Human Development Report 2007/2008 - Fighting Climate Change: Human Solidarity in a Divided World [Chapter 1 - The 21st Century climate challenge]

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The 21st Century climate challenge

“One generation plants a tree; the next generation gets the shade.”

Chinese Proverb

“You already know enough. So do I. It is not knowledge we lack. What is missing is the courage to understand what we know and to draw conclusions.”

Sven Lindqvist

CHAPTER 1

The 21st Century climate challenge

The supreme reality of our time is the spectre of dangerous climate change

Easter Island in the Pacific Ocean is one of the most remote locations on Earth. The gigantic stone statues located in the Rono Raraku volcanic crater are all that remain of what was a complex civilization. That civilization disappeared because of the over-exploitation of environmental resources. Competition between rival clans led to rapid deforestation, soil erosion and the destruction of bird populations, undermining the food and agricultural systems that sustained human life.[1] The warning signs of impending destruction were picked up too late to avert collapse.

The Easter Island story is a case study in the consequences of failure to manage shared ecological resources. Climate change is becoming a 21st Century variant of that story on a global scale. There is, however, one important difference. The people of Easter Island were overtaken by a crisis that they could not anticipate—and over which they had little control. Today, ignorance is no defence. We have the evidence, we have the resources to avert crisis, and we know the consequences of carrying on with business-as-usual.

President John F. Kennedy once remarked that "the supreme reality of our time is our indivisibility and our common vulnerability on this planet".[2] He was speaking in 1963 in the aftermath of the Cuban missile crisis at the height of the Cold War. The world was living with the spectre of nuclear holocaust. Four decades on, the supreme reality of our time is the spectre of dangerous climate change.

That spectre confronts us with the threat of a twin catastrophe. The first is an immediate threat to human development. Climate change affects all people in all countries. However, the world's poorest people are on the front line. They stand most directly in harm's way—and they have the least resources to cope. This first catastrophe is not a distant future scenario. It is unfolding today, slowing progress towards the Millennium Development Goals (MDGs) and deepening inequalities within and across countries. Left unattended, it will lead to human development reversals throughout the 21st Century.

The second catastrophe is located in the future. Like the threat of nuclear confrontation during the Cold War, climate change poses risks not just for the world's poor, but for the entire planet—and for future generations. Our current path offers a one-way route to ecological disaster. There are uncertainties relating to the speed of warming, and to the exact timing and forms of the impacts. But the risks associated with accelerated disintegration of the Earth's great ice sheets, the warming of the oceans, the collapse of rainforest systems and other possible outcomes are real. They have the potential to set in train processes that could recast the human and physical geography of our planet.

Our generation has the means—and the responsibility—to avert that outcome. Immediate risks are heavily skewed towards the world's poorest countries and their most vulnerable citizens. However, there are no risk free havens over the long term. Rich countries and people not on the front line of the unfolding disaster will ultimately be affected. That is why precautionary climate change mitigation is

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an essential insurance against future catastrophe for humanity as a whole, including future generations in the developed world.

The heart of the climate change problem is that the Earth's capacity to absorb carbon dioxide (CO_2) and other greenhouse gases is being overwhelmed. Humanity is living beyond its environmental means and running up ecological debts that future generations will be unable to repay.

Climate change challenges us to think in a profoundly different way about human interdependence. Whatever else divides us, humanity shares a single planet just as surely as the people of Easter Island shared a single island. The ties that bind the human community on the planet stretch across countries and generations. No nation, large or small, can be indifferent to the fate of others, or oblivious to the consequences of today's actions for people living in the future.

Future generations will see our response to climate change as a measure of our ethical values. That response will provide a testimony on how political leaders today acted on their pledges to combat poverty and build a more inclusive world. Leaving large sections of humanity even more marginalized would signify a disregard for social justice and equity between countries. Climate change also asks tough questions about how we think about our links to people in the future. Our actions will serve as a barometer of our commitment to cross-generational social justice and equity—and as a record against which future generations will judge our actions.

There are encouraging signs. Five years ago, climate change scepticism was a flourishing industry. Liberally financed by large companies, widely cited in the media, and attentively listened to by some governments, climate sceptics exercised an undue influence on public understanding. Today, every credible climate scientist believes that climate change is real, that it is serious, and that it is linked to the release of CO_2. Governments across the world share that view. Scientific consensus does not mean that debates on the causes and consequences of global warming are over: the science of climate change deals in probabilities, not certainties. But at least the political debate is now rooted in scientific evidence.

The problem is that there is a large gap between scientific evidence and political action. So far most governments have been failing the test on climate change mitigation. Most have responded to the recently released Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) by recognizing that the evidence on climate change is "unequivocal" and that urgent action is needed. Successive meetings of the Group of Eight (G8) industrialized countries have reaffirmed the need for concrete measures to be put in place. They have acknowledged that the ship is heading for an object that looks ominously like an iceberg. Unfortunately, they have yet to initiate decisively evasive action by charting a new emissions trajectory for greenhouse gases.

There is a very real sense in which time is running out. Climate change is a challenge that has to be addressed throughout the 21st Century. No quick technological fixes are available. But the long-time horizon is not a window of opportunity for prevarication and indecision. In forging a solution, governments have to confront the problems of stocks and flows in the global carbon budget. Stocks of greenhouse gases are building up, driven by rising emissions. However, even if we stopped all emissions tomorrow the stocks would fall only very slowly. The reason: once emitted CO_2 stays in the atmosphere a long time and climate systems respond slowly. This inertia built into the system means that there is a long time-lag between today's carbon mitigation and tomorrow's climate outcomes.

The window of opportunity for successful mitigation is closing. There is a limit to the amount of carbon dioxide that the Earth's sinks can absorb without creating dangerous climate change effects—and we are nearing those limits. We have less than a decade to ensure that the window of opportunity is kept open. That does not mean we have a decade to decide on whether to act and to formulate a plan, but a decade in which to start the transition to low-carbon energy systems. One certainty in an area marked by high levels of uncertainty is this: if the next decade looks the same as the last one, then the world will be locked on course for the avoidable 'twin catastrophe' of near-term human development reversals and the risk of ecological disaster for future generations.

Like the catastrophe that struck Easter Island, that outcome is preventable. Expiry of the current commitment period of the Kyoto Protocol in 2012 provides an opportunity to develop a multilateral strategy that could redefine how we manage global ecological interdependence. The priority, as the world's governments negotiate that agreement, is to define a sustainable carbon budget for the 21st Century, and to develop a strategy for budget implementation that recognizes the "common but differentiated" responsibilities of countries.

Success will require the world's richest countries to demonstrate leadership: they have both the deepest carbon footprints, and the technological and financial capabilities to achieve deep and early cuts in emissions. However, a successful multilateral framework will require the active participation of all major emitters, including those in the developing world.

Establishing a framework for collective action that balances urgency with equity is the starting point for avoiding dangerous climate change.

This chapter sets out the scale of the challenge ahead. Section 1 looks at the interaction between climate change and human development. In section 2, we set out the evidence provided by climate science and scenarios for temperature changes. Section 3 provides a breakdown of the world's carbon footprint. Then in section 4, we contrast current emission trends with a sustainable emissions pathway for the 21st Century, drawing upon climate modelling work—and we

Special contribution

Climate change—together we can win the battle

The *Human Development Report 2007/2008* comes at a time when climate change—long on the international agenda—is starting to receive the very highest attention that it merits. The recent findings of the IPCC sounded a clarion call; they have unequivocally affirmed the warming of our climate system and linked it directly to human activity.

The effects of these changes are already grave, and they are growing. This year's Report is a powerful reminder of all that is at stake: climate change threatens a 'twin catastrophe', with early setbacks in human development for the world's poor being succeeded by longer term dangers for all of humanity.

We are already beginning to see these catastrophes unfold. As sea levels rise and tropical storms gather in intensity, millions of people face displacement. Dryland inhabitants, some of the most vulnerable on our planet, have to cope with more frequent and more sustained droughts. And as glaciers retreat, water supplies are being put at risk.

This early harvest of global warming is having a disproportionate effect on the world's poor, and is also hindering efforts to achieve the MDGs. Yet, in the longer run, no one—rich or poor—can remain immune from the dangers brought by climate change.

I am convinced that what we do about this challenge will define the era we live in as much as it defines us. I also believe that climate change is exactly the kind of global challenge that the United Nations is best suited to address. That is why I have made it my personal priority to work with Member States to ensure that the United Nations plays its role to the full.

Tackling climate change requires action on two fronts. First, the world urgently needs to step up action to mitigate greenhouse gas emissions. Industrialized countries need to make deeper emission reductions. There needs to be further engagement of developing countries, as well as incentives for them to limit their emissions while safeguarding economic growth and efforts to eradicate poverty.

Adaptation is the second global necessity. Many countries, especially the most vulnerable developing nations, need assistance in improving their capacity to adapt. There also needs to be a major push to generate new technologies for combating climate change, to make existing renewable technologies economically viable, and to promote a rapid diffusion of technology.

Climate change threatens the entire human family. Yet it also provides an opportunity to come together and forge a collective response to a global problem. It is my hope that we will rise as one to face this challenge, and leave a better world for future generations.

Ban Ki-moon
Secretary-General of the United Nations

Climate change will be one of the defining forces shaping prospects for human development during the 21st Century

look at the cost of making the transition to a more sustainable future. Section 5 contrasts our sustainable emissions pathway with the business-as-usual alternative. The chapter ends by setting out the ethical and economic case for urgent action on climate change mitigation and adaptation.

1.1 Climate change and human development

Human development is about people. It is about expanding people's real choices and the substantive freedoms—the capabilities—that enable them to lead lives that they value. Choice and freedom in human development mean something more than the absence of constraints.[3] People whose lives are blighted by poverty, ill-health or illiteracy are not in any meaningful sense free to lead the lives that they value. Neither are people who are denied the civil and political rights they need to influence decisions that affect their lives.

Climate change will be one of the defining forces shaping prospects for human development during the 21st Century. Through its impact on ecology, rainfall, temperature and weather systems, global warming will directly affect all countries. Nobody will be immune to its consequences. However, some countries and people are more vulnerable than others. In the long term, the whole of humanity faces risks but more immediately, the risks and vulnerabilities are skewed towards the world's poorest people.

Climate change will be superimposed upon a world marked by large human development deficits. While there are many uncertainties about the timing, nature and scale of future impacts, the forces unleashed by global warming can be expected to magnify existing disadvantages. Location and livelihood structures will emerge as powerful markers for disadvantage. Concentrated in fragile ecological areas, drought-prone arid lands, flood-prone coastal areas, and precarious urban slums, the poor are highly exposed to climate change risks—and they lack the resources to manage those risks.

The backdrop

The interface between climate change and human development outcomes will be shaped by differences in localized climate effects, by differences in social and economic coping capacities, and by public policy choices, among other factors. The starting point for any consideration of how climate change scenarios might play out is the human development backdrop.

That backdrop includes some good news stories that are often overlooked. Since the first *Human Development Report* was published in 1990 there have been spectacular—if spectacularly uneven—advances in human development. The share of the population living in developing countries on less than US$1 a day has fallen from 29 percent in 1990 to 18 percent in 2004. Over the same period, child mortality rates have fallen from 106 deaths per thousand live births to 83 and life expectancy has increased by 3 years. Progress in education has gathered pace. Globally, the primary school completion rate rose from 83 percent to 88 percent between 1999 and 2005.[4]

Economic growth, a condition for sustained progress in poverty reduction, has accelerated across a large group of countries. Based on this strong growth, numbers living in extreme poverty fell by 135 million between 1999 and 2004. Much of this progress has been driven by East Asia in general and China in particular. More recently, the emergence of India as a high-growth economy, with per capita incomes rising at an average of 4–5 percent since the mid-1990s, has created enormous opportunities for accelerated human development. While sub-Saharan Africa lags behind on many dimensions of human development, here too there are signs of progress. Economic growth has picked up since 2000 and the share of people in the region living in extreme poverty has finally started to fall, although the absolute number of poor has not declined.[5]

The bad news is that forces generated by climate change will be superimposed on a world marked by deep and pervasive human development deficits, and by disparities that divide the 'haves' and the 'have-nots'. While globalization has created unprecedented opportunities for some, others have been left behind. In some countries—India is an example—rapid economic growth has produced modest progress in poverty reduction and in nutrition. In others—including most of sub-Saharan Africa—economic growth is too slow and uneven to sustain rapid progress in poverty reduction. Despite high growth across much of Asia, on current trends most countries are off track for achieving the MDG targets for reducing extreme poverty and deprivation in other areas by 2015.

The state of human development is presented in more detail elsewhere in this Report. What is important in the context of climate change is that emerging risks will fall disproportionally on countries already characterized by high levels of poverty and vulnerability:

- *Income poverty.* There are still around 1 billion people living at the margins of survival on less than US$1 a day, with 2.6 billion—40 percent of the world's population—living on less than US$2 a day. Outside East Asia, most developing regions are reducing poverty at a slow pace—too slowly to achieve the MDG target of halving extreme poverty by 2015. Unless there is an acceleration of poverty reduction from 2008 onwards, the target looks likely to be missed by around 380 million people.[6]
- *Nutrition.* Around 28 percent of all children in developing countries are estimated to be underweight or stunted. The two regions that account for the bulk of the deficit are South Asia and sub-Saharan Africa—and both are off track in terms of achieving the MDG target of halving under-nutrition by 2015. If India's high economic growth is unequivocal good news, the bad news is that this has not been translated into accelerated progress in cutting under-nutrition. One-half of all rural children are underweight for their age—roughly the same proportion as in 1992.[7]
- *Child mortality.* Progress on child mortality lags behind progress in other areas. Around 10 million children die each year before the age of 5, the vast majority from poverty and malnutrition. Only around 32 countries out of 147 monitored by the World Bank are on track to achieve the MDG of a two-thirds reduction in child mortality by 2015.[8] South Asia and sub-Saharan Africa are comprehensively off track. On current trends the MDG target will be missed by a margin that will represent 4.4 million additional deaths in 2015.[9]
- *Health.* Infectious diseases continue to blight the lives of the poor across the world. An estimated 40 million people are living with HIV/AIDS, with 3 million deaths in 2004. Every year there are 350–500 million cases of malaria, with 1 million fatalities: Africa accounts for 90 percent of malarial deaths and African children account for over 80 percent of malaria victims worldwide.[10]

These deficits in human development draw attention to deep inequalities across the world. The 40 percent of the world's population living on less than US$2 a day accounts for 5 percent of global income. The richest 20 percent accounts for three-quarters of world income. In the case of sub-Saharan Africa, a whole region has been left behind: it will account for almost one-third of world poverty in 2015, up from one-fifth in 1990.

Income inequality is also rising within countries. Income distribution influences the rate at which economic growth translates into poverty reduction. More than 80 percent of the world's population lives in countries where income differentials are widening. One consequence is that more growth is needed to achieve an equivalent poverty reduction outcome. According to one analysis, developing countries have to grow at over three times the pre-1990 rate to achieve the same reduction in poverty incidence.[11]

Skewed income distribution intersects with wider inequalities. Child death rates among the poorest one-fifth in the developing world

While globalization has created unprecedented opportunities for some, others have been left behind

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are falling at half the average rate for the richest, reflecting deep disparities in nutrition and access to health provision.[12] In an increasingly urbanized world, disparities between rural and urban populations remain substantial. Rural areas account for three in every four people living on less than US$1 a day and a similar share of the world population suffering from malnutrition.[13] However, urbanization is not synonymous with human progress. Urban slum growth is outpacing urban growth by a wide margin.

