. To do so, they run their integrated assessment model (FAIR), varying the model's settings along the range found in the literature, notably those associated with two well-known economists: Nicholas Stern, who advocates early and ambitious action; and William Nordhaus, who supports a gradual approach to climate mitigation.

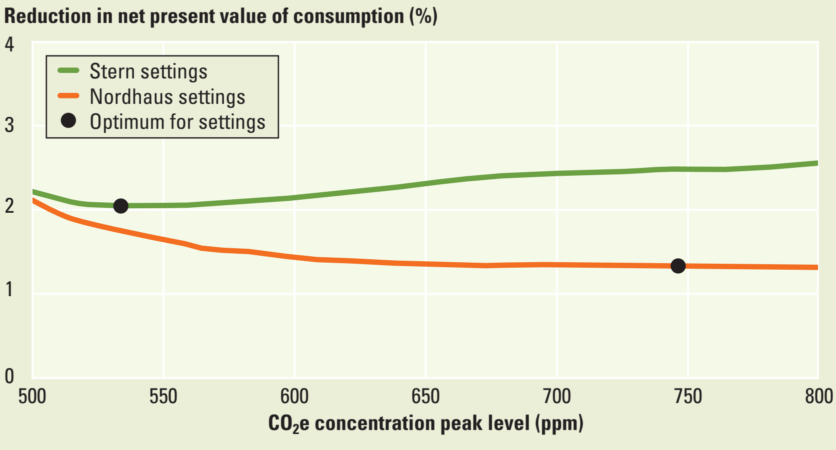
Not surprisingly, their model results in completely different optimal targets depending on which settings are used. (The optimal target is defined as the concentration that would result in the lowest reduction in the present value of global consumption.) The "Stern settings" (which include relatively high climate sensitivity and climate damages, and a long time horizon combined with low discount rates and mitigation costs) produce an optimum peak CO_2e concentration of 540 parts per million (ppm). The "Nordhaus settings" (which assume lower climate sensitivity and damages, a shorter time horizon, and a higher discount rate) produce an optimum of 750 ppm. In both cases, adaptation costs are included implicitly in the climate damage function.

The figure plots the least cost of stabilizing atmospheric concentrations in the range of 500 to 800 ppm for the Stern and Nordhaus settings (reported as the difference between the modeled present value of consumption and the present value of consumption that the world would enjoy with no climate change). A key point evident in the figure is the relative flatness of the consumption loss curves over wide ranges of peak CO_2e concentrations. As a consequence, moving from 750 ppm to 550 ppm results in a relatively small loss in consumption (0.3 percent) for the Nordhaus settings. The results therefore suggest that the cost of precautionary mitigation to 550 ppm is small. In the Stern settings, a 550 ppm target results in a *gain* in present value of consumption of about 0.5 percent relative to the 750 ppm target.

A strong motivation for choosing a lower peak concentration target is to reduce the risk of catastrophic outcomes linked to global warming. From this perspective, the cost of moving from a high target for peak CO_2e concentrations to a lower target can be viewed as the cost of climate insurance—the amount of welfare the world would sacrifice to reduce the risk of catastrophe. The analysis of Hof, den Elzen, and van Vuuren suggests that the cost of climate insurance is modest under a very wide range of assumptions about the climate system and the cost of mitigating climate change.

Source: Hof, den Elzen, and van Vuuren 2008.

Looking at tradeoffs: The loss in consumption relative to a world without warming for different peak CO_2e concentrations



Source: Adapted from Hof, den Elzen, and van Vuuren 2008, figure 3.

Note: The curves show the percentage loss in the present value of consumption, relative to what it would be with a constant climate, as a function of the target for peak CO_2e concentrations. The "Stern settings" and "Nordhaus settings" refer to choices about the value of key parameters of the model as explained in the text. The dot shows the optimum for each setting, where the optimum is defined as the greenhouse gas concentration that would minimize the global consumption loss resulting from the sum of mitigation costs and impact damages.

the total cost of the optimal solution is not much more than the total costs implied by the much more ambitious option of 2°C warming. Why? Partly because the savings from less mitigation are largely offset by the additional costs of more severe impacts or higher adaptation spending.[31] And partly because the real difference between ambitious and modest climate action lies with costs that occur in the future, which gradualists heavily discount.

The large uncertainties about the potential losses associated with climate change and the possibility of catastrophic risks may well justify earlier and more aggressive action than a simple cost-benefit analysis would suggest. This incremental amount could be thought of as the insurance premium to keep climate change within what scientists consider a safer band.[32] Spending less than half a percent of GDP as "climate insurance" could well be a socially acceptable proposition: the world spends 3 percent of global GDP on insurance today.[33]

But beyond the question of "climate insurance" is the question of what might be the required mitigation and adaptation investments—and the associated financing needs. In the medium term the mitigation tab is significant but not prohibitive, with annual global mitigation investments ranging from $260 billion to $1.2 trillion by 2030 (table 1), with the median at $375 billion. That is equivalent to 0.2 percent of projected world GDP in 2030, or 3 percent of today's global investment spending. In other words, keeping warming around 2°C could entail a 3 percent increase in global investments.[34] Again, significant but not prohibitive.

What about the longer term? Needed mitigation investments will increase over time to cope with growing population and energy needs—but so will income. As a result, the present value of mitigation investments to 2100 is expected to remain well below 1 percent of GDP, with estimates ranging between 0.3 percent and 0.7 percent of GDP (see table 1).

These investments should be considered in relation to averted damages or reduced risk (as they are in a cost-benefit framework). In addition, they would be partly offset by the value of co-benefits (such as savings from energy efficiency gains) so the net cost to the world economy is therefore likely to be much lower. McKinsey, for example, estimates that the net mitigation cost would be only $225 billion a year in 2030, because many of the investments identified pay for themselves. Still financing will be a challenge, particularly because additional resources will be needed for adaptation and for coping with the residual losses.

There are far fewer estimates of needed adaptation investments, and those that exist are not readily comparable. Some look only at the cost of climate-proofing foreign aid projects. Others include only certain sectors. Very few try to look at overall country needs (see chapter 6). A recent World Bank study that attempts to tackle these issues suggests that the investments needed could be upward of $80 billion annually in developing countries alone.[35]

Table 1 Mitigation investments needed to stay close to 2°C

Integrated assessment models	Mitigation investments in 2030 ($ billions)		Present value of total mitigation investments to 2100 (percent of GDP)	
	World	Developing	World	Developing
Energy only				
MESSAGE	310	137	0.3	0.5
IEA ETP	900	600		
REMIND	375		0.4	
MiniCAM	257	168	0.7	1.2
All sectors				
PAGE			0.4	0.9
FAIR "low settings"			0.6	
DICE			0.7	
McKinsey	1,215	675		
Average	611	395	0.5	0.9
Median	375	384	0.5	0.9

Sources: MESSAGE: IIASA 2009; IEA ETP: IEA 2008c; REMIND: Knopf and others, forthcoming; MiniCAM: Edmonds and others 2008 and personal communications; PAGE: Hope 2009 and personal communications; FAIR: Hof, den Elzen, and van Vuuren 2008; DICE: Nordhaus 2008 (estimated from table 5.3 and figure 5.3); McKinsey: McKinsey Global Institute 2009 and personal communications.

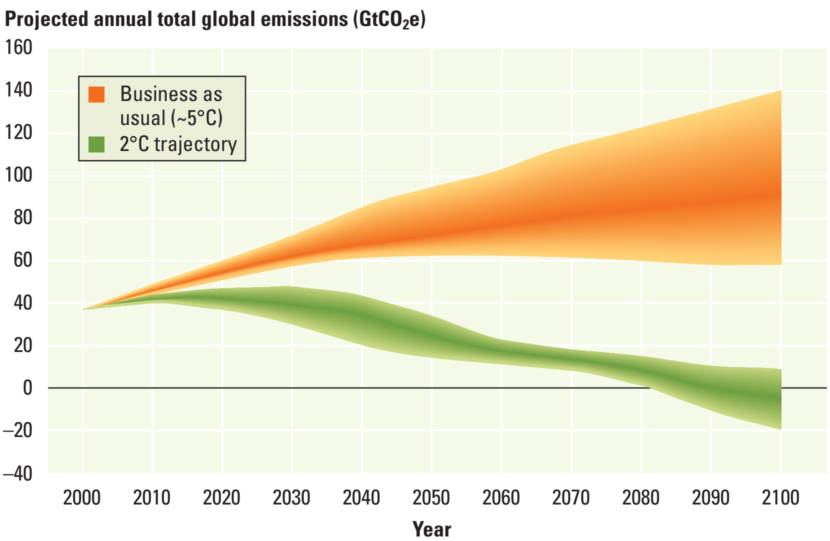
Note: DICE, FAIR, MESSAGE, MiniCAM, PAGE, and REMIND are peer-reviewed models. IEA ETP is the model developed by the International Energy Agency, and McKinsey is the proprietary methodology developed by the McKinsey Global Institute. Estimates are for stabilization of greenhouse gases at 450 ppm CO_2e, which would provide a 40–50 percent chance of staying below 2°C warming by 2100 (Schaeffer and others 2008a; Hare and Meinshausen 2006). MiniCAM includes both operational and investment expenditures; all other models include only investment expenditures. The FAIR model result reports abatement costs using the low settings (see table 3 in Hof, den Elzen, and van Vuuren 2008). Developing countries are defined using the 2009 World Bank classification.

A climate-smart world is within reach if we act now, act together, and act differently

Even if the incremental cost of reducing climate risk is small and the investment needs far from prohibitive, stabilizing warming around 2°C above preindustrial temperatures is extremely ambitious. By 2050 emissions would need to be 50 percent below 1990 levels and be zero or negative by 2100 (figure 5). This would require immediate and Herculean efforts: within the next 20 years global emissions would have to fall, compared to a business-as-usual path, by an amount equivalent to total emissions from high-income countries today. In addition, even 2°C warming would also require costly adaptation—changing the kinds of risks people prepare for; where they live; what they eat; and the way they design, develop, and manage agroecological and urban systems.[36]

So both the mitigation and the adaptation challenges are substantial. But the hypothesis of this Report is that they can be tackled through climate-smart policies that entail acting now, acting together (or globally), and acting differently. Acting now, because of the tremendous inertia in both climate and socioeconomic systems. Acting together, to keep costs down and protect the most vulnerable. And acting differently, because a climate-smart world requires a transformation of our energy, food production, and risk management systems.

Figure 5 What does the way forward look like? Two options among many: business as usual or aggressive mitigation



Source: Results of multiple models from different institutions were provided by the Energy Modeling Forum. Clarke and others forthcoming.