The state of the world's environment is a vital link between climate change and human development. In 2005, the United Nations' (UN) *Millennium Ecosystem Assessment* drew attention to the global deterioration of vital ecosystems, including mangrove swamps, wetlands and forests. These ecosystems are highly vulnerable to climate change—as are the people who depend on the services they provide.

At a time when climate change concerns are mounting across the world, it is important that complex future scenarios are considered in the context of initial human development conditions. Climate change is a global phenomenon. However, the human development impacts of climate change cannot automatically be inferred from global scenarios, or from predicted movements in average global temperatures. People (and countries) vary in their resilience and capacity to manage the incremental risks associated with climate change. They vary in their capacity to adapt.

Inequalities in capacity to cope with these risks will fuel wider inequalities in opportunity. As the incremental risks created by climate change intensify over time, they will interact with existing structures of disadvantage. Prospects for sustained human development in the years and decades after the 2015 target date for the MDGs are directly threatened.

Dangerous climate change—five human development 'tipping points'

Average global temperature has become a popular metric for the state of the global climate.[14] That metric tells us something important. We know that the world is warming and that the average global temperature has increased by around 0.7°C (1.3°F) since the advent of the industrial era. We know also that the trend is accelerating: average global mean temperature is rising at 0.2°C every decade. With the global rise in temperature, local rainfall patterns are changing, ecological zones are shifting, the seas are warming and ice caps are melting. Forced adaptation to climate change is already happening across the world. In the Horn of Africa, adaptation means that women have to walk further to find water in the dry season. In Bangladesh and Viet Nam, it means that small-scale farmers have to cope with losses caused by more intense storms, floods and sea surges.

Fifteen years have now passed since the UN Framework Convention on Climate Change (UNFCCC) set out the broad objectives for multilateral action. Those objectives include stabilizing greenhouse gas concentrations in the atmosphere at "a level that would prevent dangerous anthropogenic interference with the climate system". Indicators for the prevention of danger include stabilization within a time frame that allows ecosystems to adapt naturally, the avoidance of disruption to food systems, and the maintenance of conditions for sustainable economic development.

Defining dangerous

At what point does climate change become dangerous? That question invites another: Dangerous for whom?[15] What is dangerous for a small-scale farmer living in Malawi might not appear very dangerous for a large, mechanized farm in the Midwest of the United States. Climate change scenarios for rising sea levels that might be viewed with equanimity from behind the flood defence systems of London or lower Manhattan might reasonably be regarded with alarm in Bangladesh, or in Viet Nam's Mekong Delta.

Such considerations caution against the drawing of hard and fast lines separating 'safe' from 'dangerous' climate change. Dangerous climate change cannot be inferred from a set of scientific observations alone. The threshold for what is dangerous depends on value judgements over what is an unacceptable cost in social, economic and ecological terms at any given level of warming. For millions of people and for many ecosystems the world has already passed the danger threshold. Determining what is an acceptable upper-limit target for future global temperature increases raises fundamental questions about power and responsibility. The extent to which those facing the greatest risks are able to articulate their concerns, and the weight attached to their voice, matters a great deal.

Yet with all of these caveats any successful climate change mitigation effort has to start by establishing a target. Our starting point is the growing consensus among climate scientists on the threshold marker for dangerous climate change. That consensus identifies 2°C (3.6°F) as a reasonable upper-bound.[16]

Beyond this point, the future risks of catastrophic climate change rise sharply. Accelerated melting of the Greenland and West Antarctic ice sheets could set in train irreversible processes, leading eventually to sea levels rising by several metres—an outcome that would cause forced human resettlement on a vast scale. Large areas of rainforest could be transformed into savannah. The world's already shrinking glaciers would be set on course for rapid decline. Above the 2°C threshold, the pressure on ecological systems such as coral reefs and biodiversity would intensify. Complex carbon on biodiversity feedback effects linked to the warming of the oceans, the loss of rainforests and melting ice sheets would accelerate the pace of climate change.

Crossing the 2°C threshold would be a step across the boundary that marks significant risk of catastrophic outcomes for future generations. More immediately, it would trigger setbacks in human development. Developing countries are at a double disadvantage in this area: they are located in tropical areas that stand to experience some of the most severe early impacts from climate change; and agriculture—the sector most immediately affected—plays a far greater social and economic role. Above all, they are characterized by high levels of poverty, malnutrition and disadvantage in health. The combination of acute deprivation on the one side, with weak social insurance provision and limited infrastructural capacity to contain climate risks on the other, points to a high potential for human development reversals.

From climate change to stalled human progress—the transmission mechanisms

Climate change is global but the effects will be local. Physical impacts will be determined by geography and microlevel interactions between global warming and existing weather patterns. The immense scope of these impacts makes generalization difficult: drought-prone areas in sub-Saharan Africa will face different problems from flood-prone areas in South Asia. Human development impacts will also vary as changes in climate patterns interact with pre-existing social and economic vulnerabilities. However, five specific risk-multipliers for human development reversals can be identified:

- *Reduced agricultural productivity.* Around three-quarters of the world's population living on less than US$1 a day depend directly on agriculture. Climate change scenarios point to large losses in productivity for food staples linked to drought and rainfall variation in parts of sub-Saharan Africa and South and East Asia. Projected revenue losses for dryland areas in sub-Saharan Africa amount to 26 percent by 2060, with total revenue losses of US$26 billion (in constant 2003 terms)—in excess of bilateral aid transfers to the region. Through its impact on agriculture and food security, climate change could leave an additional 600 million facing acute malnutrition by the 2080s over and above the level in a no-climate change scenario.[17]
- *Heightened water insecurity.* Exceeding the 2°C threshold will fundamentally change the distribution of the world's water resources. Accelerated glacial melt in the Himalayas will compound already severe ecological problems across northern China, India and Pakistan, initially increasing floods before reducing the flow of water to major river systems vital for irrigation. In Latin America, accelerated melting of tropical glaciers will threaten water supplies for urban populations, agriculture and hydroelectricity,

Through its impact on agriculture and food security, climate change could leave an additional 600 million facing acute malnutrition by the 2080s

Special contribution **Climate policy as human development**

How does human development relate to our environmental concerns in general and to climate change in particular? There are well established traditions in policy discussions to make us think of the demands of development and the preservation of the environment in rather antagonistic terms. Attention is often concentrated on the fact that many of the deteriorating environmental trends in the world, including global warming and other disturbing evidence of climate change, are linked with heightened economic activity, such as industrial growth, increased energy consumption, more intensive irrigation, commercial felling of trees, and other activities that tend to correlate with economic expansion. At a superficial level, it may well appear that the process of development is responsible for environmental damage.

On the other side, environmental protagonists are frequently accused by development enthusiasts of being 'anti-development' since their activism often takes the form of being rather unwelcoming to processes that can raise incomes and reduce poverty—because of their allegedly unfavourable environmental impact. The battle lines may or may not be very sharply drawn, but it is hard to escape the sense of tension that does exist, in varying degrees, between the champions of poverty reduction and development, on one side, and the advocates of ecology and environmental preservation, on the other.

Does the human development approach have something to offer to make us understand whether this apparent conflict between development and environmental sustainability is real or imaginary? There is a huge contribution that the human development approach can make by invoking the central perspective of seeing development as the expansion of substantive human freedom, which is indeed the point of departure of the human development approach. In this broader perspective, assessment of development cannot be divorced from considering the lives that people can lead and the real freedoms that they can enjoy. Development cannot be seen merely in terms of enhancement of inanimate objects of convenience, such as a rise in the GNP (or in personal incomes). This is the basic insight that the human development approach brought to the development literature right from the outset of that approach, and this insight is critically important today for clarity regarding environmental sustainability.

Once we appreciate the necessity of seeing the world in the broader perspective of the substantive freedoms of human beings, it immediately becomes clear that development cannot be divorced from ecological and environmental concerns. Indeed, important components of human freedoms—and crucial ingredients of our quality of life—are thoroughly dependent on the integrity of the environment, involving the air we breathe, the water we drink, the epidemiological surroundings in which we live, and so on. Development has to be environment-inclusive, and the belief that development and environment must be on a collision course is not compatible with the central tenets of the human development approach.

The environment is sometimes misleadingly seen as the state of 'nature', reflected by such measures as the extent of forest cover, the depth of the groundwater table, and so on. This understanding, however, is seriously incomplete for two important reasons.

First, the value of the environment cannot be just a matter of what there is, but also of the opportunities it actually offers. The impact of the environment on human lives must *inter alia* be among the relevant considerations in assessing the richness of the environment. Indeed, the visionary report of the World Commission on Environment and Development chaired by Gro Brundtland, *Our Common Future* (1987), made this clear by focusing on sustaining the fulfilment of human 'needs'. We can, in fact, go beyond the Brundtland Report's focus on human needs and bring in the larger domain of human freedoms, since the human development approach requires us to see people not merely as 'needy', but as people whose freedom to do what they have reason to do is important and demands sustaining (and if possible expansion).

People have reason to satisfy their needs, of course, and the elementary applications of the human development approach (for example what we get from the simple Human Development Index, the HDI) do indeed focus exactly on that. But the domain of freedom can go well beyond that, and the use of the fuller human development perspective can take into account the freedom of people to do things that

Special contribution **Climate policy as human development** (continued)

are not governed exclusively by their own needs. Human beings may not, for example, ‘need’ spotted owls in any obvious sense, and yet if they have reason to object to the extinction of such species, then the value of their freedom to achieve this deliberated goal can be the basis of a reasoned judgement. Prevention of the extinction of animal species that we human beings want to preserve (not so much because we ‘need’ these animals in any specific way, but because we judge that it is a bad idea to let existing species disappear forever) can be an integral part of the human development approach. In fact, the preservation of biodiversity is likely to be among the concerns in our responsible thinking about climate change.

Second, the environment is not only a matter of passive preservation, but also one of active pursuit. We must not think of the environment exclusively in terms of pre-existing natural conditions, since the environment can also include the results of human creation. For example, purification of water is a part of improving the environment in which we live. The elimination of epidemics, such as smallpox (which has already occurred) and malaria (which ought to occur very soon if we can get our acts together), is a good illustration of an environmental improvement that we can bring about.

This positive recognition does not, of course, change the significant fact that the process of economic and social development can, in many circumstances, also have strongly destructive consequences. Those unfavourable effects have to be clearly identified and firmly resisted, along with strengthening the positive and constructive contributions of development. Even though many human activities that accompany the process of development may have destructive consequences, it is also within human power to resist and reverse many of these bad consequences if timely action is taken.

In thinking about the steps that may be taken to halt environmental destruction we have to search for constructive human intervention. For example, greater levels of female education and women’s employment can help to reduce fertility rates, which in the long run can reduce the pressure on global warming and the increasing destruction of natural habitats. Similarly, the spread of school education and improvements in its quality can make us more environmentally conscious. Better communication and a richer media can make us more aware of the need for environment-oriented thinking.

Indeed, the need for public participation in ensuring environmental sustainability is critically important. It is also crucial not to reduce important issues of human evaluation, which demand reflection and deliberative social assessment, into narrowly technocratic matters of formulaic calculation. For example, consider the ongoing debate on what ‘discount rate’ to use in balancing present sacrifices against future security. A central aspect of such discounting is social evaluation of gains and losses over time. This is at bottom a deeply reflective exercise and a matter for public deliberation, rather than one for some kind of a mechanical resolution on the basis of some simple formula.

Perhaps the most telling concern here comes from the uncertainty that is inescapably associated with any future prediction. One reason for being cautious about the ‘best guess’ regarding the future is the possibility that if we get it wrong, the world we end up with may be extremely precarious. There are even fears that what can be prevented now may become close to irreversible if no preventive action is taken without delay, no matter how much the future generations might be ready to spend to reverse the catastrophe. Some of these predicaments may be particularly damaging for the developing world (for example, the submerging of parts of Bangladesh or the whole of the Maldives due to rising sea levels).

These are critically important matters for public consideration and discussion, and the development of such public dialogue is an important part of the human development approach. The need for such public deliberation is as important in dealing with climate change and environmental dangers as it is in tackling more traditional problems of deprivation and continuing poverty. What characterizes human beings—perhaps more than anything else—is our ability to think and to talk to each other, and to decide what to do and then to do it. We need to make good use of this quintessential human capability as much for reasoned sustaining of the environment as we do for coordinated eradication of old-fashioned poverty and deprivation. Human development is involved in both.

Amartya Sen

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especially in the Andean region. By 2080, climate change could increase the number of people facing water scarcity around the world by 1.8 billion.[18]

- *Increased exposure to coastal flooding and extreme weather events.* The IPCC forecasts an increase in extreme weather events.[19] Droughts and floods are already the main drivers of a steady increase in climate-related disasters. On average around 262 million people were affected each year between 2000 and 2004, over 98 percent of them living in developing countries. With an increase in temperatures above 2°C, warmer seas will fuel more violent tropical cyclones. Drought-affected areas will increase in extent, jeopardizing livelihoods and compromising progress in health and nutrition. The world is already committed to rising sea levels in the 21st Century because of past emissions. Temperature increases in excess of 2°C would accelerate the rise, causing the widespread displacement of people in countries such as Bangladesh, Egypt and Viet Nam and the inundation of several small-island states. Rising sea levels and more intense tropical storm activity could increase the number of people experiencing coastal flooding by between 180 million and 230 million.[20]
- *The collapse of ecosystems.* All predicted species extinction rates accelerate beyond the 2°C threshold, with 3°C marking the point at which 20–30 percent of species would be at 'high risk' of extinction.[21] Coral reef systems, already in decline, would suffer extensive 'bleaching' leading to the transformation of marine ecologies, with large losses of biodiversity and ecosystem services. This would adversely affect hundreds of millions of people dependent upon fish for their livelihoods and nutrition.
- *Increased health risks.* Climate change will impact on human health at many levels. Globally an additional 220–400 million people could be at increased risk of malaria. Exposure rates for sub-Saharan Africa, which accounts for around 90 percent of deaths, are projected to increase by 16–28 percent.[22]

These five drivers for major human development reversal cannot be viewed in isolation. They will interact with each other, and with pre-existing human development problems, creating powerful downward spirals. While the processes are already apparent in many countries, breaching the 2°C threshold would mark a qualitative shift: it would mark a transition to far greater ecological, social and economic damage.

That transition will have important implications for long term human development prospects. Climate change scenarios provide a snapshot of a plausible future. They enable us not to predict when or where a specific climate event might happen, but the average probabilities associated with emerging climate patterns.

From a human development perspective, these are outcomes that can set in train dynamic and cumulative processes of disadvantage. In chapter 2 we set out a model that captures this process through detailed analysis of household survey data. The results powerfully illustrate a hidden dimension of human costs associated with climate change. To give one example, Ethiopian children who were born in a drought year in their district are 41 percent more likely than their counterparts born in a non-drought year to be stunted. For 2 million Ethiopian children this translates into diminished opportunities for the development of human capabilities. The important implication is that even a small incremental risk of more droughts can lead to large human development setbacks. Climate change will create large incremental risks.