Note: The top band shows the range of estimates across models (GTEM, IMAGE, MESSAGE, MiniCAM) for emissions under a business-as-usual scenario. The lower band shows a trajectory that could yield a concentration of 450 ppm of CO_2e (with a 50 percent chance of limiting warming to less than 2°C). Greenhouse gas emissions include CO_2, CH_4, and N_2O. Negative emissions (eventually required by the 2°C path) imply that the annual rate of emissions is lower than the rate of uptake and storage of carbon through natural processes (for example, plant growth) and engineered processes (for example, growing biofuels and when burning them, sequestering the CO_2 underground). GTEM, IMAGE, MESSAGE, and MiniCAM are the integrated assessment models of the Australian Bureau of Agricultural and Resource Economics, the Netherlands Environmental Assessment Agency, International Institute of Applied Systems Analysis, and Pacific Northwest National Laboratory.

Act now: Inertia means that today's actions will determine tomorrow's options

The climate system exhibits substantial inertia (figure 6). Concentrations lag emission reductions: CO_2 remains in the atmosphere for decades to centuries, so a decline in emissions takes time to affect concentrations. Temperatures lag concentrations: temperatures will continue increasing for a few centuries after concentrations have stabilized. And sea levels lag temperature reductions: the thermal expansion of the ocean from an increase in temperature will last 1,000 years or more while the sea-level rise from melting ice could last several millennia.[37]

The dynamics of the climate system therefore limit how much future mitigation can be substituted for efforts today. For example, stabilizing the climate near 2°C (around 450 ppm of CO_2e) would require global emissions to begin declining immediately by about 1.5 percent a year. A five-year delay would have to be offset by faster emission declines. And even longer delays simply could not be offset: a ten-year delay in mitigation would most likely make it impossible to keep warming from exceeding 2°C.[38]

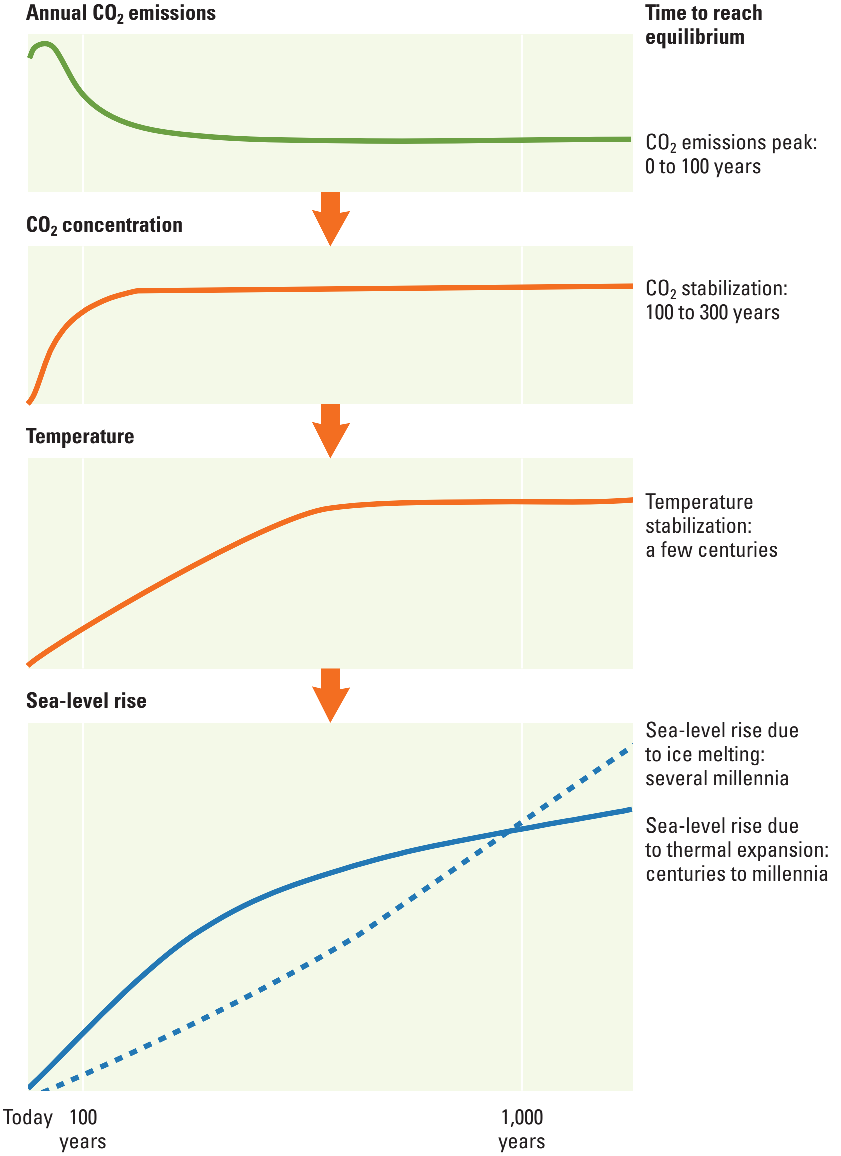
Inertia is also present in the built environment, limiting flexibility in reducing greenhouse gases or designing adaptation responses. Infrastructure investments are lumpy, concentrated in time rather than evenly distributed.[39] They are also long-lived: 15–40 years for factories and power plants, 40–75 years for road, rail, and power distribution networks. Decisions on land use and urban form—the structure and density of cities—have impacts lasting more than a century. And long-lived infrastructure triggers investments in associated capital (cars for low-density cities; gas-fired heat and power generation capacity in response to gas pipelines), locking economies into lifestyles and energy consumption patterns.

The inertia in physical capital is nowhere close to that in the climate system and is more likely to affect the cost rather than the feasibility of achieving a particular emission goal—but it is substantial. The opportunities to shift from high-carbon to low-carbon capital stocks are not evenly distributed in time.[40] China is expected to double its building stock between 2000 and 2015. And the coal-fired power plants proposed around the world over the next 25 years are so numerous that their lifetime CO_2 emissions would equal those of all coal-burning activities since the beginning of the industrial era.[41] Only some of those currently being built could be retrofitted for carbon capture and storage (if and when that technology becomes commercially available: see chapters 4 and 7). Retiring these plants before the end of their useful life—if changes in the climate force such action—would be extremely costly.

Inertia is also a factor in research and development (R&D) and in the deployment of new technologies. New energy sources have historically taken about 50 years to reach half their potential.[42] Substantial investments in R&D are needed now to ensure that new technologies are available and rapidly penetrating the marketplace in the near future. This could require an additional $100 billion to $700 billion annually.[43] Innovation is also needed in transport, building, water management, urban design, and many other sectors that affect climate change and are in turn affected by climate change—so innovation is a critical issue for adaptation as well.

Inertia is also present in the behavior of individuals and organizations. Despite greater public concern, behaviors have not changed much. Available energy-efficient technologies that are effective and pay for themselves are not adopted. R&D in renewables is underfunded. Farmers face incentives to over-irrigate their crops, which in turn affects energy use, because energy is a major input in water provision and treatment. Building continues in hazard-prone areas, and infrastructure continues to be designed for the climate of the past.[44] Changing behaviors and organizational goals and standards is difficult and usually slow, but it has been done before (see chapter 8).

Figure 6 Climate impacts are long-lived: rising temperatures and sea levels associated with higher concentrations of CO_2



Source: WDR team based on IPCC 2001.
Note: Stylized figures; the magnitudes in each panel are intended for illustrative purposes.

Act together: For equity and efficiency

Collective action is needed to effectively tackle climate change and reduce the costs of mitigation.[45] It is also essential to facilitate adaptation, notably through better risk management and safety nets to protect the most vulnerable.

To keep costs down and fairly distributed. Affordability hinges on mitigation being done cost effectively. When estimating the mitigation costs discussed earlier, modelers assume that greenhouse gas emission reductions occur wherever and whenever they are cheapest. *Wherever* means pursuing greater energy efficiency and other low-cost options to mitigate in whatever country or sector the opportunity arises. *Whenever* entails timing investments in new equipment, infrastructure, or farming and forestry projects to minimize costs and keep economies from getting locked into high-carbon conditions that would be expensive to alter later. Relaxing the wherever, whenever rule—as would necessarily happen in the real world, especially in the absence of a global carbon price—dramatically increases the cost of mitigation.

The implication is that there are enormous gains to global participation in mitigation efforts—on this point, analysts are unanimous. If any country or group of countries does not mitigate, others must reach into higher-cost mitigation options to achieve a given global target. For example, by one estimate, the nonparticipation of the United States, which is responsible for 20 percent of world emissions, in the Kyoto Protocol increases the cost of achieving the original target by about 60 percent.[46]

Both equity and efficiency argue for developing financial instruments that separate who finances mitigation from where it happens. Otherwise, the substantial mitigation potential in developing countries (65–70 percent of emission reductions, adding up to 45–70 percent of global mitigation investments in 2030)[47] will not be fully tapped, substantially increasing the cost of achieving a given target. Taking it to the extreme, a lack of financing that results in fully postponing mitigation in developing countries to 2020 could more than double the cost of stabilizing around 2°C.[48] With mitigation investments estimated to add up to $4 trillion to $25 trillion[49] over the next century, the losses implied by such delays are so large that there are clear economic benefits for high-income countries committed to limiting dangerous climate change to finance early action in developing countries.[50] More generally, the total cost of mitigation could be greatly reduced through well-performing carbon-finance mechanisms, financial transfers, and price signals that help approximate the outcome produced by the whenever, wherever assumption.

To manage risk better and protect the poorest. In many places previously uncommon risks are becoming more widespread. Consider floods, once rare but now increasingly common, in Africa and the first hurricane ever recorded in the South Atlantic, which hit Brazil in 2004.[51] Reducing disaster risk—through community-based early warning systems, climate monitoring, safer infrastructure, and strengthened and enforced zoning and building codes, along with other measures—becomes more important in a changing climate. Financial and institutional innovations can also limit risks to health and livelihoods. This requires domestic action—but domestic action will be greatly enhanced if it is supported by international finance and sharing of best-practice.

But as discussed in chapter 2, actively reducing risk will never be enough because there will always be a residual risk that must also be managed through better preparedness and response mechanisms. The implication is that development may need to be done differently, with much greater emphasis on climate and weather risk. International cooperation can help, for example, through pooling efforts to improve the production of climate information and its broad availability (see chapter 7) and through sharing best practices to cope with the changing and more variable climate.[52]

Insurance is another instrument to manage the residual risk, but it has its limitations. Climate risk is increasing along a trend and tends to affect entire regions or large groups of people simultaneously, making it difficult to insure. And even with insurance, losses associated with catastrophic events (such as widespread flooding or severe droughts) cannot be fully absorbed by individuals, communities, and the private sector. In a more volatile climate, governments will increasingly become insurers of last resort and have an implicit responsibility to support disaster recovery and reconstruction. This requires that governments protect their own liquidity in times of crisis, particularly poorer or smaller countries that are financially vulnerable to the impacts of climate change: Hurricane Ivan caused damages equivalent to 200 percent of Grenada's GDP.[53] Having immediate funds available to jump-start the rehabilitation and recovery process reduces the derailing effect of disasters on development.