Not all of the human development costs associated with climate change can be measured in terms of quantitative outcomes. At a fundamental level, human development is also about people having a say in the decisions that affect their lives. In articulating a vision of development as freedom, the Nobel Laureate Amartya Sen draws attention to the role of human beings as agents of social change, emphasizing both "the processes that allow freedoms of actions and decisions, and actual opportunities that people have, given their personal and social circumstances".[23] Climate change is a profound denier of freedom of action and a source of disempowerment. One section of humanity—broadly the poorest 2.6 billion—will have to respond to climate change forces over which they have no control, manufactured through political choices in countries, where they have no voice.

The world is now at or near the warmest level on record in the current interglacial period, which began around 12,000 years ago

1.2 Climate science and future scenarios

Understanding the scientific evidence on climate change is a starting point for understanding the human development challenges of the 21st Century. There is a vast amount of scientific literature on the subject. Here we focus on the consensus set out by the IPCC, while drawing attention to the large areas of uncertainty over future outcomes. In looking at the future under climate change there are many 'known unknowns'—events that can be predicted but without any certainty as to their timing or magnitude. It should come as no surprise that scientists cannot be certain about precisely how the Earth's ecological systems will respond to human-induced greenhouse gas emissions: we are living with an experiment that has never been conducted before.

One of the 'knowns' is that we are on a trajectory that, if uncorrected, will lead to a very high probability of dangerous climate change outcomes. Those outcomes would provide a continuum from near-term human development setbacks to long term ecological disaster.

Human-induced climate change

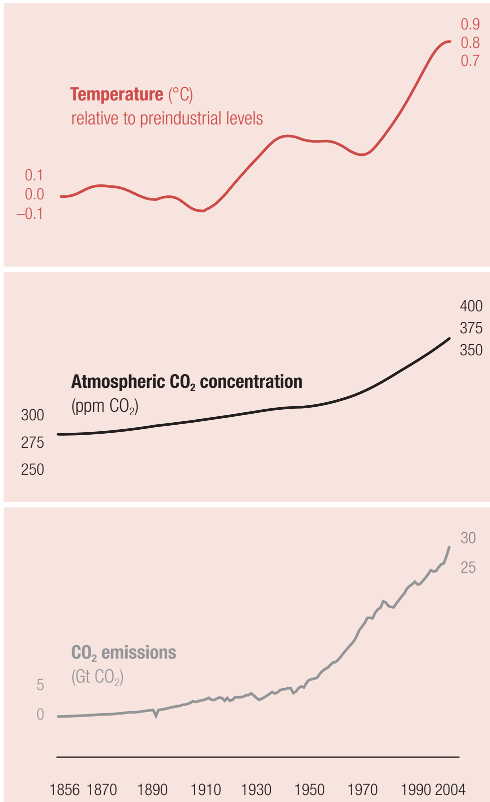
Throughout its history, the earth has experienced oscillations between warm and cool periods. These shifts in climate have been traced to a wide variety of 'climate forcings', including orbital variations, solar fluctuations, volcanic activity, water vapour, and the atmospheric concentration of greenhouse gases, such as CO_2. The changes that we see happening today are occurring at a more rapid rate, with stronger magnitudes and patterns that cannot be explained by natural cycles.

Average global surface temperature is the most fundamental measure of climate change. Temperatures in the past half-century have probably been the highest of any 50-year period for the past 1,300 years. The world is now at or near the warmest level on record in the current interglacial period, which began around 12,000 years ago. There is strong evidence that the process is accelerating. Eleven of the twelve warmest years since 1850 occurred between 1995 and 2006. Over the past 100 years the Earth has warmed by 0.7°C. There are large interannual variations. However, on a decade-by-decade basis, the linear warming trend for the past 50 years is nearly twice that for the past 100 years (figure 1.1).[24]

There is an overwhelming body of scientific evidence linking rising temperatures to increased atmospheric concentrations of CO_2 and other greenhouse gases. The effect of these gases in the atmosphere is to retain part of the outgoing solar radiation, thereby raising the temperature of the Earth. This natural 'greenhouse effect' is what keeps our planet habitable: without it, the planet would be 30°C colder. Throughout the Earth's four previous glacial and warming cycles, there has been a high correlation between atmospheric concentrations of CO_2 and temperature.[25]

What is different about the current warming cycle is the rapid rate at which CO_2 concentrations are increasing. Since preindustrial times, atmospheric CO_2 stocks have increased by one-third—a rate of increase unprecedented during at least the last 20,000 years. Evidence from ice cores shows that current atmospheric concentrations exceed the natural range of the last 650,000 years. The increase in stocks of CO_2 has been accompanied by rising concentrations of other greenhouse gases.

Figure 1.1 **Rising CO_2 emissions are pushing up stocks and increasing temperature**



Source: CDIAC 2007; IPCC 2007a.

While the current warming cycle is not unique in terms of temperature change, it is unique in one important respect: it is the first time that humanity has decisively changed a cycle. Mankind has been releasing CO_2 into the atmosphere through burning and land-use changes for over 500,000 years. But climate change can be traced back to two great transformations in energy use. In the first, water power was replaced by coal—a source of energy condensed by nature over millions of years. It was coal harnessed to new technologies that fuelled the industrial revolution, unleashing unprecedented increases in productivity.

The second great transformation happened 150 years later. Oil had been a source of human energy for millennia: China had oil wells in the 4th Century. However, the harnessing of oil to the internal combustion engine in the early 20th Century marked the start of a revolution in transport. The burning of coal and oil, supplemented by natural gas, has transformed human societies, providing the energy that has driven vast increases in wealth and productivity. It has also fuelled climate change.

In recent years there has been a protracted debate over the attribution of global temperature changes to human activities. Some scientists have argued that natural cycles and other forces are more important. However, while natural factors such as volcanic activity and solar intensity can explain much of the global temperature trend in the early 19th Century, they do not explain the rise since then. Other candidates for explaining global warming have also been rejected. For example, it has been argued that recent temperature changes can be traced not to greenhouse gases but to increases in the sun's output and cosmic rays. Detailed research investigating this claim showed that, for the past two decades, the sun's output has in fact declined while temperatures on Earth have risen.[26]

Debates on attribution may continue. But the scientific jury came in with the verdict on the core issues some time ago. That verdict was confirmed in the IPCC's most recent assessment, which concluded that "it is extremely unlikely that global climate change can be explained without external forcing".[27] Put differently, there is greater than 90 percent likelihood that most of the observed warming is due to human-generated greenhouse gases.

Global carbon accounting—stocks, flows and sinks

Climate change has provided an important reminder of a sometimes forgotten fact. Human activities take place in ecological systems that are not marked by national borders. Unsustainable management of these systems has consequences for the environment and for the well-being of people today and in the future. Reduced to its essentials, the threat of dangerous climate change is a symptom of unsustainable ecological resource management on a global scale.

Human energy systems interact with global ecological systems in complex ways. The burning of fossil fuels, land-use changes and other activities release greenhouse gases, which are continuously recycled between the atmosphere, oceans and land biosphere. Current concentrations of greenhouse gases are the net results of past emissions, offset by chemical and physical removal processes. The Earth's soils, vegetation and oceans act as large 'carbon sinks'. Emissions of CO_2 are the primary source of increased concentrations. Other long-lived greenhouse gases like methane and nitrous dioxide generated from agricultural activities and industry, mix with CO_2 in the atmosphere. The total warming or 'radiative forcing' effect is measured in terms of CO_2 equivalence, or CO_2e.[28] The sustained rate of increase in radiative forcing from greenhouse gases over the past four decades is at least six times faster than at any time before the industrial revolution.

The global carbon cycle can be expressed in terms of a simple system of positive and negative flows. Between 2000 and 2005 an average of 26 Gt CO_2 was released into the atmosphere each year. Of this flow, around 8 Gt CO_2 was absorbed into the oceans and another 3 Gt CO_2 was removed by oceans, land and vegetation. The net effect: an annual increase of 15 Gt CO_2 in the Earth's atmospheric stocks of greenhouse gases.

Global mean concentration of CO_2 in 2005 was around 379 ppm. Other long-lived greenhouse gases add about 75 ppm to this stock measured in terms of radiative forcing effects. However, the net effect of all human-induced greenhouse gas emissions is reduced by the cooling effect of aerosols. [29] There are large degrees of uncertainty associated with these cooling effects. According to the IPCC, they are roughly equivalent to the warming generated by non-CO_2 greenhouse gases.[30]

Atmospheric concentrations of CO_2 are on a sharply rising trend.[31] They are increasing at around 1.9 ppm each year. For CO_2 alone the annual concentration growth rate over the past 10 years has been around 30 percent faster than the average for the past 40 years.[32] In fact, in the 8,000 years prior to industrialization, atmospheric CO_2 increased by only 20 ppm.

Current rates of absorption by carbon sinks are sometimes confused with the 'natural' rate. In reality, carbon sinks are being overwhelmed. Take the world's largest sink—its oceans. These naturally absorb just 0.1 Gt more CO_2 per year than they release. Now they are soaking up an extra 2 Gt a year—more than 20 times the natural rate.[33] The result is serious ecological damage. Oceans are becoming warmer and increasingly acidic. Rising acidity attacks carbonate, one of the essential building blocks for coral and small organisms at the start of the marine food chain. Based on current trends, future carbon dioxide releases could produce chemical conditions in the oceans that have not been witnessed in the past 300 million years, except during brief catastrophic events.[34]

The future rate of accumulation in greenhouse gas stocks will be determined by the relationship between emissions and carbon sinks. There is bad news on both fronts. By 2030 greenhouse gas emissions are set to increase by between 50 and 100 percent above 2000 levels.[35] Meanwhile, the capacity of the Earth's ecological systems to absorb these emissions could shrink. This is because feedbacks between the climate and the carbon cycle may be weakening the absorptive capacity of the world's oceans and forests. For example, warmer oceans absorb less CO_2 and rainforests could shrink with higher temperatures and reduced rainfall.

Even without taking into account uncertainties over future carbon absorption we are heading for a rapid increase in greenhouse gas stock accumulation. In effect, we are opening the taps to increase the flow of water into an already overflowing bath. The overflow is reflected in the rate at which CO_2 is entering and being locked into the Earth's atmosphere.

Atmospheric concentrations of CO_2 are on a sharply rising trend

Climate change scenarios—the known, the known unknowns, and the uncertain

The world is already committed to future climate change. Atmospheric stocks of greenhouse gases are rising with increases in emissions. Total emissions of all greenhouse gases amounted to around 48 Gt CO_2e in 2004—an increase of one-fifth since 1990. Rising concentrations of greenhouse gases mean that global temperatures will continue to increase over time. The rate of increase and the ultimate level of temperature change will be determined by concentrations of CO_2 and other greenhouse gases.

Climate models cannot predict specific events associated with global warming. What they can do is simulate ranges of probability for average temperature change. While the modelling exercises themselves are enormously complex, one simple conclusion emerges: following current trends concentrations of greenhouse gases could commit the world to climate change at levels far above the 2°C threshold.

The world is warming

One of the early pioneers of climate science, the Swedish physicist Svante Arrenhuis, predicted with surprising accuracy that a doubling of CO_2 stocks in the Earth's atmosphere would raise average global temperatures between 4 and 5°C—a marginal overestimate according to recent IPCC models.[36] Less accurately, Arrhenuis assumed that it would take around 3,000 years for atmospheric concentrations to double over preindustrial levels. On current trends that point, around 550 ppm, could be reached by the mid-2030s.

Future temperature increases will depend on the point at which stocks of greenhouse gases stabilize. At whatever level, stabilization requires that emissions must be reduced to the point at which they are equivalent to the rate at which CO_2 can be absorbed through natural processes, without damaging the ecological systems of the carbon sinks. The longer that emissions remain above this level, the higher the point at which accumulated stocks will stabilize. Over the long term, the Earth's natural capacity to remove greenhouse gases without sustaining damage to the ecological systems of carbon sinks is probably between 1 and 5 Gt CO_2e. With emissions running at around 48 Gt CO_2e, we are currently overloading the Earth's carrying capacity by a factor of between 10 and 50.

If emissions continue to rise following current trends then stocks will be increasing at 4–5 ppm a year by 2035—almost double the current rate. Accumulated stocks will have risen to 550 ppm. Even without further increases in the rate of emissions, stocks of greenhouse gases would reach over 600 ppm by 2050 and 800 ppm by the end of the 21st Century.[37]

The IPCC has developed a family of six scenarios identifying plausible emissions pathways for the 21st Century. These scenarios are differentiated by assumptions about population change, economic growth, energy use patterns and mitigation. None of the scenarios points to stabilization below 600 ppm and three are associated with greenhouse gas concentrations of 850 ppm or above.

The relationship between stabilization point and temperature change is uncertain. The IPCC scenarios have been used to identify a set of possible ranges for 21st Century temperature change, with a 'best-estimate' indicator within each range (table 1.1 and figure 1.2). That best estimate is between 2.3°C and 4.5°C (factoring in the 0.5°C increase from the start of the industrial era to 1990).[38] With the doubling of atmospheric concentrations, the IPCC projects a temperature increase of 3°C as the most likely outcome with the rider that "values substantially higher than 4.5°C cannot be excluded."[39] In other words, none of the IPCC scenarios point to a future below the 2°C threshold for dangerous climate change.

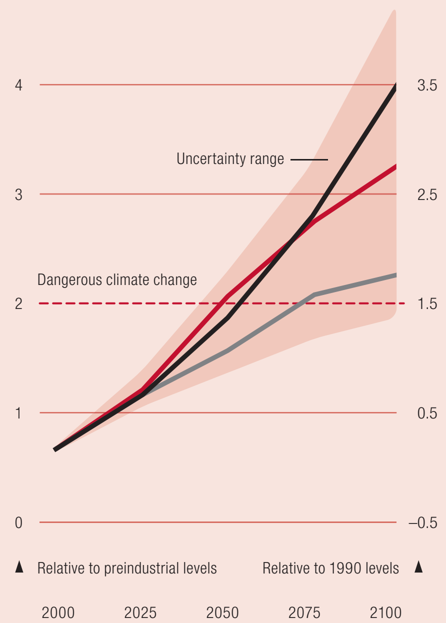
Table 1.1 Temperature ranges rise with CO_2 stocks—projections for 2080

IPCC scenarios	Relative to 1980–1999 average temperature (°C)	Relative to preindustrial temperature (°C)
Constant year 2000 concentrations	0.6 (0.3–0.9)	1.1
B1 scenario	1.8 (1.1–2.9)	2.3
A1T scenario	2.4 (1.4–3.8)	2.9
B2 scenario	2.4 (1.4–3.8)	2.9
A1B scenario	2.8 (1.7–4.4)	3.3
A2 scenario	3.4 (2.0–5.4)	3.9
A1FI scenario	4.0 (2.4–6.4)	4.5

Note: **IPCC scenarios** describe plausible future patterns of population growth, economic growth, technological change and associated CO_2 emissions. The **A1 scenarios** assume rapid economic and population growth combined with reliance on fossil fuels (A1FI), non-fossil energy (A1T) or a combination (A1B). The **A2 scenario** assumes lower economic growth, less globalization and continued high population growth. The **B1** and **B2 scenarios** contain some mitigation of emissions, through increased resource efficiency and technology improvement (B1) and through more localized solutions (B2).
Source: IPCC 2007a.

Figure 1.2 **Global temperature forecast: three IPCC scenarios**

Mean surface warming projections (°C)



- IPCC scenario A1B
- IPCC scenario A2
- IPCC scenario B1

Note: **IPCC scenarios** describe plausible future patterns of population growth, economic growth, technological change and associated CO_2 emissions. The **A1 scenarios** assume rapid economic and population growth combined with reliance on fossil fuels (A1FI), non-fossil energy (A1T) or a combination (A1B). The **A2 scenario** assumes lower economic growth, less globalization and continued high population growth. The **B1** and **B2 scenarios** contain some mitigation of emissions, through increased resource efficiency and technology improvement (B1) and through more localized solutions (B2).

Source: IPCC 2007a.

Heading for dangerous climate change

In two important respects the IPCC's best-estimate range for the 21st Century might understate the problem. First, climate change is not just a 21st Century phenomenon. Temperature adjustments to rising concentrations of CO_2 and other greenhouse gases will continue to take place in the 22nd Century. Second, IPCC best-estimates do not rule out the possibility of higher levels of climate change. At any given level of stabilization, there is a probability range for exceeding a specified temperature. Illustrative probability ranges identified in modelling work include the following:

- Stabilization at 550 ppm, which is below the lowest point on the IPCC scenarios, would carry an 80 percent probability of overshooting the 2°C dangerous climate change threshold.[40]
- Stabilization at 650 ppm carries a probability of between 60 and 95 percent of exceeding 3°C. Some studies predict a 35–68 percent likelihood of overshooting 4°C.[41]
- At around 883 ppm, well within the IPCC non-mitigation scenario range, there would be a 50 percent chance of exceeding a 5°C temperature increase.[42]

Probability ranges are a complex device for capturing something of great importance for the future of our planet. An increase in average global temperature in excess of 2–3°C would bring with it enormously damaging ecological, social and economic impacts. It would also create a heightened risk of catastrophic impacts, acting as a trigger for powerful feedback effects from temperature change to the carbon cycle. Temperature increases above 4–5°C would amplify the effects, markedly increasing the probability of catastrophic outcomes in the process. In at least three of the IPCC scenarios, the chances of exceeding a 5°C increase are greater than 50 percent. Put differently, under current scenarios, there is a far stronger likelihood that the world will overshoot a 5°C threshold than keep within the 2°C climate change threshold.

One way of understanding these risks is to reflect on what they might mean in the lives of ordinary people. We all live with risks. Anybody who drives a car or walks down a street faces a very small risk of an accident that will create serious injury. If the risk of such an accident increased above 10 percent most people would think twice about driving or taking a stroll: a one in ten chance of serious injury is not a negligible risk. If the odds on a serious accident increased to 50:50, the case for embarking upon serious risk reduction measures would become overwhelming. Yet we are on a greenhouse gas emission course that makes dangerous climate change a virtual certainty, with a very high risk of crossing a threshold for ecological catastrophe. This is an overwhelming case for risk reduction, but the world is not acting.

In the course of one century or slightly more, there is a very real prospect that current

Today, we are living with the consequences of the greenhouses gases emitted by earlier generations—and future generations will live with the consequences of our emissions

trends will see global temperatures increase by more than 5°C. That figure approximates the increase in average temperature that has taken place since the end of the last ice age some 10,000 years ago. During that age, most of Canada and large areas of the United States were under ice. The giant Laurentide glacier covered much of the north-east and north-central United States with ice several miles deep. The retreat of that ice created the Great Lakes and scoured-out new land formations, including Long Island. Much of northern Europe and north-west Asia were also covered in ice.

Comparisons between 21st Century climate change and the transition from the last ice age should not be overstated. There is no direct analogy for the warming processes now underway. However, geological evidence strongly suggests that temperature changes on the scale and at the pace of those now underway could culminate in transformations of the Earth's geography, along with marked changes in the distribution of species and human geography.

Probability ranges for temperature change associated with greenhouse gas concentrations help to identify targets for mitigation. By changing the flow of emissions we can alter the rate at which stocks of greenhouse gases accumulate and hence the probabilities of overshooting specific temperature targets. However, the relationship between greenhouse gas flows, accumulated stocks and future temperature scenarios is not simple. Long time-lags between today's actions and tomorrow's outcomes are built into the system. Policies for climate change mitigation have to deal with powerful forces of inertia that have an important bearing on the timing of mitigation.

- *Current emissions define future stocks.* Basic chemistry is one force of inertia. When CO_2 is released into the atmosphere it stays there a long time. Half of every tonne emitted remains in the atmosphere for a period of between several centuries and several thousand years. What this means is that traces of the CO_2 released when the first coal-powered steam engines designed by John Newcomen were operating in the early 18th Century are still in the atmosphere. So are traces of the emissions generated by the world's first coal-fired power station, designed by Thomas Edison and opened in lower Manhattan in 1882. Today, we are living with the consequences of the greenhouses gases emitted by earlier generations—and future generations will live with the consequences of our emissions.
- *Stocks, flows and stabilization.* There are no rapid rewind buttons for running down stocks of greenhouse gases. People living at the end of the 21st Century will not have the opportunity to return in their lifetime to a world of 450 ppm if we continue on a business-as-usual path. The accumulated stock of greenhouse gases that they inherit will depend on the emissions pathway that links the present to the future. Keeping emissions at current levels would not reduce stocks because they exceed the absorptive capacity of the Earth's carbon sinks. Stabilizing emissions at 2000 levels would increase stocks by over 200 ppm by the end of the 21st Century. Because of cumulative processes, the rate of emissions reduction required to meet any stabilization goal is very sensitive to the timing and the level of the peak in global emissions. The later and the higher the peak, the deeper and the more rapid the cuts needed to achieve a specified stabilization target.
- *Climate systems respond slowly.* By the late 21st Century, actions taken today will be the major factor affecting climate change. However, mitigation efforts today will not produce significant effects until after 2030.[43] The reason: changing emission pathways does not produce a simultaneous response in climate systems. The oceans, which have absorbed about 80 percent of the increase in global warming, would continue to rise, and ice sheets would continue melting under any medium-term scenario.

Uncertain future and 'nasty surprises'—catastrophic risk under climate change

Rising global average temperature is a predictable climate change outcome. It is one of the 'knowns' that emerge from climate modelling exercises. There is also a wide range of 'known unknowns'. These are predictable events with large areas of uncertainty attached to their timing and magnitude. Uncertain but significant risks of catastrophic outcomes are part of the emerging climate change scenario.

The IPCC's fourth assessment draws attention to a wide range of uncertainties linked to potentially catastrophic events. Two such events have figured prominently in debates on climate change. The first is a reversal of the meridional overturning circulation (MOC), the vast conveyor of warm water in the Atlantic Ocean. The heat transported by the Gulf Stream is equivalent to around 1 percent of humanity's current energy use.[44] As a result of this heat transport, Europe is up to 8°C warmer, with the largest effects apparent in winter. It is the threat to the comparatively mild European climate, as well as climate concerns elsewhere, that has given rise to worries about the future of the MOC.

Additional fresh water flowing into the North Atlantic as a result of glacial melting has been identified as a potential force for shutting down or slowing the MOC. Switching off the Gulf Stream would put northern Europe on course for an early ice age. While the IPCC concludes that a large abrupt transition is very unlikely in the 21st Century, it warns that "longer-term changes in the MOC cannot be assessed with confidence". Moreover, the likelihood range for an abrupt transition is still 5–10 percent. While this may be "very unlikely" in terms of the IPCC's statistical accounting, the magnitude of the threat and the considerable uncertainty that surrounds it make a powerful case for precautionary behaviour in the interests of future generations.

The same applies to rising sea levels. The IPCC scenarios point to rises of between 20 and 60 centimetres by the end of the 21st Century. That is more than a marginal change. Moreover, the fourth assessment acknowledges that "larger values cannot be excluded." Outcomes will depend upon complex ice formation and melting processes, and on wider carbon cycle effects. The IPCC anticipates the continuing contraction of the great ice sheet in Greenland as a source of rising sea levels, with uncertainty over the future of the ice sheets of Antarctica. However, in the case of Antarctica the IPCC acknowledges that recent models provide evidence pointing to processes that could "increase the vulnerability of the ice-sheets to warming".[45]

These uncertainties are of more than passing academic concern. Consider first the evidence on the melting of ice sheets and rising sea levels. So far, the rise in sea level has been dominated by thermal expansion due to increased temperatures rather than glacial melt—but this could change. For humanity as a whole, the accelerated disintegration and eventual demise of the Greenland and West Antarctic ice sheets are perhaps the greatest of all the threats linked to climate change. Recent evidence suggests that warming ocean waters are now thinning some West Antarctic ice shelves by several metres a year. The area of Greenland on which summer melting of ice took place has increased by more than 50 percent during the past 25 years. Concern over the fate of Antarctic ice shelves has been gathering since the enormous Larsen B ice shelf collapsed in 2002. Several more ice shelves have broken up rapidly in recent years.[46]

One of the reasons for uncertainty about the future is that ice sheet disintegration, unlike ice sheet formation, can happen very rapidly. According to one of the world's most prominent climate scientists working at the North American Space Agency (NASA), a business-as-usual scenario for ice sheet disintegration in the 21st Century could yield sea level rises in the order of 5 metres this century. Note that this does not take into account accelerated melting of the Greenland ice sheet, the complete elimination of which would add around 7 metres to sea levels.[47] The IPCC sets out what can be thought of as a lowest common denominator consensus. However, its assessment of the risks and uncertainties does not include recent evidence of accelerated melting, nor does it factor in the possibility of large-scale, but imperfectly understood, carbon cycle effects. The upshot is that the headline risk numbers may err on the side of understatement.

The 'known unknowns' surrounding rising sea levels are a particularly striking example of threats facing the whole of humanity. The one certainty is that current trends and past evidence are a weak guide to the future. Climate change could trigger a range of 'surprises':

Uncertain but significant risks of catastrophic outcomes are part of the emerging climate change scenario rapid, non-linear responses of the climate system to human-induced forcing (box 1.1).

Climate scientists have drawn a distinction between 'imaginable surprises', which are currently seen as possible but unlikely (deglaciation of polar ice sheets or MOC reversals are examples) and 'true surprises', or risks that have not been identified because of the complexity of climate systems.[48] Feedback effects between climate change and the carbon cycle, with changes in temperature giving rise to unpredictable outcomes, are the source of these potential surprises.

There is growing evidence that natural carbon absorption will weaken as temperatures rise. Modelling by the Hadley Centre suggests that climate change feedback effects could reduce the absorptive capacity consistent with stabilization at 450 ppm by 500 Gt CO_2, or 17 years of global emissions at current levels.[49] The practical consequence of carbon cycle feedback effects is that emissions may need to peak at lower levels or be cut more rapidly, especially at higher levels of greenhouse gas concentrations.

The focus on potentially catastrophic outcomes should not divert attention from the more immediate risks. There is a large section of humanity that would not have to await the advanced disintegration of ice sheets to experience catastrophe under these conditions. Precise numbers can be debated, but for the poorest 40 percent of the world's population—around 2.6 billion people—we are on the brink of climate change events that will jeopardize prospects for human development. We will develop this point further in chapter 2.

Risk and uncertainty as a case for action

How should the world respond to the uncertainties associated with climate change? Some commentators argue for a 'wait-and-see' approach, with the mitigation effort to be scaled up in light of developments. The fact that the IPCC's assessment and wider climate science point to uncertain risks with low probabilities of global catastrophe in the medium term is cited as grounds for delayed action.

Such responses fail a number of public policy tests for the development of climate change mitigation strategies. Consider first the response to the range of possibilities identified by climate science. These ranges are not a

Box 1.1 Feedback effects could accelerate climate change

There are many positive feedback effects that could transform climate change scenarios for the 21st Century. High levels of uncertainty about positive feedback effects are reflected in IPCC scenario projections.

Multiple feedbacks have been observed in ice sheet disintegration. One example is the 'albedo flip'—a process that occurs when snow and ice begin to melt. Snow-covered ice reflects back to space most of the sunlight that strikes it. When surface ice melts, darker wet ice absorbs more solar energy. The meltwater produced burrows through the ice sheet, lubricating its base, and speeding the discharge of icebergs into the ocean. As an ice sheet discharges more icebergs into the ocean, it loses mass and its surface sinks to a lower altitude, where the temperature is warmer, causing it to melt even faster. Meanwhile, warming oceans add yet another positive feedback to this process, melting the offshore accumulation of ice—ice shelves—that often form a barrier between ice sheets and the ocean.

The accelerated melting of permafrost in Siberia with global warming is another concern. This could release vast amounts of methane—a highly potent greenhouse gas—into the atmosphere, which would increase warming and the rate at which permafrost melts.

The interaction between climate change and the carbon sink capacity of rainforests provides another example of positive feedback uncertainties. Rainforests can be thought of as vast 'carbon banks'. Trees in the Amazon region of Brazil alone store 49 billion tonnes of carbon. Another 6 billion tonnes is stored in Indonesia's forests. As global temperatures rise, changing climate patterns could generate processes that will lead to the release of large amounts of carbon from these reservoirs.

Rainforests are already contracting at an alarming rate in the face of commercial pressures, illegal logging and other activities. Under a business-as-usual scenario, climate models forecast temperatures in most of the Amazon region rising by 4–6°C by 2100. This could convert up to 30 percent of the Amazon rain forest into a type of dry savannah, according to research carried out under the auspices of Brazil's National Space Research Institute. Such an outcome would in turn drive up net global emissions of CO_2. Because rainforests recycle at least half of rainfall back into the atmosphere, accelerated deforestation would also increase drought and fuel the spread of savannah areas.

Source: FAO 2007b; Hansen 2007a, 2007b; Houghton 2005; Nobre 2007; Volpi 2007.

justification for inaction. They are an invitation to assess the nature of identified risks and to develop strategies for risk mitigation. As a group of eminent United States military leaders has argued, no commander in the field would look at risks comparable to those posed by climate change and decide not to act because of uncertainty: "We cannot wait for certainty. Failing to act because a warning is not precise enough is not acceptable." [50]

The nature of the risks associated with climate change uncertainties reinforces that assessment on three counts. First, these are risks that threaten the whole of future generations of humanity with catastrophic outcomes. The sea level rises that would accompany the collapse of the ice sheets on Greenland and the West Antarctic would overwhelm the flood defences of even the richest countries, submerging large areas of Florida and much of the Netherlands, as well as inundating the Ganges Delta, Lagos and Shanghai. Second, the outcomes associated with the risks are irreversible: the West Antarctic ice sheet cannot be restored by future generations. Third, uncertainty cuts both ways: there is as much chance of outcomes being more malign as there is of them being more benign.

In a one-country world inhabited by citizens who shared a concern for the well-being of future generations, climate change mitigation would be an urgent priority. It would be viewed as an insurance policy against catastrophic risk and as an imperative rooted in considerations of cross-generational equity. Uncertainty in this one-country world would be viewed not as grounds for inaction but as evidence of the case for acting with resolve to reduce the risks.