Multicountry facilities and reinsurance can help. The Caribbean Catastrophe Risk Insurance Facility spreads risk among 16 Caribbean countries, harnessing the reinsurance market to provide liquidity to governments quickly following destructive hurricanes and earthquakes.[54] Such facilities may need help from the international community. More generally, high-income countries have a critical role in ensuring that developing countries have timely access to the needed resources when shocks hit, whether by supporting such facilities or through the direct provision of emergency funding.

But insurance and emergency funding are only one part of a broader risk-management framework. Social policies will become more important in helping people cope with more frequent and persistent threats to their livelihoods. Social policies reduce economic and social vulnerability and increase resilience to climate change. A healthy, well-educated population with access to social protection can better cope with climate shocks and climate change. Social protection policies will need to be strengthened where they exist, developed where they are lacking, and designed so that they can be expanded quickly after a shock.[55] Creating social safety nets in countries that do not yet have them is critical, and Bangladesh shows how it can be done even in very poor countries (box 4). Development agencies could help spread successful models of social safety nets and tailor them to the needs created by the changing climate.

BOX 4 *Safety nets: From supporting incomes to reducing vulnerability to climate change*

Bangladesh has had a long history of cyclones and floods, and these could become more frequent or intense. The government has safety nets that can be tailored fairly easily to respond to the effects of climate change. The best examples are the vulnerable-group feeding program, the food-for-work program, and the new employment guarantee program.

The vulnerable-group feeding program runs at all times and usually covers more than 2 million households. But it is designed to be ramped up in response to a crisis: following the cyclone in 2008, the program was expanded to close to 10 million households. Targeting, done by the lowest level of local government and monitored by the lowest administrative level, is considered fairly good.

The food-for-work program, which normally operates during the low agriculture season, is ramped up during emergencies. It too is run in collaboration with local governments, but program management has been subcontracted to nongovernmental organizations in many parts of the country. Workers who show up at the work site are generally given work, but there is usually not enough to go around, so the work is rationed through rotation.

The new employment guarantee program provides those with no other means of income (including access to other safety nets) with employment for up to 100 days at wages linked to the low-season agricultural wage. The guarantee element ensures that those who need help get it. If work cannot be provided, the individual is entitled to 40 days of wages at the full rate and then 60 days at half the rate.

Bangladesh's programs, and others in India and elsewhere, suggest some lessons. Rapid response requires rapid access to funding, targeting rules to identify people in need—chronic poor or those temporarily in need—and procedures agreed on well before a shock hits. A portfolio of "shovel-ready" projects can be preidentified as particularly relevant to increasing resilience (water storage, irrigation systems, reforestation, and embankments, which can double as roads in low-lying areas). Experience from India and Bangladesh also suggests the need for professional guidance (engineers) in the selection, design, and implementation of the public works and for equipment and supplies.

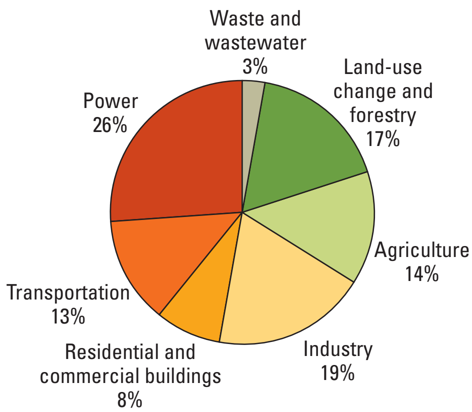
Source: Contributed by Qaiser Khan.

To ensure adequate food and water for all countries. International action is critical to manage the water and food security challenges posed by the combination of climate change and population pressures—even with improved agricultural productivity and water-use efficiency. One fifth of the world's freshwater renewable resources are shared between countries.[56] That includes 261 transboundary river basins, home to 40 percent of the world's people and governed by over 150 international treaties that do not always include all riparian states.[57] If countries are to manage these resources more intensively, they will have to scale up cooperation on international water bodies through new international treaties or the revision of existing ones. The system of water allocation will need to be reworked due to the increased variability, and cooperation can be effective only when all riparian countries are involved and responsible for managing the watercourse.

Similarly, increasing arid conditions in countries that already import a large share of their food, along with more frequent extreme events and growth in income and population, will increase the need for food imports.[58] But global food markets are thin—relatively few countries export food crops.[59] So small changes in either supply or demand can have big effects on prices. And small countries with little market power can find it difficult to secure reliable food imports.

To ensure adequate water and nutrition for all, the world will have to rely on an improved trade system less prone to large price shifts. Facilitating access to markets for developing countries by reducing trade barriers, weatherproofing transport (for example, by increasing access to year-round roads), improving procurement methods,

Figure 7 Global CO_2e emissions by sector: Energy, but also agriculture and forestry, are major sources



Source: IPCC 2007a, figure 2.1.

Note: Share of anthropogenic (human-caused) greenhouse gas emissions in 2004 in CO_2e (see figure 1 for the definition of CO_2e). Emissions associated with land use and land-use change, such as agricultural fertilizers, livestock, deforestation, and burning, account for about 30 percent of total greenhouse gas emissions. And uptakes of carbon into forests and other vegetation and soils constitute an important carbon sink, so improved land-use management is essential in efforts to reduce greenhouse gases in the atmosphere.

and providing better information on both climate and market indexes can make food trade more efficient and prevent large price shifts. Price spikes can also be prevented by investing in strategic stockpiles of key grains and foodstuffs and in risk-hedging instruments.[60]

Act differently: To transform energy, food production, and decision-making systems

Achieving the needed emission reductions will require a transformation both of our energy system and of the way we manage agriculture, land use, and forests (figure 7). But these transformations must also incorporate the needed adaptations to a changing climate. Whether they involve deciding which crop to plant or how much hydroelectric power to develop, management and investment decisions must factor in changing hydrological conditions and temperatures: rather than being optimally adapted to the climate of the past, decisions will have to be robust to the variety of climate outcomes we could face in the future.

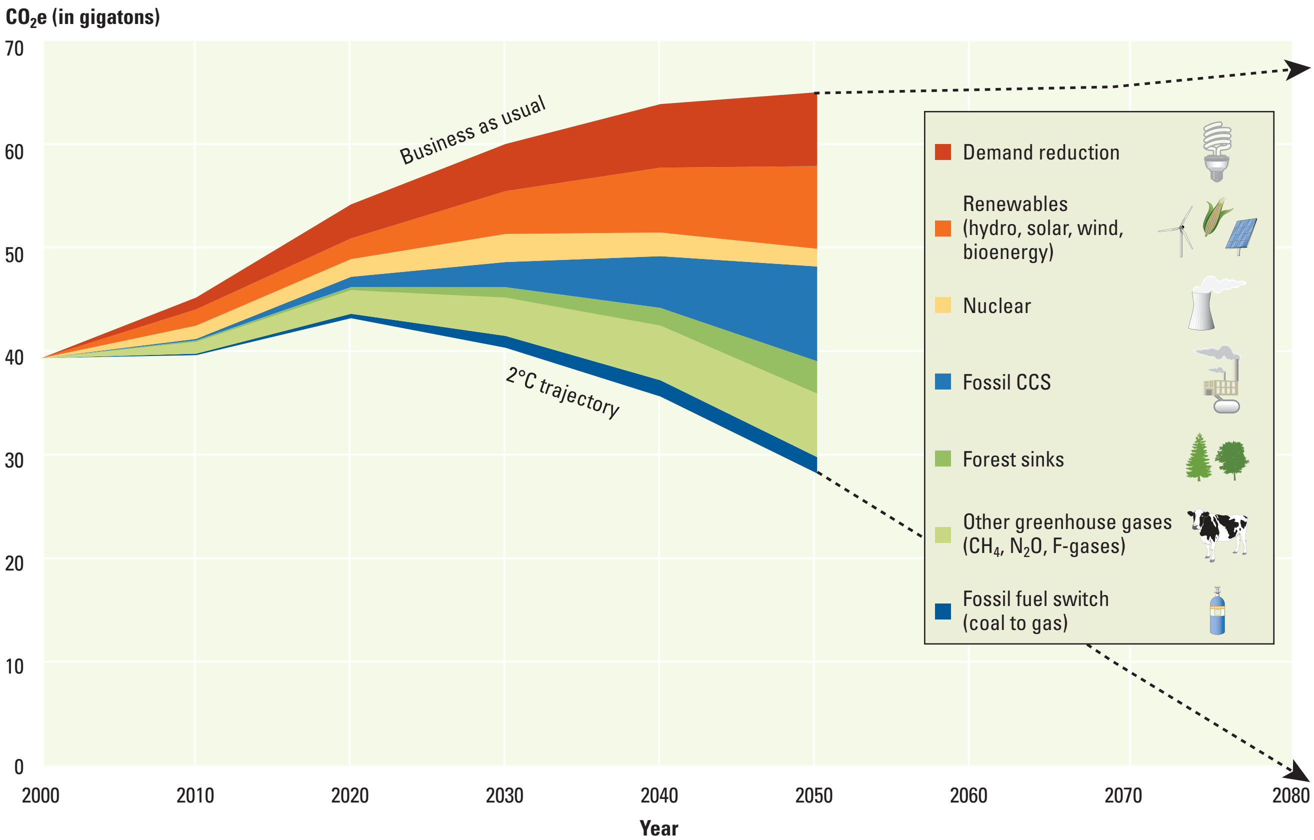
To ignite a veritable energy revolution. If financing is available, can emissions be cut sufficiently deeply or quickly without sacrificing growth? Most models suggest that they can, although none find it easy (see chapter 4). Dramatically higher energy efficiency, stronger management of energy demand, and large-scale deployment of existing low-CO_2-emitting electricity sources could produce about half the emission reductions needed to put the world on a path toward 2°C (figure 8). Many have substantial co-benefits but are hampered by institutional and financial constraints that have proven hard to overcome.