In a world of many countries at vastly different levels of development there is a complementary case for urgent action. That case is first of all rooted in considerations of social justice, human rights and ethical concern for the world's poorest and most vulnerable people. Millions of these people are already dealing with the early impacts of climate change. These impacts are already slowing human progress and all plausible scenarios point to more of the same, and worse. Because mitigation will have a limited influence on climate change for several decades, investment in adaptation should be seen as part of the insurance policy for the world's poor.

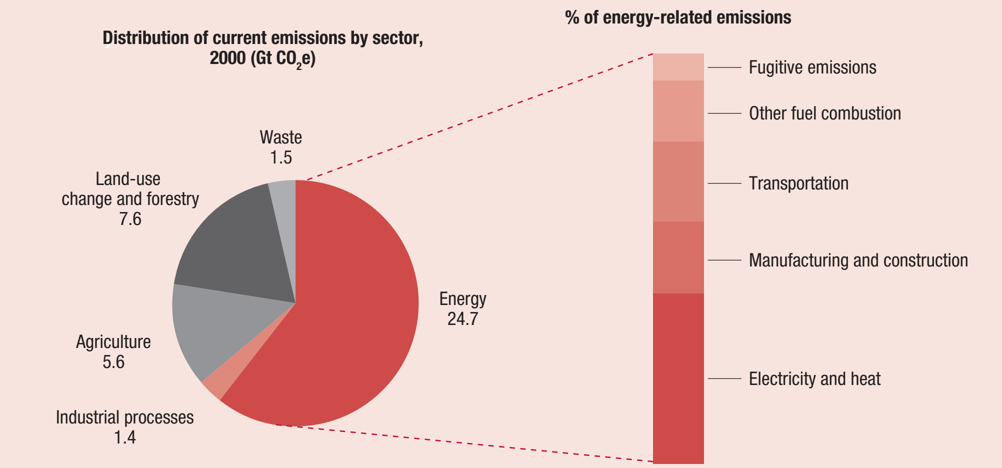
Both mitigation and adaptation should be seen as human security imperatives in a broader sense. Dangerous climate change, and the ecological damage that will follow in its wake, threatens to cause massive human displacement and the collapse of livelihoods on a vast scale. The ripple effects would extend far beyond the localities of those most immediately affected. Associated outcomes will extend from the movement of displaced people across national borders to the potential collapse of fragile states. In an interdependent world, no country would be immune to the consequences. Of course, many rich countries might seek to protect their citizens against climate insecurity through investment in flood defences and other actions. However, the anger and resentment that would be felt by those most immediately affected would create wider insecurities.

In a one-country world inhabited by citizens who shared a concern for the well-being of future generations, climate change mitigation would be an urgent priority

1.3 From global to local—measuring carbon footprints in an unequal world

For global carbon accounting purposes the world is a single country. The Earth's atmosphere is a common resource without borders. Emissions of greenhouse gases mix freely in the atmosphere over time and space. It makes no difference for climate change whether the marginal tonne of CO_2 comes from a coal-fired power plant, from a car, or from a loss of carbon sinks in tropical rainforests. Similarly, when greenhouse gases enter the Earth's atmosphere they are not segmented by country of origin: a tonne of

Figure 1.3 **Greenhouse gas emissions are dominated by energy and land-use changes**

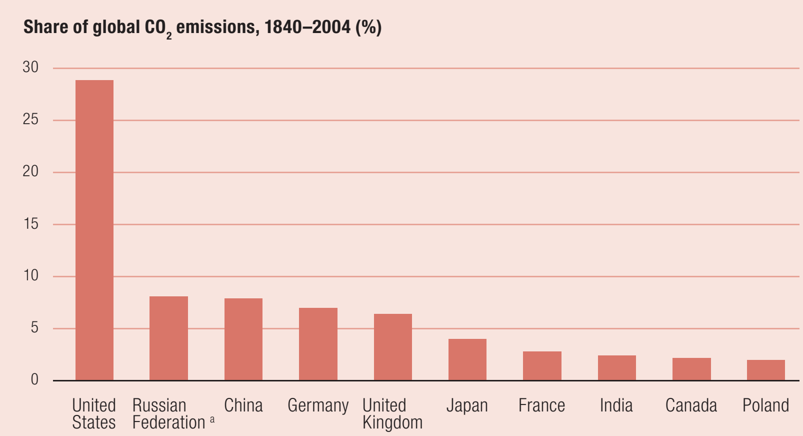


Source: WRI 2007a.

CO_2 from Mozambique is the same weight as a tonne of CO_2 from the United States.

While each tonne of carbon dioxide carries equal weight, the global account masks large variations in contributions to overall emissions from different sources. All activities, all countries and all people register in the global carbon account—but some register far more heavily than others. In this section we look at the carbon footprint left by emissions of CO_2. Differences in the depth of carbon footprints can help to identify important issues of equity and distribution in approaches to mitigation and adaptation.

Figure 1.4 **Rich countries dominate the cumulative emissions account**



a. Includes a share of USSR emissions proportional to the Russian Federation's current share of CIS emissions.
Source: CDIAC 2007.

National and regional footprints—the limits to convergence

Most human activities—fossil fuel combustion for power generation, transport, land-use changes and industrial processes—generate emissions of greenhouse gases. That is one of the reasons why mitigation poses such daunting challenges.

The breakdown of the distribution of greenhouse gas emissions underlines the scope of the problem (figure 1.3). In 2000, just over half of all emissions came from the burning of fossil fuels. Power generation accounted for around 10 Gt CO_2e, or around one-quarter of the total. Transport is the second largest source of energy-related CO_2e emissions. Over the past three decades, energy supply and transport have increased their greenhouse gas emissions by 145 and 120 percent respectively. The critical role of the power sector in global emissions is not fully captured by its current share. Power generation is dominated by capital-intensive infrastructural investments. Those investments create assets that have a long lifetime: power plants opening today will still be emitting CO_2 in 50 years time.

Land-use change also plays an important role. Deforestation is by far the largest source of CO_2 emissions in this context, releasing sequestered carbon into the atmosphere as a result of burning and loss of biomass. Data in this area are more uncertain than for other sectors. However, best estimates suggest that around 6 Gt CO_2 are released annually.[51] According to the IPCC, the share of CO_2 originating from deforestation ranges between 11 and 28 percent of total emissions.[52]

One of the conclusions to emerge from the sectoral analysis of carbon footprints is that mitigation aimed at reducing CO_2 emissions from power generation, transport and deforestation is likely to generate high returns.

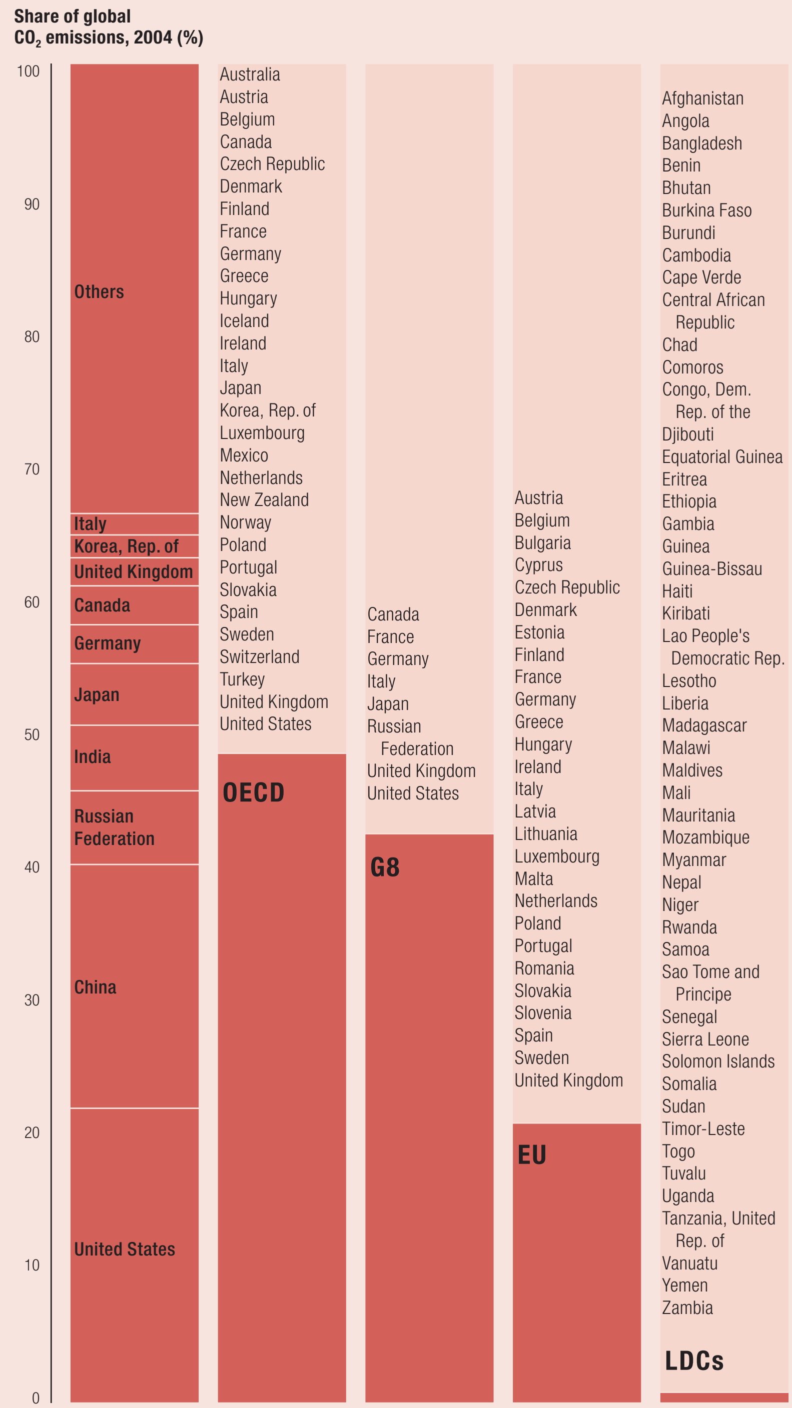
National carbon footprints can be measured in terms of stocks and flows. National footprint depth is closely related to historic and current energy use patterns. While the aggregate footprint of the developing world is becoming deeper, historic responsibility for emissions rests heavily with the developed world.

Rich countries dominate the overall emissions account (figure 1.4). Collectively, they account for about 7 out of every 10 tonnes of CO_2 that have been emitted since the start of the industrial era. Historic emissions amount to around 1,100 tonnes of CO_2 per capita for Britain and America, compared with 66 tonnes per capita for China and 23 tonnes per capita for India.[53] These historic emissions matter on two counts. First, as noted earlier, cumulative past emissions drive today's climate change. Second, the envelope for absorbing future emissions is a residual function of past emissions. In effect, the ecological 'space' available for future emissions is determined by past action.

Turning from stocks to flows produces a different picture. One striking feature of that picture is that emissions are highly concentrated in a small group of countries (figure 1.5). The United States is the largest emitter, accounting for around one-fifth of the total. Collectively, the top five—China, India, Japan, the Russian Federation and the United States —account for more than half; the top ten for over 60 percent. While climate change is a global problem, national and multilateral action involving a relatively small group of countries or groupings—such as the G8, the European Union (EU), China and India—would encompass a large share of the total flow of emissions.

Much has been made of the convergence in emissions between developed and developing

Figure 1.5 **Global CO_2 emissions are highly concentrated**



Source: CDIAC 2007.

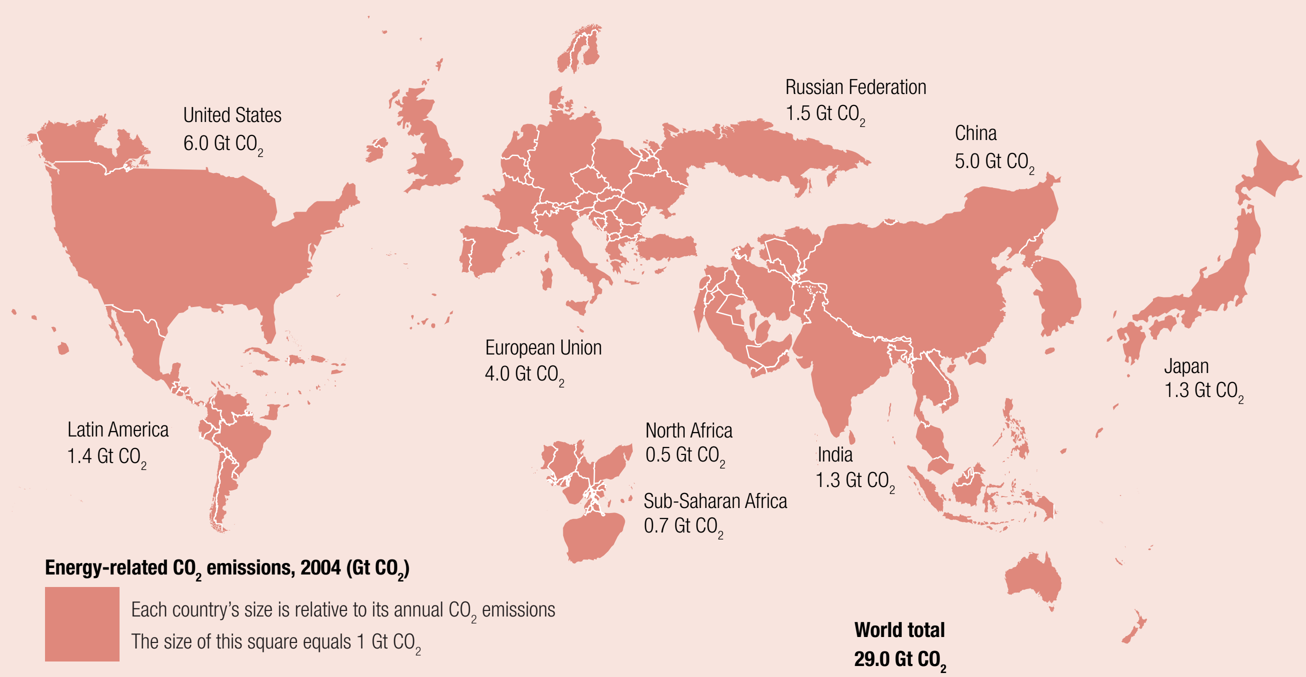
countries. At one level, the process of convergence is real. Developing countries account for a rising share of global emissions. In 2004, they accounted for 42 percent of energy-related CO_2 emissions, compared to around 20 percent in 1990 (appendix table). China may be about to overtake the United States as the world's largest emitter and India is now the world's fourth largest emitter. By 2030 developing countries are projected to account for just over half of total emissions.[54]

Factoring in deforestation reconfigures the global CO_2 emissions league table. If the world's rainforests were a country, that country would stand at the top of the world's league table for CO_2 emissions. Taking into account just emissions from deforestation, Indonesia, would rank as the third largest source of annual CO_2 emissions (2.3 Gt CO_2) with Brazil ranking fifth (1.1 Gt CO_2).[55] There are large interannual variations in emissions, making it difficult to compare countries. In 1998, when El Niño events triggered severe droughts in South-east Asia, an estimated 0.8–2.5 billion tonnes of carbon were released to the atmosphere through fires in peat forests.[56] In Indonesia, land-use change and forestry are estimated to release about 2.5 Gt CO_2e annually—around six times the emissions from energy and agriculture combined.[57] For Brazil, emissions linked to land use changes account for 70 percent of the national total.