So known technologies and practices can buy time—if they can be scaled up. For that to happen, appropriate energy pricing is absolutely essential. Cutting subsidies and increasing fuel taxes are politically difficult, but the recent spike and fall in oil and gas prices make the time opportune for doing so. Indeed, European countries used the 1974 oil crisis to introduce high fuel taxes. As a result, fuel demand is about half what it likely would have been had prices been close to those in the United States.[61] Similarly, electricity prices are twice as high in Europe as they are in the United States and electricity consumption per capita is half.[62] Prices help explain why European emissions per capita (10 tons of CO_2e) are less than half those in the United States (23 tons).[63] Global energy subsidies in developing countries were estimated at $310 billion in 2007,[64] disproportionately benefiting higher-income populations. Rationalizing energy subsidies to target the poor and encourage sustainable energy and transport could reduce global CO_2 emissions and provide a host of other benefits.

But pricing is only one tool for advancing the energy-efficiency agenda, which suffers from market failures, high transaction costs, and financing constraints. Norms, regulatory reform, and financial incentives are also needed—and are cost-effective. Efficiency standards and labeling programs cost about 1.5 cents a kilowatt-hour, much less than any electricity supply options,[65] while industrial energy performance targets spur innovation and increase competitiveness.[66] And because utilities are potentially effective delivery channels for making homes, commercial buildings, and industry more energy efficient, incentives have to be created for utilities to conserve energy. This can be done by decoupling a utility's profits from its gross sales, with profits instead increasing with energy conservation successes. Such an approach is behind California's remarkable energy conservation program; its adoption has become a condition for any U.S. state to receive federal energy-efficiency grants from the 2009 fiscal stimulus.

For renewable energy, long-term power-purchase agreements within a regulatory framework that ensures fair and open grid access for independent power producers will

Figure 8 The full portfolio of existing measures and advanced technologies, not a silver bullet, will be needed to get the world onto a 2°C path



Source: WDR team with data from IIASA 2009.

attract investors. This can be done through mandatory purchases of renewable energy at a fixed price (known as a feed-in tariff) as in Germany and Spain; or through renewable portfolio standards that require a minimum share of power to come from renewables, as in many U.S. states.[67] Importantly, predictably higher demand is likely to reduce the costs of renewables, with benefits for all countries. In fact, experience shows that expected demand can have an even higher impact than technological innovation in driving down prices (figure 9).

But new technologies will be indispensable: every energy model reviewed for this Report concludes that it is impossible to get onto the 2°C trajectory with only energy efficiency and the diffusion of existing technologies. New or emerging technologies, such as carbon capture and storage, second-generation biofuels, and solar photovoltaics, are also critical.

Few of the needed new technologies are available off the shelf. Ongoing carbon capture and storage demonstration projects currently store only about 4 million tons of CO_2 annually.[68] Fully proving the viability of this technology in different regions and settings will require about 30 full-size plants at a total cost of $75 billion to $100 billion.[69] Storage capacity of 1 billion tons a year of CO_2 is necessary by 2020 to stay within 2°C warming.

Investments in biofuels research are also needed. Expanded production using the current generation of biofuels would displace large areas of natural forests and grasslands and compete with the production of food.[70] Second-generation biofuels that rely on nonfood crops may reduce competition with agriculture by using more marginal lands. But they could still lead to the loss of pasture land and grassland ecosystems and compete for water resources.[71]

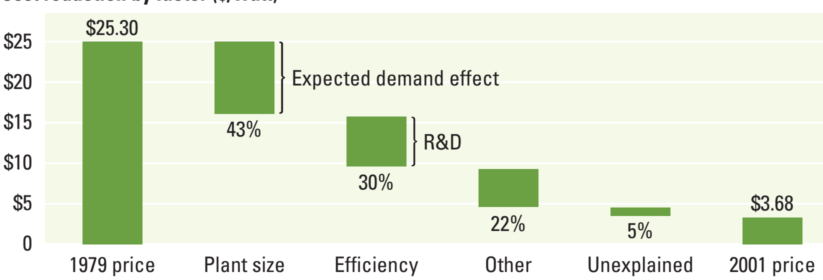
Breakthroughs in climate-smart technologies will require substantially more spending for research, development, demonstration, and deployment. As mentioned earlier, global public and private spending on energy RD&D is modest, both relative to estimated needs and in comparison with what innovative industries invest.[72] The modest spending means slow progress, with renewable energy still accounting for only 0.4 percent of all patents.[73] Moreover, developing countries will need access to these technologies, which will require boosting domestic capacity to identify and adapt new technologies as well as strengthening international mechanisms for technology transfer (see chapter 7).

To transform land and water management and manage competing demands. By 2050 the world will need to feed 3 billion more people and cope with the changing dietary demands of a richer population (richer people eat more meat, a resource-intensive way to obtain proteins). This must be done in a harsher climate with more storms, droughts, and floods. And it has to incorporate agriculture in the mitigation agenda—because agriculture drives about half the deforestation every year and directly contributes 14 percent to overall emissions. And ecosystems, already weakened by pollution, population pressure, and overuse, are further threatened by climate change. Producing more and protecting better in a harsher climate while reducing greenhouse gas emissions is a tall order. It will require managing the competing demands for land and water from agriculture, forests and other ecosystems, cities, and energy.

So agriculture will have to become more productive, getting more crop per drop and per hectare—but without the increase in environmental costs currently associated

Figure 9 High expected demand drove cost reductions in solar photovoltaics by allowing for larger-scale production

Cost reduction by factor ($/watt)



Source: Adapted from Nemet 2006.

Note: Bars show the portion of the reduction in the cost of solar photovoltaic power, from 1979 to 2001, accounted for by different factors such as plant size (which is determined by expected demand) and improved efficiency (which is driven by innovation from R&D). The "other" category includes reductions in the price of the key input silicon (12 percent) and a number of much smaller factors (including reduced quantities of silicon needed for a given energy output, and lower rates of discarded products due to manufacturing error).

with intensive agriculture. And societies will have to put much more effort into protecting ecosystems. To avoid pulling more land into cultivation and spreading into "unmanaged" land and forests, agricultural productivity will have to increase, perhaps by as much as 1.8 percent a year compared to 1 percent a year without climate change.[74] Most of that increase will have to occur in developing countries because agriculture in high-income countries is already close to maximum feasible yields. Fortunately, new technologies and practices are emerging (box 5). Some improve productivity and resilience as they sequester carbon in the soil and reduce the nutrient runoff that damages aquatic ecosystems. But more research is needed to understand how to scale them up.

Increased efforts to conserve species and ecosystems will need to be reconciled with food production (whether agriculture or fisheries). Protected areas—already 12 percent of the earth's land but only a tiny portion of the ocean and fresh water system—cannot be the only solution to maintaining biodiversity, because species ranges are likely to shift outside the boundaries of such areas. Instead ecoagricultural landscapes, where farmers create mosaics of cultivated and natural habitats, could facilitate the migration of species. While benefiting biodiversity, ecoagriculture practices also increase agriculture's resilience to climate change along with farm productivity and incomes. In Central America farms using these practices suffered half or less of the damage inflicted on others by Hurricane Mitch.[75] Improved fallow practices in Zambia, including the use of leguminous trees[76] and cover crops, increased soil fertility and reduced erosion—thereby almost tripling annual net farm incomes.[77]

Better management of water is essential for agriculture to adapt to climate change. River basins will be losing natural water storage in ice and snow and in reduced aquifer recharge, just as warmer temperatures increase evaporation. Water can be used more efficiently through a combination of new and existing technologies,

BOX 5 *Promising approaches that are good for farmers and good for the environment*

Promising practices

Cultivation practices such as zero-tillage (which involves injecting seeds directly into the soil instead of sowing on ploughed fields) combined with residue management and proper fertilizer use can help to preserve soil moisture, maximize water infiltration, increase carbon storage, minimize nutrient runoff, and raise yields. Now being used on about 2 percent of global arable land, this practice is likely to expand. Zero tillage has been largely adopted in high-income countries, but is expanding rapidly in countries such as India. In 2005, in the rice–wheat farming system of the Indo-Gangetic plain, farmers adopted zero-tillage on 1.6 million hectares; by 2008, 20–25 percent of the wheat in two Indian states (Haryana and Punjab) was cultivated using minimum tillage. And in Brazil, about 45 percent of cropland is farmed using these practices.

Promising technologies

Precision agriculture techniques for targeted, optimally timed application of the minimum necessary fertilizer and water could help the intensive, high-input farms of high-income countries, Asia, and Latin America to reduce emissions and nutrient runoff, and increase water-use efficiency. New technologies that limit emissions of gaseous nitrogen include controlled-release nitrogen through the deep placement of supergranules of fertilizer or the addition of biological inhibitors to fertilizers. Remote sensing technologies for communicating precise information about soil moisture and irrigation needs can eliminate unnecessary application of water. Some of these technologies may remain too expensive for most developing-country farmers (and could require payment schemes for soil carbon conservation or changes in water pricing). But others such as biological inhibitors require no extra labor while improving productivity.

Learning from the past

Another approach building on a technology used by indigenous peoples in the Amazon rain forest could sequester carbon on a huge scale while improving soil productivity. Burning wet crop residues or manure (biomass) at low temperatures in the almost complete absence of oxygen produces biochar, a charcoal-type solid with a very high carbon content. Biochar is highly stable in soil, locking in the carbon that would otherwise be released by simply burning the biomass or allowing it to decompose. In industrial settings this process transforms half the carbon into biofuel and the other half into biochar. Recent analysis suggests biochar may be able to store carbon for centuries, possibly millennia, and more studies are underway to verify this property.

Sources: de la Torre, Fajnzylber, and Nash 2008; Derpsch and Friedrich 2009; Erenstein 2009; Erenstein and Laxmi 2008; Lehmann 2007; Wardle, Nilsson, and Zackrisson 2008.

better information, and more sensible use. And that can be done even in poor countries and among small farmers: in Andhra Pradesh, India, a simple scheme, in which farmers monitor their rain and groundwater and learn new farming and irrigation techniques, has caused 1 million farmers to voluntarily reduce groundwater consumption to sustainable levels.[78]

Efforts to increase water resources include dams, but dams can be only a part of the solution, and they will need to be designed flexibly to deal with more variable rainfall. Investments to store more water underground and replenish aquifers are popular in water-stressed developing countries, notably India and in the Middle East. They include check dams (small structures that slow the flow of water in ditches or drainage canals), storage ponds, and other approaches that directly inject stormwater and treated wastewater into aquifers. Other approaches include using recycled water and desalination, which, while costly, can be worthwhile for high-value use in coastal areas, especially if powered by renewable energy (see chapter 3).

But changing practices and technologies can be a challenge, particularly in poor, rural, and isolated settings, where introducing new ways of doing things requires working with a large number of very risk-averse actors located off the beaten track and facing different constraints and incentives. Extension agencies usually have limited resources to support farmers and are staffed with engineers and agronomists rather than trained communicators. Taking advantage of emerging technologies will also require bringing higher technical education to rural communities. New models of entrepreneurial education, such as the one adopted by EARTH University in Costa Rica, one of the world's first sustainable development universities, can bring the benefits of technical education to farming communities and tailor scientific knowledge to local circumstances.