Convergence in aggregate emissions is sometimes cited as evidence that developing countries as a group need to embark on rapid mitigation. That assessment overlooks some important considerations. Developing country participation will be required if global mitigation is to succeed. However, the extent of convergence has been heavily overstated.

With just 15 percent of the world population, rich countries account for 45 percent of CO_2 emissions. Sub-Saharan Africa also accounts for around 11 percent of the world population, but represents 2 percent of global emissions. Low income countries as a group account for one-third of the world's population but for just 7 percent of emissions.

Map **1.1** **Mapping the global variation in CO_2 emissions**



Note: The boundaries and names shown and the designations used on this map do not imply offical endorsement or acceptance by the United Nations. Dotted lines represent approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Source: Mapping Worlds 2007, based on data from CDIAC.

Inequalities in carbon footprinting—some people walk more lightly than others

Differences in the depth of carbon footprints are linked to the history of industrial development. But, they also reflect the large 'carbon debt' accumulated by rich countries—a debt rooted in the over-exploitation of the Earth's atmosphere. People in the rich world are increasingly concerned about emissions of greenhouse gases from developing countries. They tend to be less aware of their own place in the global distribution of CO_2 emissions (map 1.1). Consider the following examples:

- The United Kingdom (population 60 million) emits more CO_2 than Egypt, Nigeria, Pakistan, and Viet Nam combined (total population 472 million).
- The Netherlands emits more CO_2 than Bolivia, Colombia, Peru, Uruguay and the seven countries of Central America combined.
- The state of Texas (population 23 million) in the United States registers CO_2 emissions of around 700 Mt CO_2 or 12 percent of the United States' total emissions. That figure is greater than the total CO_2 footprint left by sub-Saharan Africa—a region of 720 million people.
- The state of New South Wales in Australia (population 6.9 million) has a carbon footprint of 116 Mt CO_2. This figure is comparable to the combined total for Bangladesh, Cambodia, Ethiopia, Kenya, Morocco, Nepal and Sri Lanka.
- The 19 million people living in New York State have a higher carbon footprint than the 146 Mt CO_2 left by the 766 million people living in the 50 least developed countries.

Extreme inequalities in national carbon footprints reflect disparities in per capita emissions. Adjusting CO_2 emission accounts to factor in these disparities demonstrates the very marked limits to carbon convergence (figure 1.6).

Carbon footprint convergence has been a limited and partial process that has started from different emission levels. While China may be about to overtake the United States as the world's largest emitter of CO_2, per capita emissions are just one-fifth of the size. Emissions from India are on a rising trend. Even so, its per capita carbon footprint is less than one-tenth of that in high-income countries. In Ethiopia, the average per capita carbon footprint is 0.1 tonnes, compared with 20 tonnes in Canada. The per capita increase in emissions since 1990 for the United States (1.6 tonnes) is higher than the total per capita emissions for India in 2004 (1.2 tonnes). The overall increase in emissions from the United States exceeds sub-Saharan Africa's total emissions. The per capita increase for Canada since 1990 (5 tonnes) is higher than per capita emissions for China in 2004 (3.8 tonnes).

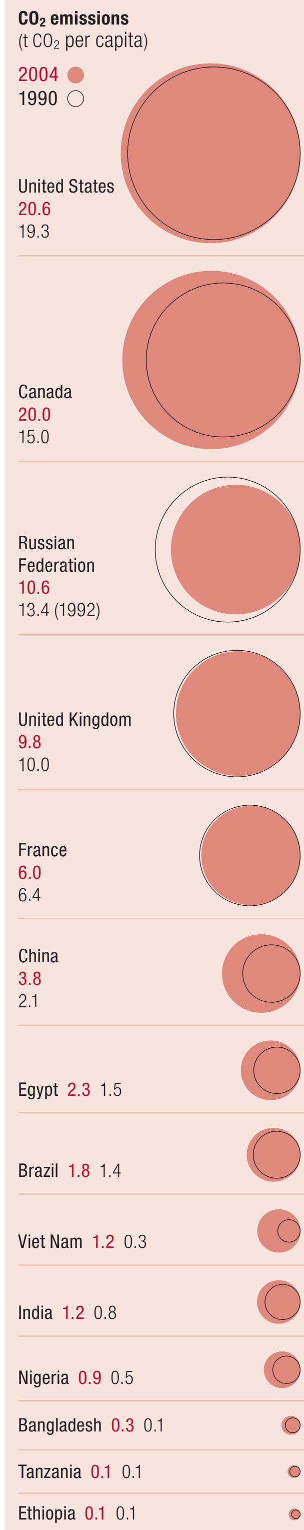
The distribution of current emissions points to an inverse relationship between climate change risk and responsibility. The world's poorest people walk the Earth with a very light carbon footprint. We estimate the carbon footprint of the poorest 1 billion people on the planet at around 3 percent of the world's total footprint. Living in vulnerable rural areas and urban slums, the poorest billion people are highly exposed to climate change threats for which they carry negligible responsibility.

The global energy divide

Inequalities in aggregate and per capita carbon footprints are intimately related to wider inequalities. They mirror the relationship between economic growth, industrial development and access to modern energy services. That relationship draws attention to an important human development concern. Climate change and the curtailment of excessive fossil fuel use may be the greatest challenge of the 21st Century, but an equally urgent and more immediate challenge is the expanded provision of affordable energy services to the world's poor.

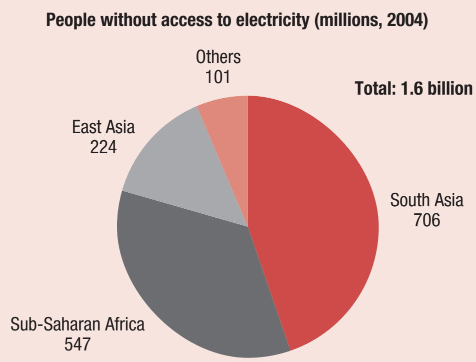
Living without electricity affects many dimensions of human development. Energy services play a critical role not just in supporting economic growth and generating employment, but also in enhancing the quality of people's lives. Around 1.6 billion people in the world lack access to such services (figure 1.7). Most

Figure 1.6 Rich countries—deep carbon footprints



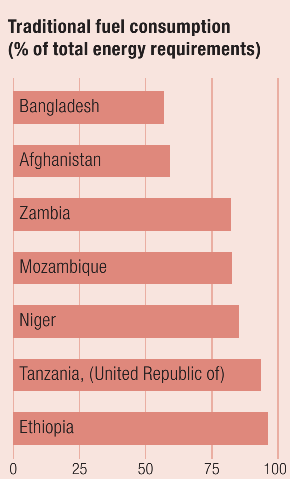
Source: CDIAC 2007.

Figure 1.7 **Living without electricity**



Source: IEA 2006c.

Figure 1.8 **Biomass dependence continues in many countries**



Source: Calculated on the basis of data on traditional fuel consumption and total energy requirement from UN 2007c.

live in sub-Saharan Africa,[58] where only around one-quarter of people use modern energy services, and South Asia.

The vast global deficit in access to basic energy services has to be considered alongside concerns over the rise in CO_2 emissions from developing countries. Emissions of CO_2 from India may have become a matter of global concern for climate security. That perspective is very partial. The number of people in India living without access to modern electricity is around 500 million—more than the total population of the enlarged European Union. These are people who live without so much as a light bulb in their homes and rely on firewood or animal dung for cooking.[59] While access to energy is increasing across the developing world, progress remains slow and uneven, holding back advances in poverty reduction. Worldwide, there will still be 1.4 billion people without access to modern energy services in 2030 if current trends continue (box 1.2).[60] Currently some 2.5 billion people depend on biomass (figure 1.8).

Changing this picture is vital for human development. The challenge is to expand access to basic energy services while limiting increases in the depth of the developing world's per capita carbon footprint. Enhanced efficiency in energy use and the development of low-carbon technologies hold the keys, as we show in chapter 3.

There are overwhelming practical and equitable grounds for an approach that reflects past responsibility and current capabilities. Mitigation responsibilities and capabilities cannot be derived from the arithmetic of carbon footprinting. Even so, that arithmetic does provide some obvious insights. For example, if everything else were equal, a cut of 50 percent in CO_2 emissions for South Asia and sub-Saharan Africa would reduce global emissions by 4 percent. Similar reductions in high-income countries would reduce emissions by 20 percent. The equity arguments are equally compelling. An average air-conditioning unit in Florida emits more CO_2 in a year than a person in Afghanistan or Cambodia during their lifetime. And an average dishwasher in Europe emits as much CO_2 in a year as three Ethiopians. While climate change mitigation is a global challenge, the starting place for mitigation is with the countries that carry the bulk of historic responsibility and the people that leave the deepest footprints.

1.4 Avoiding dangerous climate change—a sustainable emissions pathway

Climate change is a global problem that demands an international solution. The starting point must be an international agreement on the limitation of greenhouse gas emissions. Strategies for limitation have to be developed at a national level. What is required at the international level is a framework that sets limits on overall emissions. That framework has to chart an emissions pathway consistent with the objective of avoiding dangerous climate change.

In this section we set out such a pathway. We start by identifying a global carbon budget for the 21st Century. The concept of a carbon budget is not new. It was developed by the architects of the Kyoto Protocol and has been taken

Box 1.2 **Millions are denied access to modern energy services**

"Our day starts before five in the morning as we need to collect water, prepare breakfast for the family and get our children ready for school. At around eight, we start collecting wood. The journey is several kilometres long. When we cannot get wood we use animal dung for cooking—but it is bad for the eyes and for the children."
Elisabeth Faye, farmer, aged 32, Mbour, Senegal

In most rich countries access to electricity is taken for granted. At the flick of a switch the lights come on, water is heated and food is cooked. Employment and prosperity are supported by the energy systems that sustain modern industry, drive computers and power transport networks.

For people like Elisabeth Faye access to energy has a very different meaning. Collecting wood for fuel is an arduous and time-consuming activity. It takes 2–3 hours a day. When she is unable to collect wood, she has no choice but to use animal dung for cooking—a serious health hazard.

In developing countries there are some 2.5 billion people like Elisabeth Faye who are forced to rely on biomass—fuelwood, charcoal and animal dung—to meet their energy needs for cooking (figure 1.8). In sub-Saharan Africa, over 80 percent of the population depends on traditional biomass for cooking, as do over half of the populations of India and China.

Unequal access to modern energy is closely correlated with wider inequalities in opportunities for human development. Countries with low levels of access to modern energy systems figure prominently in the low human development group. Within countries, inequalities in access to modern energy services between rich and poor and urban and rural areas interact with wider inequalities in opportunity.

Poor people and poor countries pay a high price for deficits in modern energy provision:

- *Health.* Indoor air pollution resulting from the use of solid fuels is a major killer. It claims the lives of 1.5 million people each year, more than half of them below the age of five: that is 4000 deaths a day. To put this number in context, it exceeds total deaths from malaria and rivals the number of deaths from tuberculosis. Most of the victims are women, children and the rural poor. Indoor air pollution is also one of the main causes of lower respiratory tract infections and pneumonia in children. In Uganda, children under the age of five are reported to suffer 1–3 episodes of acute respiratory tract infection annually. In India, where three in every four households in rural areas depend on firewood and dung for cooking and heat, pollution from unprocessed biofuels accounts for some 17 percent of child deaths. Electrification is often associated with wider advances in health status. For example, in Bangladesh, rural electrification is estimated to increase income by 11 percent—and to avert 25 child deaths for every 1000 households connected.
- *Gender.* Women and young girls have to allocate large amounts of time to the collection of firewood, compounding gender inequalities in livelihood opportunities and education. Collecting fuelwood and animal dung is a time-consuming and exhausting task, with average loads often in excess of 20kg. Research in rural Tanzania has found that women in some areas walk 5–10 kilometres a day collecting and carrying firewood, with loads averaging 20kg to 38kg. In rural India, average collection times can amount to over 3 hours a day. Beyond the immediate burden on time and body, fuelwood collection often results in young girls being kept out of school.
- *Economic costs.* Poor households often spend a large share of their income on fuelwood or charcoal. In Guatemala and Nepal, wood expenditure represents 10–15 percent of total household expenditure in the poorest quintile. Collection time for fuelwood has significant opportunity costs, limiting opportunities for women to engage in income generating activities. More broadly, inadequate access to modern energy services restricts productivity and helps keep people poor.
- *Environment.* Deficits in access to modern energy can create a vicious circle of environmental, economic and social reversal. Unsustainable production of charcoal in response to rising urban demand has placed a huge strain on areas surrounding major cities such as Luanda in Angola and Addis Ababa in Ethiopia. In some cases, charcoal production and wood collection has contributed to local deforestation. As resources shrink, dung and residues are diverted to fuel use instead of being ploughed back into fields, undermining soil productivity.

Expanded access to affordable electricity for the poor remains an overarching development priority. Current projections show that the number of people relying on biomass will increase over the next decade and beyond, especially in sub-Saharan Africa. This will compromise progress towards several MDGs, including those relating to child and maternal survival, education, poverty reduction and environmental sustainability.

Source*:* IEA 2006c; Kelkar and Bhadwal 2007; Modi et al. 2005; Seck 2007b; WHO 2006; World Bank 2007b.

up by some governments (chapter 3). In effect, the carbon budget is akin to a financial budget. Just as financial budgets have to balance spending against resources, so carbon budgets have to balance greenhouse gas emissions against ecological capacity. However, carbon budgets have to operate over a very long time-horizon. Because the emissions that drive the accumulation of greenhouse gas stocks are cumulative and long-lived, we have to set an expenditure framework that spans decades rather than years.

There are further parallels between financial budgeting and carbon budgeting. When

Our carbon budget has a single goal: keeping average global temperature increases (over preindustrial levels) below 2°C

households or governments set budgets they target a range of objectives. Households have to avoid unsustainable spending patterns or face the prospect of debt. Government budgets are geared towards a range of public policy goals in areas such as employment, inflation and economic growth. If public spending exceeds revenues by large margins, the consequences are reflected in large fiscal deficits, inflation and the accumulation of debt. Ultimately, budgets are about living within the bounds of financial sustainability.

Carbon budgeting for a fragile planet

Carbon budgets define the bounds of ecological sustainability. Our carbon budget has a single goal: keeping average global temperature increases (over preindustrial levels) below 2°C. The rationale for this goal is, as we have seen, rooted in climate science and human development imperatives. Climate science identifies 2°C as a potential 'tipping point' for long-run catastrophic outcomes. More immediately, it represents a 'tipping point' for large scale human development reversals during the 21st Century. Remaining within the 2°C threshold should be seen as a reasonable and prudent long term objective for avoiding dangerous climate change. Many governments have adopted that objective. Sustainable carbon budget management should be seen as a means to that end.

What is the upper limit on greenhouse gas emissions for a world committed to avoiding dangerous climate change? We address that question by using simulations carried out at the Potsdam Institute for Climate Impact Research (PIK).