To transform decision-making processes: Adaptive policy making to tackle a riskier and more complex environment. Climate change has largely killed stationarity, the idea that natural systems fluctuate within an unchanging envelope of variability and that has been at the heart of infrastructure design and planning, insurance pricing, and numerous private decisions—from planting and harvesting dates to siting factories and designing buildings.[79] Decision makers now have to contend with the changing climate compounding the uncertainties they already faced. More decisions now have to be made in a context of changing trends and greater variability, not to mention possible carbon constraints.

The approaches being developed and applied by public and private agencies, cities, and countries around the world from Australia to the United Kingdom are showing that it is possible to increase resilience even in the absence of expensive and sophisticated modeling of future climate.[80] Of course better projections and less uncertainty help, but these new approaches tend to focus on strategies that are "robust" across a range of possible future outcomes, not just optimal for a particular set of expectations (box 6).[81] Robust strategies can be as simple as picking seed varieties that do well in a range of climates.

Robust strategies typically build flexibility, diversification, and redundancy in response capacities (see chapter 2). They favor "no-regrets" actions that provide benefits (such as water and energy efficiency) even without climate change. They also favor reversible and flexible options to keep the cost of wrong decisions as low as possible (restrictive urban planning for coastal areas can easily be relaxed while forced retreats or increased protection can be difficult and costly). They include safety margins to increase resilience (paying the marginal costs of building a higher bridge or one that can be flooded, or extending safety nets to groups on the brink). And they rely on long-term planning based on scenario analysis and an assessment of strategies under a wide range of possible futures.[82] Participatory design and implementation is critical, because it permits the use of local knowledge about existing vulnerability and fosters ownership of the strategy by its beneficiaries.

Policy making for adaptation also needs to be adaptive itself, with periodic reviews

BOX 6 *Ingenuity needed: Adaptation requires new tools and new knowledge*

Regardless of mitigation efforts, humanity will need to adapt to substantial changes in the climate—everywhere, and in many different fields.

Natural capital
A diversity of natural assets will be needed to cope with climate change and ensure productive agriculture, forestry, and fisheries. For example, crop varieties are needed that perform well under drought, heat, and enhanced CO_2. But the private-sector- and farmer-led process of choosing crops favors homogeneity adapted to past or current conditions, not varieties capable of producing consistently high yields in warmer, wetter, or drier conditions. Accelerated breeding programs are needed to conserve a wider pool of genetic resources of existing crops, breeds, and their wild relatives. Relatively intact ecosystems, such as forested catchments, mangroves, and wetlands, can buffer the impacts of climate change. Under a changing climate these ecosystems are themselves at risk, and management approaches will need to be more proactive and adaptive. Connections between natural areas, such as migration corridors, may be needed to facilitate species movements to keep up with the change in climate.

Physical capital
Climate change is likely to affect infrastructure in ways not easily predictable and varying greatly with geography. For example, infrastructure in low-lying areas is threatened by flooding rivers and rising seas whether in Tangier Bay, New York City, or Shanghai. Heat waves soften asphalt and can require road closures; they affect the capacity of electricity transmission lines and warm the water needed to cool thermal and nuclear power plants just as they increase electricity demand. Uncertainties are likely to influence not only investment decisions but the design of infrastructure that will need to be robust to the future climate. Similar uncertainty about the reliability of water supply is leading to both integrated management strategies and improved water-related technologies as hedges against climate change. Greater technical knowledge and engineering capabilities will be needed to design future infrastructure in the light of climate change.

Human health
Many adaptations of health systems to climate change will initially involve practical options that build on existing knowledge. But others will require new skills. Advances in genomics are making it possible to design new diagnostic tools that can detect new infectious diseases. These tools, combined with advances in communications technologies, can detect emerging trends in health and provide health workers with early opportunities to intervene. Innovations in a range of technologies are already transforming medicine. For example, the advent of hand-held diagnostic devices and video-mediated consultations are expanding the prospects for telemedicine and making it easier for isolated communities to connect to the global health infrastructure.

Sources: Burke, Lobell, and Guarino forthcoming; Ebi and Burton 2008; Falloon and Betts forthcoming; Guthrie, Juma, and Sillem 2008; Keim 2008; Koetse and Rietveld 2009; National Academy of Engineering 2008; Snoussi and others 2009.

based on the collection and monitoring of information, something increasingly feasible at low cost thanks to better technologies. For example, a key problem in water management is the lack of knowledge about underground water, or about who consumes what. New remote-sensing technology makes it possible to infer groundwater consumption, identify which farmers have low water productivity, and specify when to increase or decrease water applications to maximize productivity without affecting crop yields (see chapter 3).

Making it happen: New pressures, new instruments, and new resources

The previous pages describe the many steps needed to manage the climate change challenge. Many read like the standard fare of a development or environmental science textbook: improve water resource management, increase energy efficiency, promote sustainable agricultural practices, remove perverse subsidies. But these have proven elusive in the past, raising the question of what might make the needed reforms and behavior changes possible. The answer lies in a combination of new pressures, new instruments, and new resources.

New pressures are coming from a growing awareness of climate change and its current and future costs. But awareness does not always lead to action: to succeed, climate-smart development policy must tackle the inertia in the behavior of individuals and organizations. Domestic perception of climate change will also determine the success of a global deal—its adoption but also its implementation. And while many of the answers to the climate and development problem will be national or even local, a global deal is needed to generate new instruments and new resources for action (see chapter 5). So while new pressures must start at home with changing behaviors and shifting public opinion, action must be enabled by an efficient and effective international agreement, one that factors in development realities.

New pressures: Success hinges on changing behavior and shifting public opinion

International regimes influence national policies but are themselves a product of domestic factors. Political norms, governance structures, and vested interests drive the translation of international law into domestic policy, while shaping the international regime.[83] And in the absence of a global enforcement mechanism, the incentives for meeting global commitments are domestic.

To succeed, climate-smart development policy has to factor in these local determinants. The mitigation policies that a country will follow depend on domestic factors such as the energy mix, the current and potential energy sources, and the preference for state or market-driven policies. The pursuit of ancillary local benefits—such as cleaner air, technology transfers, and energy security—is crucial to generating sufficient support.

Climate-smart policies also have to tackle the inertia in the behavior of individuals and organizations. Pricing is only part of the problem. The way problems are seen matters as well. Weaning modern economies from fossil fuels and increasing resilience to climate change will require attitudinal shifts by consumers, business leaders, and decision makers. The challenges in changing ingrained behaviors call for a special emphasis on nonmarket policies and interventions.

Throughout the world disaster risk management programs are focused on changing community perceptions of risk. The City of London has made targeted communication and education programs a centerpiece of its "London Warming" Action Plan. And utilities across the United States have begun using social norms and peer community pressure to encourage lower energy demand: simply showing households how they are faring relative to others, and signaling approval of lower than average consumption is enough to encourage lower energy use (see chapter 8).

Addressing the climate challenge will also require changes in the way governments operate. Climate policy touches on the mandate of many government agencies, yet belongs to none. For both mitigation and adaptation, many needed actions require a long-term perspective that goes well beyond those of any elected administration. Brazil, China, India, Mexico, and the United Kingdom have created lead agencies for climate change, set up high-level coordination bodies, and improved the use of scientific information in policy making (see chapter 8).

Cities, provinces, and regions provide political and administrative space closer to the sources of emissions and the impacts of climate change. In addition to implementing and articulating national policies and regulations, they perform policy-making, regulatory, and planning functions in sectors key to mitigation (transportation, construction, public services, local advocacy) and adaptation (social protection, disaster risk reduction, natural resource management). Because they are closer to citizens, these governments can raise public awareness and mobilize private actors.[84] And at the intersection of the government and the public, they become the space where government accountability for appropriate responses is played out. That is why many local governments have preceded national governments in climate action (box 7).

New instruments and new resources: The role of a global agreement

Immediate and comprehensive action is not feasible without global cooperation, which requires a deal perceived as equitable by all parties—high-income countries, which need to make the most immediate and stringent efforts; middle-income countries, where substantial mitigation and adaptation need to happen; and low-income countries, where the priority is technical and financial assistance to cope with vulnerability to today's conditions, let alone unfolding changes in the climate. The deal must also be effective in achieving climate goals, incorporating lessons from other international agreements and from past successes and failures with large international transfers of resources. Finally, it has to be efficient, which requires adequate

BOX 7 *Cities reducing their carbon footprints*

The movement toward carbon-neutral cities shows how local governments are taking action even in the absence of international commitments or stringent national policies. In the United States, which has not ratified the Kyoto Protocol, close to a thousand cities have agreed to meet the Kyoto Protocol target under the Mayors' Climate Protection agreement. In Rizhao, a city of 3 million people in northern China, the municipal government combined incentives and legislative tools to encourage the large-scale efficient use of renewable energy. Skyscrapers are built to use solar power, and 99 percent of Rizhao's households use solar-power heaters. Almost all traffic signals, street lights, and park illuminations are powered by photovoltaic solar cells. In total the city has over 500,000 square meters of solar water heating panels, the equivalent of about 0.5 megawatts of electric water heaters. As a result of these efforts, energy use has fallen by nearly a third and CO_2 emissions by half.

Examples of movements to carbon-neutral cities are mushrooming well beyond China. In 2008 Sydney became the first city in Australia to become carbon neutral, through energy efficiency, renewable energy, and carbon offsets. Copenhagen is planning to cut its carbon emissions to zero by 2025. The plan includes investments in wind energy and encouraging the use of electric and hydrogen-powered cars with free parking and recharging.

More than 700 cities and local governments around the world are participating in a "Cities for Climate Protection Campaign" to adopt policies and implement quantifiable measures to reduce local greenhouse gas emissions (http://www.iclei.org). Together with other local government associations, such as the C40 Cities Climate Leadership Group and the World Mayors Council on Climate Change, they have embarked on a process that seeks empowerment and inclusion of cities and local governments in the UN Framework Convention on Climate Change.

Sources: Bai 2006; World Bank 2009d; C40 Cities Climate Leadership Group, http://www.c40cities.org (accessed August 1, 2009).

funding and financial instruments that can separate where mitigation happens from who funds it—thereby achieving mitigation at least cost.

An equitable deal. Global cooperation at the scale needed to deal with climate change can happen only if it is based on a global agreement that addresses the needs and constraints of developing countries, only if it can separate where mitigation happens from who bears the burden of this effort, and only if it creates financial instruments to encourage and facilitate mitigation, even in countries that are rich in coal and poor in income or that have contributed little or nothing historically to climate change. Whether these countries seize the opportunity to embark on a more sustainable development path will be heavily influenced by the financial and technical support that higher-income countries can muster. Otherwise the transition costs could be prohibitive.

Global cooperation will require more than financial contributions, however. Behavioral economics and social psychology show that people tend to reject deals they perceive as unfair toward them, even if they stand to benefit.[85] So the fact that it is in everyone's interest to collaborate is no guarantee of success. There are real concerns among developing countries that a drive to integrate climate and development could shift responsibility for mitigation onto the developing world.

Enshrining a principle of equity in a global deal would do much to dispel such concerns and generate trust. A long-term goal of per capita emissions converging to a band could ensure that no country is locked into an unequal share of the atmospheric commons. India has recently stated that it would never exceed the average per capita emissions of high-income countries.[86] So drastic action by high-income countries to reduce their own carbon footprint to sustainable levels is essential. This would show leadership, spur innovation, and make it feasible for all to switch to a low-carbon growth path.

Another major concern of developing countries is technology access. Innovation in climate-related technologies remains concentrated in high-income countries, although developing countries are increasing their presence (China was seventh in overall renewable energy patents,[87] and an Indian firm is now the leader in on-road electric cars[88]). In addition, developing countries—at least the smaller or poorer ones—may need assistance to produce new technology or tailor it to their circumstances. This is particularly problematic for adaptation, where technologies can be very location specific.

International transfers of clean technologies have so far been modest. They have occurred in at best one-third of the projects funded through the Clean Development Mechanism (CDM), the main channel for financing investments in low-carbon technologies in developing countries.[89] The Global Environmental Facility, which has historically allocated about $160 million a year to climate mitigation programs,[90] is supporting technology needs assessments in 130 countries. About $5 billion has recently been pledged under the new Clean Technology Fund to assist developing countries by supporting large, risky investments involving clean technologies, but there are disputes over what constitutes clean technology.

Building technology agreements into a global climate deal could boost technology innovation and ensure developing-country access. International collaboration is critical for producing and sharing climate-smart technologies. On the production side, cost-sharing agreements are needed for large-scale and high-risk technologies such as carbon capture and storage (see chapter 7). International agreements on standards create markets for innovation. And international support for technology transfer can take the form of joint production and technology sharing—or financial support for the incremental cost of adopting new cleaner technology (as was done through the Multilateral Fund for the Implementation of the Montreal Protocol on Substances that Deplete the Ozone Layer).

A global deal will also have to be acceptable to high-income countries. They worry about the financial demands that could be placed on them and want to ensure that financial transfers deliver the desired adaptation and mitigation results. They also are concerned that a tiered approach allowing developing countries to delay actions might affect their own competitiveness with leading middle-income countries.

An effective deal: Lessons from aid effectiveness and international agreements. An effective climate deal will achieve agreed targets for mitigation and adaptation. Its design can build on the lessons of aid effectiveness and international agreements. Climate finance is not aid finance, but the aid experience does offer critical lessons. In particular, it has become clear that commitments are seldom respected unless they correspond to a country's objectives—the conditionality versus ownership debate. So funding for adaptation and mitigation should be organized around a process that encourages recipient-country development and ownership of a low-carbon development agenda. The aid experience also shows that a multiplicity of funding sources imposes huge transaction costs on recipient countries and reduces effectiveness. And while the sources of funding might be separate, the spending of adaptation and mitigation resources must be fully integrated into development efforts.

International agreements also show that tiered approaches can be an appropriate way of bringing hugely different partners into a single deal. Look at the World Trade Organization: special and differential treatment for developing countries has been a defining feature of the multilateral trading system for most of the postwar period. Proposals are emerging in the climate negotiations around the multitrack framework put forward in the UNFCCC's Bali Action Plan.[91] These proposals would have developed countries commit to output targets, where the "output" is greenhouse gas emissions, and developing countries commit to policy changes rather than emission targets.

This approach is appealing for three reasons. First, it can advance mitigation opportunities that carry development co-benefits. Second, it is well suited to developing countries, where fast population and economic growth is driving the rapid expansion of the capital stock (with opportunities for good or bad lock-in) and increases the urgency of moving energy, urban, and transport systems toward a lower-carbon path. A policy-based track can also offer a good framework for countries with a high share of hard-to-measure emissions from land use, land-use change, and forestry. Third, it is less likely to require monitoring of complex flows—a challenge for many countries. Nevertheless, some overall monitoring and evaluation of these approaches is critical, if only to understand their effectiveness.[92]

An efficient deal: The role of climate finance

Climate finance can reconcile equity and efficiency by separating where climate action takes place from who pays for it. Sufficient finance flowing to developing countries—combined with capacity building and access to technology—can support low-carbon growth and development. If mitigation finance is directed to where mitigation costs are lowest, efficiency will increase. If adaptation finance is directed to where the needs are greatest, undue suffering and loss can be avoided. Climate finance offers the means to reconcile equity, efficiency, and effectiveness in dealing with climate change.

But current levels of climate finance fall far short of foreseeable needs. Mitigation finance needed in developing countries could be around $400 billion a year by 2030 (using the median of the estimates in table 1). Current flows of mitigation finance averaging some $8 billion a year to 2012 pale in comparison. And the estimated $75 billion that could be needed annually for adaptation in developing countries dwarfs the less than $1 billion a year now available (figure 10).

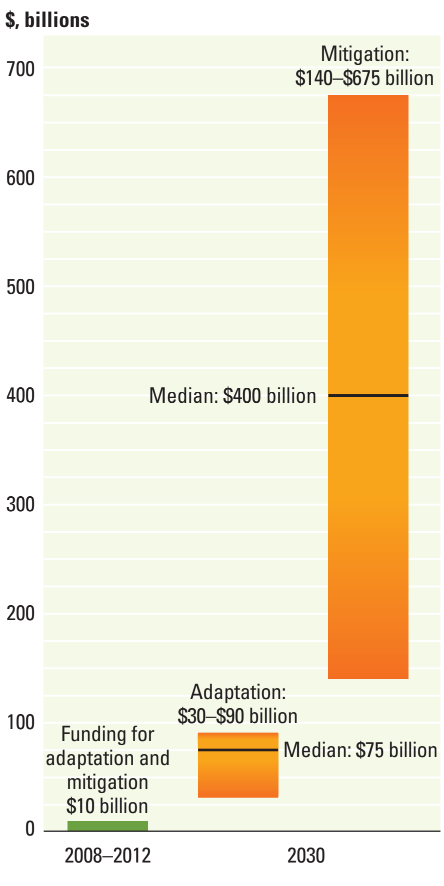
Compounding the shortfalls in climate finance are significant inefficiencies in how funds are generated and deployed. Key problems include fragmented sources of finance; high costs of implementing market mechanisms such as the Clean Development Mechanism; and insufficient, distortionary instruments for raising adaptation finance.

Chapter 6 identifies nearly 20 different bilateral and multilateral funds for climate change currently proposed or in operation. This fragmentation has a cost identified in the Paris Declaration on Aid Effectiveness: each fund has its own governance, raising transaction costs for developing countries; and alignment with country development objectives may suffer if sources of finance are narrow. Other tenets of the Paris Declaration, including ownership, donor harmonization, and mutual accountability, also suffer when financing is highly fragmented. An eventual consolidation of funds into a more limited number is clearly warranted.

Looking forward, pricing carbon (whether through a tax or through a cap and trade scheme) is the optimal way of both generating carbon-finance resources and directing those resources to efficient opportunities. In the near future, however, the CDM and other performance-based mechanisms for carbon offsets are likely to remain the key market-based instruments for mitigation finance in developing countries and are therefore critical in supplementing direct transfers from high-income countries.

The CDM has in many ways exceeded expectations, growing rapidly, stimulating

Figure 10 The gap is large: Estimated annual climate funding required for a 2°C trajectory compared with current resources



Sources: For mitigation: UNFCCC 2008; IIASA 2009; IEA 2008c; McKinsey Global Institute 2009a; additional data communication from McKinsey for 2030, using a dollar-to-Euro exchange rate of $1.50 to €1.00; Edmonds and others 2008; and additional data provided by Jae Edmonds. For adaptation: Agrawala and Fankhauser 2008; World Bank 2009c; and Project Catalyst 2009.

Note: Shaded bars represent *range* of estimates of adaptation and mitigation needs in 2030, as well as the median.

learning, raising awareness of mitigation options, and building capacity. But it also has many limitations, including low development co-benefits, questionable additionality (because the CDM generates carbon credits for emission reductions relative to a baseline, the choice of baseline can always be questioned), weak governance, inefficient operation, limited scope (key sectors such as transport are not covered), and concerns about market continuity beyond 2012.[93] For the effectiveness of climate actions it is also important to understand that CDM transactions do not reduce global carbon emissions beyond agreed commitments—they simply change where they occur (in developing rather than developed countries) and lower the cost of mitigation (thereby increasing efficiency).

The Adaptation Fund under the Kyoto Protocol employs a novel financing instrument in the form of a 2 percent tax on certified emission reductions (units of carbon offset generated by the CDM). This clearly raises finance that is additional to other sources, but as pointed out in chapter 6, this approach has several undesirable characteristics. The instrument is taxing a good (mitigation finance) rather than a bad (carbon emissions) and like any tax, there are inevitable inefficiencies (deadweight losses). Analysis of the CDM market suggests that most of the lost gains from trade as a result of the tax would fall on developing-country suppliers of carbon credits.[94] Adaptation finance will also require an allocation mechanism that ideally would embrace the principles of transparency, efficiency, and equity—efficient approaches would direct finance to the most vulnerable countries and those with the greatest capacity to manage adaptation, while equity would require that particular weight be given to the poorest countries.

Strengthening and expanding the climate finance regime will require reforming existing instruments and developing new sources of climate finance (see chapter 6). Reform of the CDM is particularly important in view of its role in generating carbon finance for projects in developing countries. One set of proposals aims at reducing costs through streamlining project approval, including upgrading the review and administrative functions. A key second set of proposals focuses on allowing the CDM to support changes in policies and programs rather than limit it to projects. "Sector no-lose targets" are an example of a performance-based scheme, where demonstrable reductions in sectoral carbon emissions below an agreed baseline could be compensated through the sale of carbon credits, with no penalty if the reductions are not achieved.

Forestry is another area where climate finance can reduce emissions (box 8). Additional mechanisms for pricing forest carbon are likely to emerge from the current climate negotiations. Already several initiatives, including the World Bank's Forest Carbon Partnership Facility, are exploring how financial incentives can reduce deforestation in developing countries and thereby reduce carbon emissions. The major challenges include developing a national strategy and implementation framework for reducing emissions from deforestation and degradation; a reference scenario for emissions; and a system for monitoring, reporting, and verification.