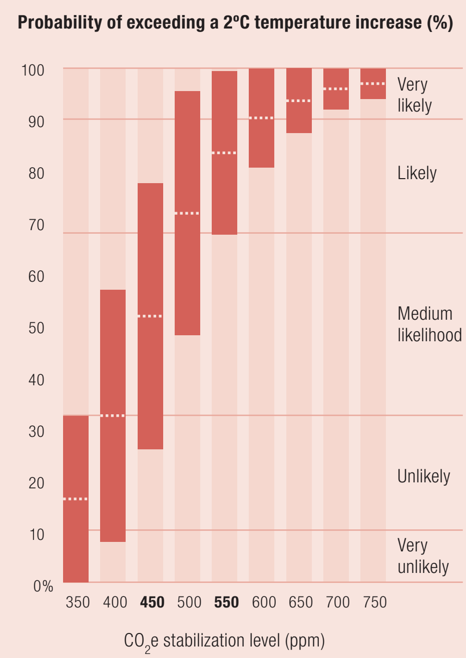
Stabilization of greenhouse gas stocks requires a balance between current emissions and absorption. A specific stabilization target can be achieved through a number of possible emission trajectories. In broad terms, emissions can peak early and decline gradually, or they can peak later and decline more rapidly. If the aim is to avoid dangerous climate change, the starting point is to identify a stabilization target consistent with the world staying within the 2°C dangerous climate change threshold.

Keeping within 2°C—the 'fifty–fifty' point

In our simulation we set the bar at the lowest reasonable level. That is, we identify the level of greenhouse gas stocks consistent with an approximately even chance of avoiding dangerous climate change. This level is around 450 ppm CO_2e. It might be argued that this is insufficiently ambitious: most people would not stake their future well-being on the toss of a coin. However, stabilizing at 450 ppm CO_2e will entail a sustained global effort.

Setting the bar above our target would lengthen the odds on avoiding dangerous climate change. At greenhouse gas stock levels of 550 ppm CO_2e the likelihood of overshooting the dangerous climate change threshold of 2°C increases to around 80 percent (figure 1.9). Opting for a 550 ppm CO_2e target would be taking a gamble at very long odds on the future of the planet and 21st Century human development prospects. In fact, there would be a one-in-three chance of overshooting 3°C.

Figure **1.9** **The risk of dangerous climate change rises with greenhouse gas stocks**



Note: Data refer to the highest, lowest and midpoint estimate resulting from several different climate models. For details see Meinshausen 2007.

Source: Meinshausen 2007.

The emerging consensus that climate change must be limited to a 2°C ceiling sets an ambitious but achievable goal. Realising that goal will require concerted strategies to limit the accumulation of greenhouse gas stocks to 450 ppm. While there is uncertainty at the margin, this remains the most plausible best-estimate for a sustainable carbon budget.

If the world were a single country, it would be implementing a recklessly extravagant and unsustainable carbon budget. If that budget were a financial budget the government of that country would be running a large fiscal deficit, exposing its citizens to hyperinflation and unsustainable debt. The lack of prudence in carbon budgeting can best be described by looking across the whole century.

We use the PIK simulations to address this task. Our approach focuses on fossil fuel-related CO_2 emissions because these are of the most direct relevance to policy debates on climate change mitigation. It identifies a level of emissions consistent with avoiding dangerous climate change. Briefly summarized, the 21st Century budget amounts to 1,456 Gt CO_2, or around 14.5 Gt CO_2 on a simple annual average basis.[61] Current emissions are running at twice this level. Put in financial budget terms, expenditure is outstripping income by a factor of two.

The bad news is that things are worse than they look because emissions are rising with population growth and economic growth. Using IPCC scenarios, the 21st Century budget consistent with avoiding dangerous climate change could expire as early as 2032, or in 2042 under more benign assumptions (figure 1.10).

Scenarios for climate security—time is running out

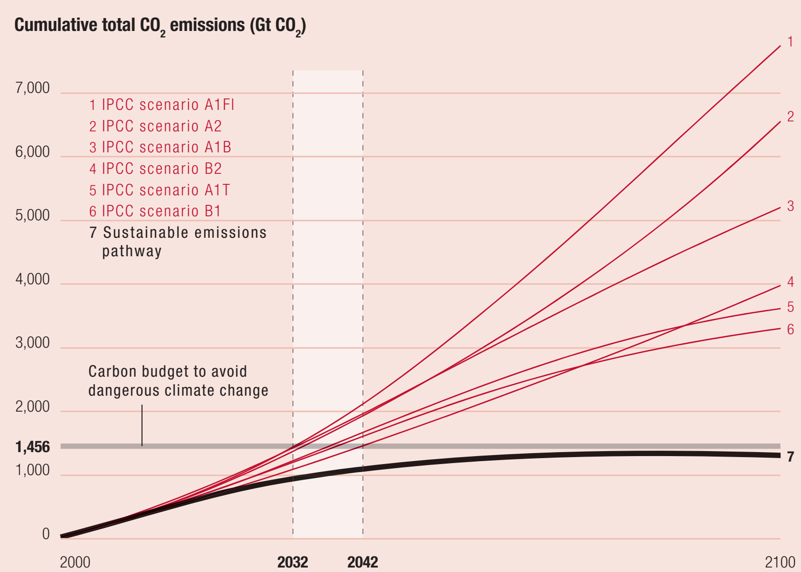
These projections tell an important story in two parts. The first part relates to basic budget management. As a global community, we are failing the most basic tests of sound budget practice. In effect, we are spending our monthly pay cheque in 10 days. Today's energy use and emission patterns are running down the Earth's ecological assets, and running up unsustainable ecological debts. Those debts will be inherited by future generations, who will have to compensate at great human and financial cost for our actions and also face the threats posed by dangerous climate change.

The second part of the budget story is equally stark. It is that time is running out. The fact that the carbon budget is set to expire between 2032 and 2042 does not mean we have two or three decades to act. Once the critical threshold has been reached, there is no way back to a more secure climate option. Moreover, emissions pathways cannot be changed overnight. They require extensive reforms in energy policies and behaviour implemented over several years.

How many planets?

On the eve of India's independence, Mahatma Gandhi was asked whether he thought the country could follow the British model of industrial development. His response retains a powerful resonance in a world that has to redefine its relation to the earth's ecology: "It took Britain half the resources of this planet to

Figure 1.10 **The 21st Century carbon budget is set for early expiry**



Note: **IPCC scenarios** describe plausible future patterns of population growth, economic growth, technological change and associated CO_2 emissions. The **A1 scenarios** assume rapid economic and population growth combined with reliance on fossil fuels (A1FI), non-fossil energy (A1T) or a combination (A1B). The **A2 scenario** assumes lower economic growth, less globalization and continued high population growth. The **B1** and **B2 scenarios** contain some mitigation of emissions, through increased resource efficiency and technology improvement (B1)and through more localized solutions (B2).

Source: Meinshausen 2007.

achieve its prosperity. How many planets will India require for development?"

We ask the same question for a world edging towards the brink of dangerous climate change. Using the annual ceiling of 14.5 Gt CO_2, if emissions were frozen at the current level of 29 Gt CO_2 we would need two planets. However, some countries are running a less sustainable account than others. With 15 percent of the world population, rich countries are using 90 percent of the sustainable budget. How many planets would we need if developing countries were to follow the example of these countries?

If every person living in the developing world had the same carbon footprint as the average for high income countries, global CO_2 emissions would rise to 85 Gt CO_2—a level that would require six planets. With a global per capita footprint at Australian levels, we would need seven planets, rising to nine for a world with Canada and United States levels of per capita emissions (table 1.2).

The answer to Gandhi's question raises some wider questions about social justice in climate change mitigation. As a global community, we are running up a large and unsustainable carbon debt, but the bulk of that debt has been accumulated by the world's richest countries.

Table 1.2 Global carbon footprints at OECD levels would require more than one planet [a]

	CO_2 emissions per capita (t CO_2) 2004	Equivalent global CO_2 emissions (Gt CO_2) 2004 [b]	Equivalent number of sustainable carbon budgets [c]
World [d]	4.5	29	2
Australia	16.2	104	7
Canada	20.0	129	9
France	6.0	39	3
Germany	9.8	63	4
Italy	7.8	50	3
Japan	9.9	63	4
Netherlands	8.7	56	4
Spain	7.6	49	3
United Kingdom	9.8	63	4
United States	20.6	132	9

a. As measured in sustainable carbon budgets.
b. Refers to global emissions if every country in the world emitted at the same per capita level as the specified country.
c. Based on a sustainable emissions pathway of 14.5 Gt CO_2 per year.
d. Current global carbon footprint.

Source: HDRO calculations based on Indicator Table 24.

The challenge is to develop a global carbon budget that charts an equitable and sustainable course away from dangerous climate change.

Charting a course away from dangerous climate change

We use the PIK model to identify plausible pathways for keeping within the 2°C threshold. One pathway treats the world as a single country, which for carbon accounting purposes it is, then identifies targets for rationing or 'burden sharing'. However, the viability of any system of burden sharing depends on participants in the system perceiving the distribution of rations to be fair. The UNFCCC itself acknowledges this through an injunction to "protect the climate system…on the basis of equity and in accordance with…common but differentiated responsibilities and respective capabilities."

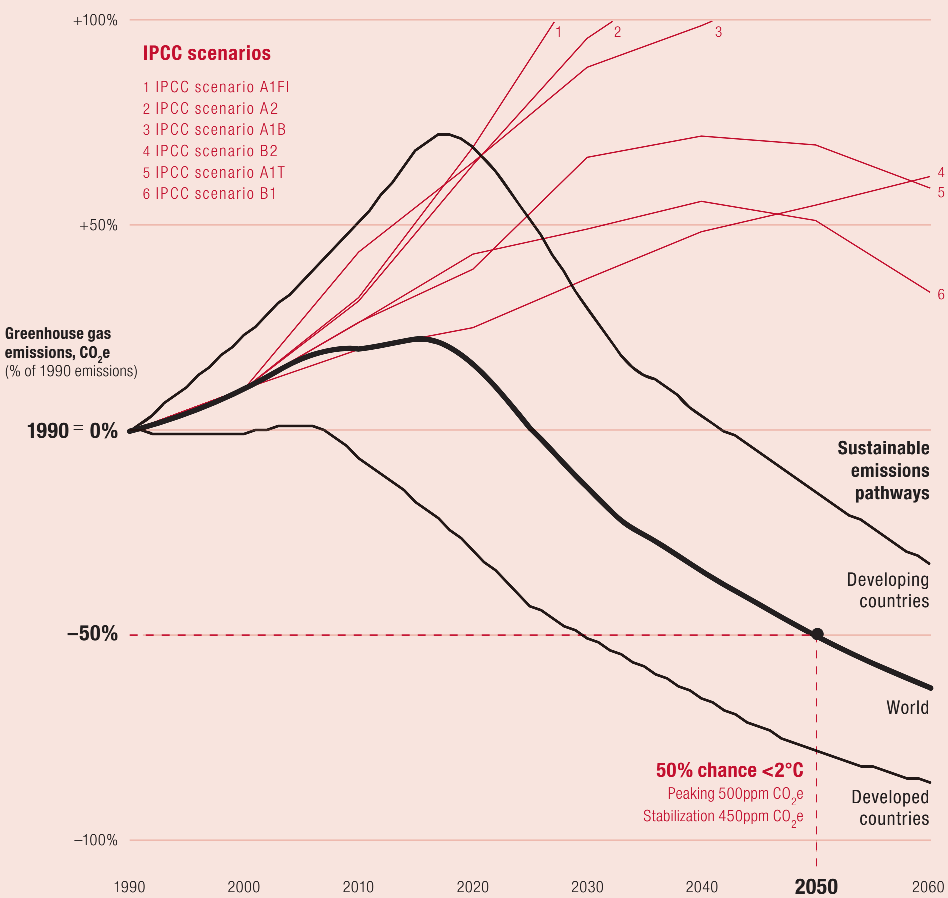
While interpretation of that injunction is a matter for negotiation, we have distinguished between industrialized countries and developing countries, charting separate pathways for the two groups. The results are summarized in figure 1.11. The cuts from a 1990 base-year on our sustainable emissions pathway are as follows:

- *The world.* Emissions for the world will have to be reduced by around 50 percent by 2050, with a peak around 2020. Emissions would fall towards zero in net terms by the end of the 21st Century.
- *Developed countries.* High-income countries would have to target an emissions peak between 2012 and 2015, with 30 percent cuts by 2020 and at least 80 percent cuts by 2050.
- *Developing countries.* While there would be large variations, major emitters in the developing world would maintain a trajectory of rising emissions to 2020, peaking at around 80 percent above current levels, with cuts of 20 percent against 1990 levels by 2050.

Contraction and convergence—sustainability with equity

We emphasize that these are feasible pathways. They are not specific proposals for individual countries. Yet the pathways do serve an important purpose. Governments are embarking

Figure 1.11 **Halving emissions by 2050 could avoid dangerous climate change**



Note: **IPCC scenarios** describe plausible future patterns of population growth, economic growth, technological change and associated CO_2 emissions. The **A1 scenarios** assume rapid economic and population growth combined with reliance on fossil fuels (A1FI), non-fossil energy (A1T) or a combination (A1B). The **A2 scenario** assumes lower economic growth, less globalization and continued high population growth. The **B1** and **B2 scenarios** contain some mitigation of emissions, through increased resource efficiency and technology improvement (B1) and through more localized solutions (B2).

Source: Meinshausen 2007.

on negotiations for the multilateral framework to succeed the current Kyoto Protocol following the expiry of the current commitment period in 2012. The PIK simulations identify the scale of emission reductions that will be required to put the world on a pathway that avoids dangerous climate change. There are various trajectories that could be adopted to achieve the 2050 targets. What our sustainable emissions pathway does is to emphasize the importance of linking near-term and long term goals.

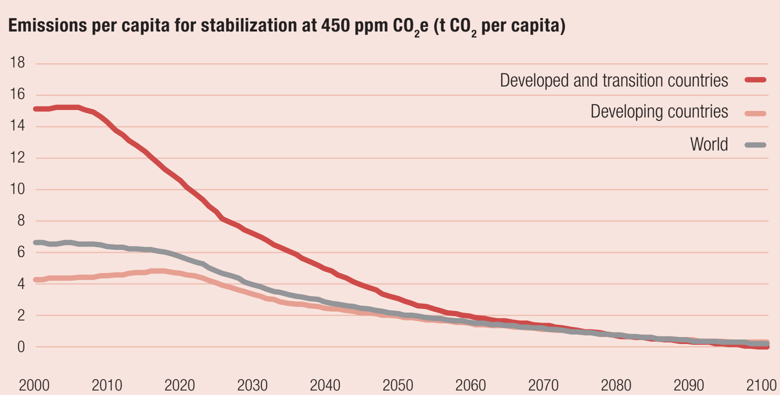
The emissions pathways also serve to highlight the importance of early and concerted action. In theory starting points for carbon emission reductions could be pushed back. But the corollary would be far deeper cuts required over a reduced time horizon. In our view that would be a prescription for failure because costs would rise and adjustments would become even more difficult. Another scenario could be drawn up in which some major Organisation for Economic Co-operation and Development (OECD) countries do not participate in quantitative carbon budgeting. Such an approach would all but guarantee failure. Given the magnitude of emission reductions required in the OECD countries, it is unlikely that participating countries would be able to compensate for the non-participation of major emitters. Even if they did, it is unlikely that they would embrace an agreement that allowed 'free riding'.