Efforts to reduce emissions of soil carbon (through incentives to change tilling practices, for example) could also be a target of financial incentives—and are essential to ensure natural areas are not converted to food and biofuel production. But the methodology is less mature than for forest carbon, and major monitoring issues would need to be resolved (see box 8). Pilot programs must be developed rapidly to encourage more resilient and sustainable agriculture and to bring more resources and innovation to a sector that has lacked both in recent decades.[95]

Within countries the role of the public sector will be critical in creating incentives for climate action (through subsidies, taxes, caps, or regulations), providing information and education, and eliminating market failures that inhibit action. But much of the finance will come from the private sector, particularly for adaptation. For private infrastructure service providers the flexibility of the regulatory regime will be crucial in providing the right incentives for climate-proofing investments and

BOX 8 *The role of land use, agriculture, and forestry in managing climate change*

Land use, agriculture, and forestry have a substantial mitigation potential but have been contentious in the climate negotiations. Could emissions and uptakes be measured with sufficient accuracy? What can be done about natural fluctuations in growth and losses from fires associated with variations in the global climate? Should countries get credits for actions taken decades or centuries before the climate negotiations? Would credits from land-based activities swamp the carbon market and drive down the carbon price, reducing incentives for further mitigation? Progress has been made on many of these issues, and the Intergovernmental Panel on Climate Change has developed guidelines for measuring land-related greenhouse gases.

Net global deforestation averaged 7.3 million hectares a year from 2000 to 2005, contributing about 5.0 gigatons of CO_2 a year in emissions, or about a quarter of the emission reduction needed. Another 0.9 gigaton reduction could come from reforestation and better forest management in developing countries. But improved forest management and reduced deforestation in developing countries are currently not part of the international Clean Development Mechanism of the UNFCCC.

There is also interest in creating a mechanism for payments for improved management of soil carbon and other greenhouse gases produced by agriculture. Technically about 6.0 gigatons of CO_2e in emissions could be reduced through less tillage of soils, better wetland and rice paddy management, and better livestock and manure management. About 1.5 gigatons of emission reductions a year could be achieved in agriculture for a carbon price of $20 a ton of CO_2e (figure).

Forestry and agricultural mitigation would produce many co-benefits. The maintenance of forests keeps open a wider diversity of livelihood options, protects biodiversity, and buffers against extreme events such as floods and landslides. Reduced tillage and better fertilizer management can improve productivity. And the resources generated could be substantial—at least for countries with large forests: if the forest carbon markets meet their full potential, Indonesia could earn $400 million to $2 billion a year. As for soil carbon, even in Africa, where relatively carbon-poor lands cover close to half the continent, the potential for soil carbon sequestration is 100 million to 400 million tons of CO_2e a year. At $10 a ton, this would be on par with current official development assistance to Africa.

Largely through the efforts of a group of developing countries that formed the Coalition for Rainforests, land use, land-use change, and forestry accounting were reintroduced into the UNFCCC agenda. Those countries seek opportunities to contribute to reducing emissions under their common but differentiated responsibility and to raise carbon finance to better manage their forested systems. Negotiations over what has become known as REDD (Reduced Emissions from Deforestation and Forest Degradation) continue, but most expect some elements of REDD to be part of an agreement in Copenhagen.

Initiatives on soil carbon are not so advanced. While carbon sequestration in agriculture would be an inexpensive, technically simple, and efficient response to climate change, developing a market for it is no easy feat. A pilot project in Kenya (see chapter 3) and soil carbon offsets on the Chicago Climate Exchange point to opportunities. Three steps can help move soil carbon sequestration forward.

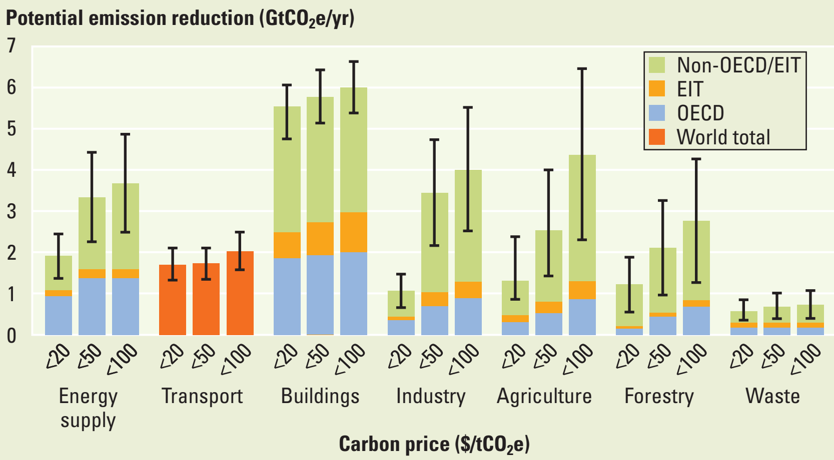
First, the carbon monitoring should follow an "activity-based" approach, where emission reductions are estimated based on the activities carried out by the farmer rather than on much more expensive soil analyses. Specific and conservative emission reduction factors can be applied for different agroecological and climatic zones. This is simpler, cheaper, and more predictable for the farmer, who knows up front what the payments, and possible penalties, are for any given activity.

Second, transaction costs can be reduced by "aggregators," who combine activities over many smallholder farms, as in the Kenya pilot project. By working with many farms, aggregators can build up a permanent buffer and average out occasional reversals in sequestration. Pooling over a portfolio of projects with conservative estimates of permanence can make soil carbon sequestration fully equivalent to CO_2 reduction in other sectors.

Third, logistical help, especially for poor farmers who need help to finance up-front costs, must include strengthened extension services. They are key to disseminating knowledge about sequestration practices and finance opportunities.

Sources: Canadell and others 2007; Eliasch 2008; FAO 2005; Smith and others 2008; Smith and others 2009; Tschakert 2004; UNEP 1990; Voluntary Carbon Standard 2007; World Bank 2008c.

It's not just about energy: At high carbon prices the combined mitigation potential of agriculture and forestry is greater than that of other individual sectors of the economy



Source: Barker and others 2007b, figure TS.27.
Note: EIT = economies in transition. The ranges for global economic potentials as assessed in each sector are shown by black vertical lines.

operations. While it will be possible to leverage private finance for specific adaptation investments (such as flood defenses) experience to date with public-private partnerships on infrastructure in developing countries suggests that the scope will be modest.

Generating additional finance for adaptation is a key priority, and innovative schemes such as auctioning assigned amount units (AAUs, the binding caps that countries accept under the UNFCCC), taxing international transport emissions, and a global carbon tax have the potential to raise tens of billions of dollars of new finance each year. For mitigation it is clear that having an efficient price for carbon, through either a tax or cap-and-trade, will be transformational. Once this is achieved, the private sector will provide much of the needed finance as investors and consumers factor in the price of carbon. But national carbon taxes or carbon markets will not necessarily provide the needed flows of finance to developing countries. If the solution to the climate problem is to be equitable, a reformed CDM and other performance-based schemes, the linking of national carbon markets, the allocation and sale of AAUs, and fiscal transfers will all provide finance to developing countries.

As this Report goes to press, countries are engaged in negotiations on a global climate agreement under the auspices of the UNFCCC. Many of these same countries are also in the throes of one of the most severe financial crises of recent decades. Fiscal difficulties and urgent needs could make it difficult to get legislatures to agree to spend resources on what is incorrectly perceived as solely a longer-term threat.

Yet a number of countries have adopted fiscal recovery packages to green the economy while restoring growth, for a global total of more than $400 billion over the next few years in the hope of stimulating the economy and creating jobs.[96] Investments in energy efficiency can produce a triple dividend of greater energy savings, fewer emissions, and more jobs—because low-carbon technologies are often more labor intensive than high-carbon ones.

The current climate negotiations, to culminate in Copenhagen in December 2009, have been making slow progress—inertia in the political sphere. For all the reasons highlighted in this Report—inertia in the climate system, inertia in infrastructure, inertia in socioeconomic systems—a climate deal is urgently needed. But it must be a smart deal, one that creates the incentives for efficient solutions, for flows of finance and the development of new technologies. And it must be an equitable deal, one that meets the needs and aspirations of developing countries. Only this can create the right climate for development.

Notes

1. Extreme poverty is defined as living on $1.25 a day or less. Chen and Ravallion 2008.
2. FAO 2009b.
3. Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) calls for stabilizing greenhouse gas concentrations in the atmosphere at a level that "would prevent dangerous anthropogenic [human-caused] interference with the climate system." http://unfccc.int/resource/docs/convkp/conveng.pdf (accessed August 1, 2009).
4. Defined as carbon emitted per dollar of GDP.

Many people are taking action to protect our environment. I think that only by working as a team will we succeed in making a difference. Even children can join together to help because we are the next generation and we should treasure our own natural environment.

—Adrian Lau Tsun Yin, China, age 8

Anoushka Bhari, Kenya, age 8

5. On a global scale, this would reduce CO_2 emissions by 4–6 gigatons a year given the current energy mix in the power sector and industry (IEA 2008e). Similar reductions would be possible in the building sector in high-income countries. See, for example, Mills 2009, http://cx.lbl.gov/documents/2009-assessment/LBNL-Cx-Cost-Benefit-Pres.pdf (accessed July 24, 2009).

6. World Bank 2009b.

7. de la Torre, Fajnzylber, and Nash 2008.

8. Greenhouse gases each have different heat-trapping potential. The carbon dioxide equivalent (CO_2e) concentration can be used to describe the composite global warming effect of these gases in terms of the amount of CO_2 that would have the same heat-trapping potential over a specified period of time.

9. Authors' calculations, based on data from Climate Analysis Indicators Tool (WRI 2008). The range is much greater if small island states such as Barbados (4.6 tons of CO_2e per capita) and oil producers such as Qatar (55 tons of CO_2e per capita) or the United Arab Emirates (39 tons of CO_2e per capita) are included.

10. IEA 2008c.

11. Edmonds and others 2008; Hamilton 2009. Blanford, Richels, and Rutherford (2008) also show substantial savings from countries announcing in advance the date when they will engage in mitigation, because that allows those investing in long-lived assets to factor in the likely change in future regulatory regimes and carbon prices and therefore minimizes the number of stranded assets.

12. Financial crises that are highly synchronized across countries are associated with similar durations and are followed by similar recoveries, although the losses tend to be more severe (5 percent of GDP on average). IMF 2009, table 3.1. Even the Great Depression in the United States lasted only three and a half years, from August 1929 to March 1933. National Bureau of Economic Research Business Cycle Expansion and Contraction database, http://www.nber.org/cycles.html (accessed August 1, 2009).

13. Matthews and Caldeira 2008.

14. Schaeffer and others 2008.

15. While the question of what constitutes dangerous climate change requires value judgments, summaries of recent research by the Intergovernmental Panel on Climate Change (IPCC) suggest that warming by more than 2°C above preindustrial levels sharply increases risks, so that "significant benefits result from constraining temperatures to not more than 1.6°C—2.6°C." Fisher and others 2007; IPCC 2007b; IPCC 2007c; Parry and others 2007. Recent scientific publications further support the notion that warming should be constrained to remain as close as possible to 2°C above preindustrial temperatures. Science focus; Mann 2009; Smith and others 2009. The organizers of the 2009 International Scientific Congress on Climate Change concluded that "there is increasing agreement that warming above 2°C would be very difficult for contemporary societies and ecosystems to cope with." http://climatecongress.ku.dk/ (accessed August 1, 2009). Other calls for not allowing warming to exceed 2°C include European Commission 2007; SEG 2007; and International Scientific Steering Committee 2005. The leaders of Australia, Brazil, Canada, China, the European Union, France, Germany, India, Indonesia, Italy, Japan, the Republic of Korea, Mexico, the Russian Federation, South Africa, the United Kingdom, and the United States—meeting at the Major Economies Forum on Energy and Climate in July 2009—recognized "the scientific view that the increase in global average temperature above pre-industrial levels ought not to exceed 2°C." http://usclimatenetwork.org/resource-database/MEF_Declarationl-0.pdf (accessed August 1, 2009).

16. IPCC 2007c.

17. Raupach and others 2007.

18. Lawrence and others 2008; Matthews and Keith 2007; Parry and others 2008; Scheffer, Brovkin, and Cox 2006; Torn and Harte 2006; Walter and others 2006.

19. Horton and others 2008.

20. This estimate does not take into account the increase of damages from storm surges, and it uses current population and economic activities. So in the absence of large-scale adaptation, it is likely to be a significant underestimate. Dasgupta and others 2009.

21. Stern 2007.

22. Easterling and others 2007, table 5.6, p 299.

23. Parry and others 2007, table TS.3, p 66.

24. Nordhaus and Boyer 2000. Stern (2007) also finds that losses associated with climate change would be much greater in India and Southeast Asia than the world average.

25. Nordhaus 2008; Stern 2007; Yohe and others 2007, figure 20.3.

26. The PAGE model, used for the Stern Review of Climate Change, estimates that 80 percent of the costs of damages would be borne by developing countries; Hope (2009), with further data breakdowns communicated by the author. The RICE model (Nordhaus and Boyer 2000), as expanded to include adaptation in de Bruin, Dellink, and Agrawala (2009), suggests that about three-quarters of the costs of damages would be borne by developing countries. See also Smith and others (2009); Tol (2008). Note that this may well be an underestimate, since it does not take into account the value of lost ecosystem services. See chapter 1 for a discussion of the limitation of models' ability to capture costs of impacts.

27. Noted during consultations with East African and Latin American countries.

28. Barbera and McConnell 1990; Barrett 2003; Burtraw and others 2005; Jaffe and others 1995; Meyer 1995.

29. Hope 2009; Nordhaus 2008.

30. Nordhaus 2008.

31. Few models incorporate adaptation costs. See de Bruin, Dellink, and Agrawala (2009) for a discussion.

32. Nordhaus 2008, p. 86, figure 5.3. Nordhaus finds the additional cost of stabilizing warming at 2°C rather than his optimal target of 3.5°C to be 0.3 percent of GDP annually. The additonal cost of 2.5°C rather than 3.5°C is less than 0.1 percent of GDP annually.

33. The developing-country average is 1.5 percent of GDP; it includes health insurance and excludes life insurance. Swiss Re 2007.

34. Based on Maddison's projected GDP for 2030, http://www.ggdc.net/maddison/ (accessed May 6, 2009) rebased to 2005 international dollars using World Bank deflators.

35. To be updated for the final release based on World Bank 2009c.

36. Adger and others 2009.

37. IPCC 2001.

38. Mignone and others 2008. This is true in the absence of effective and acceptable geoengineering technology (see chapter 7).

39. This can result from economies of scale in technology provision (as was the case for the French nuclear program and appears to be an issue for concentrated solar power); network effects (for a highway or rail construction program); or demographic or economic shocks. This and the rest of the paragraph are based on Shalizi and Lecocq 2009.

40. Shalizi and Lecocq 2009.

41. Folger 2006; Levin and others 2007.

42. Anderer and others 1981, as cited in Ha-Duong, Grubb, and Hourcade 1997.

43. Davis and Owens 2003; IEA 2008b; Nemet and Kammen 2007; SEG 2007; Stern 2007.

44. Repetto 2008.

45. Stern 2007, part VI.

46. Based on the formula used in Nordhaus 2008.

47. These are rounded values based on the following. The IPCC estimates that at carbon prices up to $50 a ton CO_2e, about 65 percent of emission reduction would take place in developing countries in 2030 (Barker and others 2007a, table 11.3). McKinsey Global Institute (2009b) estimates this share at 68 percent for a 450 ppm scenario if done using a least-cost allocation. As to the least-cost share of global mitigation investments in 2030 taking place in developing countries, it is estimated at 44–67 percent for a 450 ppm CO_2e concentration (see table 1: 44 percent, MESSAGE; 56 percent, McKinsey; 66 percent, MiniCAM; 67 percent, IEA ETP). Over the course of the century (using present value of all investments to 2100), the estimated share of developing countries is somewhat higher, with ranges between 66 percent (Edmonds and others 2008) and 71 percent (Hope 2009).

48. Edmonds and others 2008.

49. For a 425–450 ppm CO_2e, or 2°C, stabilization scenario, IIASA (2009) estimates the cost at $4 trillion; Knopf and others (forthcoming) at $6 trillion; Edmonds and others (2008) at $9 trillion; Nordhaus (2008) at $11 trillion; and Hope (2009) at $25 trillion. These are present value, and the large differences among them are largely driven by the different discount rate used. All follow a first-best scenario where mitigation takes place wherever and whenever most cost-effective.

50. Hamilton 2009.

51. The Nameless Hurricane, http://science.nasa.gov/headlines/y2004/02apr_hurricane.htm (accessed March 12, 2009).

52. Rogers 2009; Westermeyer 2009.

53. OECS 2004.

54. World Bank 2008a.

55. Kanbur 2009.

56. FAO 2009a.

57. Worldwatch Institute, "State of the World 2005 Trends and Facts: Water Conflict and Security Cooperation," http://www.worldwatch.org/node/69 (accessed July 1, 2009); Wolf and others 1999.

58. Easterling and others 2007; Fisher and others 2007.

59. FAO 2008.

60. von Braun and others 2008; World Bank 2009a.

61. Sterner 2007. The average fuel price in the Euro area in 2007 was more than twice what it was in the United States ($1.54 a liter as opposed to 63 cents a liter). Variations in emissions not driven by income can be captured by the residuals of a regression of emissions per capita on income. When these residuals are regressed on gasoline prices, the elasticity is estimated at –0.5, meaning that a doubling of fuel prices would halve emissions, holding income per capita constant.

62. Based on average electricity prices for households in 2006–07 from the U.S. Energy Information Agency, http://www.eia.doe.gov/emeu/international/elecprih.html (accessed August 1, 2009).

63. Emission data is from WRI (2008).

64. IEA 2008d; UNEP 2008. A 2004 report by the European Environment Agency (EEA 2004) estimated European subsidies to energy at €30 billion in 2001, two-thirds for fossil fuels, the rest for nuclear and renewables.

65. http://www.eia.doe.gov/emeu/international/elecprih.html (accessed July 2009).

66. Price and Worrell 2006.

67. ESMAP 2006.

68. http://co2captureandstorage.info/index.htm (accessed August 1, 2009).

69. Calvin and others forthcoming; IEA 2008a.

70. Gurgel, Reilly, and Paltsev 2008; IEA 2006; Wise and others 2009.

71. NRC 2007; Tilman, Hill, and Lehman 2006; WBGU 2009.

72. IEA 2008c; IEA 2008d.

73. OECD 2008.

74. Lotze-Campen and others 2009; Wise and others 2009. See chapter 3 for a discussion.

75. Scherr and McNeely 2008.

76. Leguminous trees fix atmospheric nitrogen, enhancing the nutrient load in the plant and the soil.

77. McNeely and Scherr 2003.

78. World Bank 2007b.

79. Milly and others 2008.

80. Fay, Block, and Ebinger 2009; Ligeti, Penney, and Wieditz 2007; Heinz Center 2007.

81. Lempert and Schlesinger 2000.

82. Keller, Yohe, and Schlesinger 2008.

83. Cass 2005; Davenport 2008; Dolsak 2001; Kunkel, Jacob, and Busch 2006.

84. Alber and Kern 2008.

85. Guth, Schmittberger, and Schwarze 1982; Camerer and Thaler 1995; Irwin 2008; Ruffle 1998.

86. *Times of India,* http://timesofindia.indiatimes.com/NEWS/India/Even-in-2031-Indias-per-capita-emission-will-be-1/7th-of-US/articleshow/4717472.cms (accessed August 2009).

87. Dechezlepretre and others 2008.

88. Maini 2005; Nagrath 2007.

89. Haites and others 2006.

90. http://www.gefweb.org/uploadedFiles/Publications/ClimateChange-FS-June2009.pdf (accessed July 6, 2009).

91. http://unfccc.int/meetings/cop_13/items/4049.php (accessed August 1, 2009).

92. The development and aid community has been moving toward impact evaluation and results-based aid, suggesting a degree of frustration with input-based programs (where the quantity of funds disbursed and the number of schools built were monitored, as opposed to the number of children graduating from schools or improvements in their performance). However, there is some difference in the way "input-based" approaches are defined in this case, because the "inputs" are policy changes rather than narrowly defined financial inputs—adoption and enforcement of a fuel efficiency standard rather than public spending on an efficiency program. Nevertheless, monitoring and evaluation would still be important to learn what works.

93. Olsen 2007; Sutter and Parreno 2007; Olsen and Fenhann 2008; Nussbaumer 2009; Michaelowa and Pallav 2007; Schneider 2007.

94. Fankhauser, Martin, and Prichard 2009.

95. World Bank 2007d.

96. Stimulus packages around the world are expected to inject about $430 billion in key climate change areas over the next few years: $215 billion will be spent on energy efficiency, $38 billion on low-carbon renewables, $20 billion on carbon capture and storage, and $92 billion on smart grids. Robins, Clover, and Singh 2009. See chapter 1 for a discussion of expected job creation.

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