Participation of the developing world in quantitative reductions is equally vital. In some respects, our 'two-country' model oversimplifies the issues to be addressed in negotiations. The developing world is not homogenous: the United Republic of Tanzania is not in the same position as China, for example. Moreover, what matters is the overall volume of emission reductions. From a global carbon budget perspective, deep reductions in sub-Saharan Africa carry negligible weight relative to reductions in major emitting countries.

However, with developing countries accounting for nearly half of worldwide emissions, their participation in any international agreement is increasingly important. At the same time, even high growth developing countries have pressing human development needs that must be taken into account. So too must the very large 'carbon debt' that the rich countries owe the world. Repayment of that debt and recognition of human development imperatives demand that rich countries cut emissions more deeply and support low-carbon transitions in the developing world.

We acknowledge that many other emissions' pathways are possible. One school of thought argues that every person in the world ought to enjoy an equivalent right to emit greenhouse gases, with countries that exceed their quota compensating those that underutilize their entitlement. Although proposals in this framework are often couched in terms of rights and equity, it is not clear that they have a rights-based foundation: the presumed 'right to emit' is clearly something different than the right to vote, the right to receive an education or the right to enjoy basic civil liberties.[62] At a practical level, attempts to negotiate a 'pollution rights' approach is unlikely to gain broad support. Our pathway is rooted in a commitment to achieve a practical goal: namely, the avoidance of dangerous climate change. The route taken requires a process of overall contraction in greenhouse gas flows and convergence in per capita emissions (figure 1.12).

Figure 1.12 **Contracting and converging to a sustainable future**



Note: **IPCC scenarios** describe plausible future patterns of population growth, economic growth, technological change and associated CO_2 emissions. The **A1 scenarios** assume rapid economic and population growth combined with reliance on fossil fuels (A1FI), non-fossil energy (A1T) or a combination (A1B). The **A2 scenario** assumes lower economic growth, less globalization and continued high population growth. The **B1** and **B2 scenarios** contain some mitigation of emissions, through increased resource efficiency and technology improvement (B1) and through more localized solutions (B2).

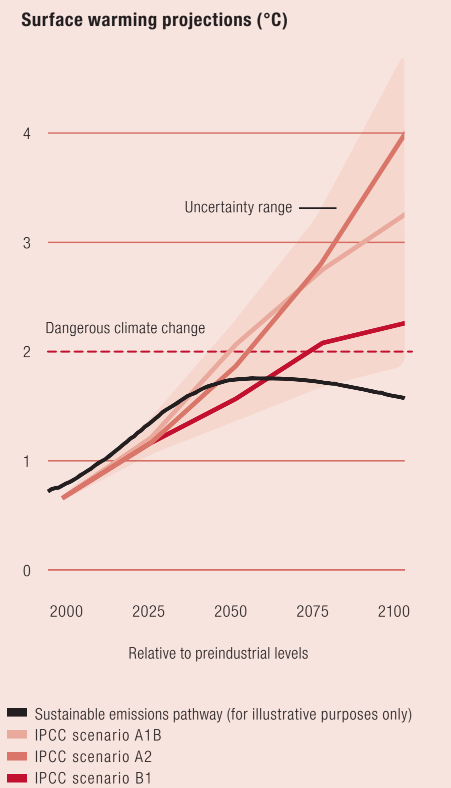
Source: Meinshausen 2007.

Urgent action and delayed response—the case for adaptation

Deep and early mitigation does not offer a short-cut for avoiding dangerous climate change. Our sustainable emissions pathway demonstrates the importance of the time lag between mitigation actions and outcomes. Figure 1.13 captures the lag. It compares the degree of warming above preindustrial levels associated with the IPCC's non-mitigation scenarios, with the anticipated warming if the world stabilizes greenhouse gas stocks at 450 ppm CO_2e. Temperature divergence begins between 2030 and 2040, becoming more emphatically marked after 2050, by which time all but one of the IPCC scenarios breach the 2°C dangerous climate change threshold.

The timing of the temperature divergence draws attention to two important public policy issues. First, even the stringent mitigation implied by our sustainable emissions pathway will not make a difference to world temperature trends until after 2030. Until then, the world in general and the world's poor in particular will have to live with the consequences of past emissions. Dealing with these consequences while maintaining progress towards the MDGs and building on that progress after 2015 is a matter not for mitigation but for adaptation. Second, the real benefits of mitigation will build cumulatively across the second half of the 21st Century and beyond.

Figure 1.13 **Stringent mitigation does not deliver early results**



Note: **IPCC scenarios** describe plausible future patterns of population growth, economic growth, technological change and associated CO_2 emissions. The **A1 scenarios** assume rapid economic and population growth combined with reliance on fossil fuels (A1FI), non-fossil energy (A1T) or a combination (A1B). The **A2 scenario** assumes lower economic growth, less globalization and continued high population growth. The **B1** and **B2 scenarios** contain some mitigation of emissions, through increased resource efficiency and technology improvement (B1) and through more localized solutions (B2).

Source: IPCC 2007a and Meinshausen 2007.

One important implication is that the motivation for urgent mitigation has to be informed by a concern for future generations. The world's poor will face the most immediate adverse impacts of temperature divergence. By the end of the 21st Century, with some of the IPCC scenarios pointing to temperature increases of 4–6°C (and rising), humanity as a whole will be facing potentially catastrophic threats.

The cost of a low-carbon transition—is mitigation affordable?

Setting carbon budgets is an exercise that has implications for financial budgets. While there have been many studies looking at the cost of achieving specific mitigation goals, our 2°C threshold is a far more stringent target than those assessed in most of these studies. While our sustainable climate pathway may be desirable, is it affordable?

We address that question by drawing on an approach that combines quantitative results from a large number of models in order to investigate the costs of achieving specified stabilization outcomes.[63] These models incorporate dynamic interactions between technology and investment, exploring a range of scenarios for achieving specified mitigation targets.[64] We use them to identify global costs for achieving a target of 450 ppm CO_2e.

Emissions of CO_2 can be cut in several ways. Increased energy efficiency, reduced demand for carbon-intensive products, changes in the energy mix—all have a role to play. Mitigation costs will vary according to how reductions are achieved and the time frame for achieving them. They arise from financing the development and deployment of new technologies and from the cost to consumers of switching to lower-emissions goods and services. In some cases, major reductions can be achieved at low cost: increased energy efficiency is an example. In others initial costs can generate benefits over the longer term. Deployment of a new generation of efficient, low-emission coal-fired power stations might fit in this category. Gradually reducing the flow of greenhouse gases over time is a lower-cost option than abrupt change.

Modelling work carried out for this Report estimates the costs of stabilization at 450 ppm CO_2e under various scenarios. Expressed in terms of headline dollars, the figures are very large. However, the costs of action are spread over many years. In a simple reference scenario, averaging out these costs produces a figure of around 1.6 percent of annual world GDP between now and 2030.[65]

That is not an insignificant investment. It would be wrong to underestimate the massive effort required to stabilize CO_2e emissions close to 450 ppm. However, the costs have to be put in perspective. As the Stern Review powerfully reminded the world's governments, they have to be evaluated against the costs of inaction.

Measured in economic terms the case for stringent mitigation makes good business sense

The 1.6 percent of global GDP required to achieve the 450 ppm targets for CO_2e represents less than two-thirds of global military expenditures. In the context of OECD countries, where government expenditure typically represents 30 to 50 percent of GDP, the stringent mitigation goals hardly appear unaffordable, especially if expenditures in other areas—such as military budget and agricultural subsidies—can be reduced.

The human and ecological costs of dangerous climate change cannot readily be captured in simple cost–benefit analysis. However, measured in economic terms the case for stringent mitigation makes good business sense. Over the long term the costs of inaction will be larger than the costs of mitigation. Estimating the costs of climate change impacts is intrinsically difficult. With warming of 5–6°C economic models that include the risk of abrupt and large-scale climate change point to losses of 5 to 10 percent of global GDP. Poor countries could suffer losses in excess of 10 percent.[66] Catastrophic climate change impacts could push the losses above this level. Reducing the risk of catastrophic outcomes is one of the most powerful arguments for early investment in mitigation to achieve the 450 ppm target.

It has to be emphasized that there are large margins of uncertainty in any assessment of mitigation costs. Most obviously, the cost structures for future low-carbon technologies, the timing of their introduction, and other factors are unknown. Higher costs than those indicated above are perfectly plausible—and political leaders need to communicate the uncertainties of financing for a 2°C climate change threshold. At the same time, it is also possible that costs could be lower. International emissions trading and the integration of carbon taxation into wider environmental tax reforms have the potential to drive down mitigation costs.[67]

All governments have to assess the financial implications of achieving climate change mitigation targets. Multilateral climate protection architecture will be left on an insecure foundation if it is not rooted in financial commitments. The 1.6 percent of average global GDP required for stringent mitigation implies a claim on scarce resources. But the alternatives are not cost-free. Political debate on financing must also address the question of whether dangerous climate change is an affordable option.

That question goes to the heart of the twin case for urgent action set out in this chapter. Given the momentous nature of the catastrophic ecological risks that will accompany dangerous climate change, 1.6 percent of global GDP might be seen as a small price to pay on an insurance policy to protect the well-being of future generations. Given that the same investment has the potential to prevent large-scale and very immediate reversals in human development for millions of the more vulnerable people across the world, the cross-generational and the cross-country social justice imperatives are mutually reinforcing.

1.5 Business-as-usual—pathways to an unsustainable climate future

Trend is not destiny and past performance can be a weak guide to future outcomes. In the case of climate change that is unequivocally a good thing. If the next 20 years look like the past 20 the battle against dangerous climate change will be lost.

Looking back—the world since 1990

Experience under the Kyoto Protocol provides some important lessons for the development of a 21st Century carbon budget. The Protocol provides a multilateral framework that sets limits on greenhouse gas emissions. Negotiated under the auspices of the UNFCCC, it took 5 years to reach an agreement—and another 8 years before that agreement was ratified by enough countries to become operational.[68] The headline target for greenhouse gas emissions cuts was 5 percent from 1990 levels.

Measured in terms of aggregate global emissions the Kyoto protocol did not set particularly ambitious targets. Moreover, quantitative ceilings were not applied to developing countries. The decisions of Australia and the United States not to ratify the protocol further limited the size of the intended cuts. The implication of these exceptions can be illustrated by reference to energy-related CO_2 emissions. From the 1990 base year the commitment made under the Kyoto protocol translates into a 2.5 percent reduction of energy-related CO_2 emissions in real terms by the 2010/2012 target date.[69]

Delivery against the targets has been disappointing so far. In 2004, overall greenhouse emissions for Annex I countries were 3 percent below 1990 levels.[70] However, the headline figure masks two major problems. First, since 1999 overall emissions have been on a rising trend, raising questions about whether the overall target will be achieved. Second, there are large variations in country performance (figure 1.14). Much of the overall decline can be traced to deep reductions in emissions in the Russian Federation and other transition economies—in some cases in excess of 30 percent. This outcome owes less to energy policy reform than to the effects of deep economic recession in the 1990s. Emissions are now rising with economic recovery. As a group, non-transition Annex I parties—broadly the OECD—have increased emissions by 11 percent from 1990 to 2004 (box 1.3).

Looking ahead—locked on a rising trajectory

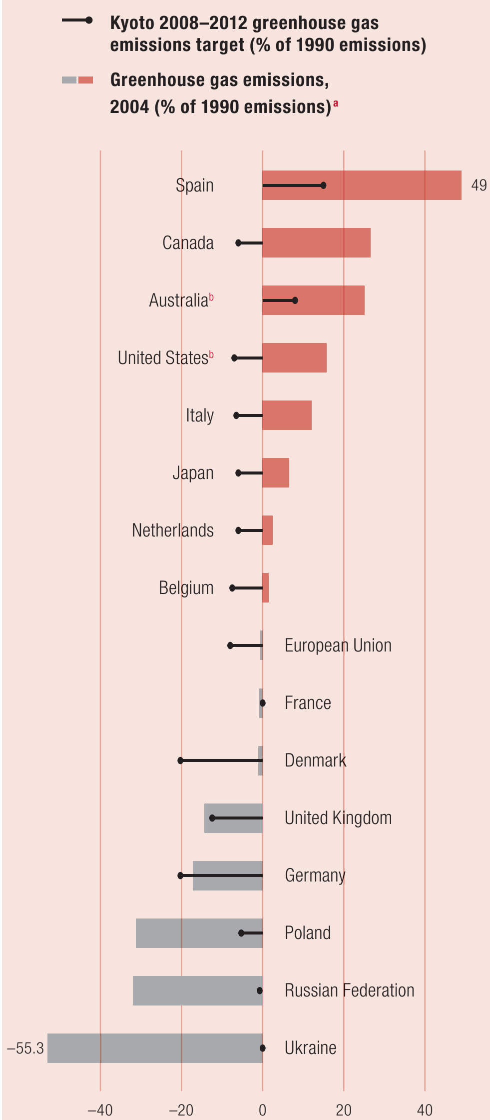
Looking back, trends since the 1990 reference-point for the Kyoto Protocol are cause for concern. Looking ahead, the scenarios for future energy use and emissions point unmistakably towards a dangerous climate future, unless the world changes course.

Changing course will require a shift in energy use patterns as far-reaching as the energy revolution that shaped the industrial revolution. Even without climate change, the future of fossil-fuel energy systems would be the subject of intense debate. Energy security—broadly defined as access to reliable and affordable supplies—is an increasingly prominent theme on the international agenda.

Since 2000, oil prices have increased by a factor of five in real terms, to around US$70

Looking ahead, the scenarios for future energy use and emissions point unmistakably towards a dangerous climate future, unless the world changes course

Figure 1.14 **Some developed countries far short of Kyoto commitments and targets**



a. Excludes emissions from land use changes. **b.** Australia and the United States have signed but not ratified the Kyoto Protocol and so are not bound by its targets.

Source: EEA 2006 and UNFCCC 2006.

Box 1.3 **Developed countries have fallen short of their Kyoto commitments**

The Kyoto Protocol was a first step in the multilateral response to climate change. It set targets for cutting greenhouse gas emissions against 1990 levels by 2010–2012. With governments embarking on negotiations for the post-2012 multilateral framework that will build on the current commitment period, it is important that lessons are learned.

There are three particularly important lessons. The first is that the level of ambition matters. Targets adopted under the first commitment period were modest, averaging around 5 percent for developed countries. The second lesson is that binding targets matter. Most countries are off track for delivering on their Kyoto commitments. The third lesson is that the multilateral framework has to cover all major emitting nations. Under the current Protocol, two major developed countries—Australia and the United States—signed the agreement but did not ratify it, creating an exemption for the targets. There are also no quantitative targets for developing countries.

While it is too early to deliver a final verdict on outcomes under the Kyoto protocol, the summary record to date on emissions without land-use changes is not encouraging. Most 68 countries are off track. Moreover, emissions' growth has strengthen since 2000.

Among the preliminary outcomes:

- The European Union made average emission reduction commitments of 8 percent under Kyoto. Actual cuts have amounted to around 2 percent and European Environment Agency projections suggest that current policies will leave this picture unchanged by 2010. Emissions from the transport sector increased by one-quarter. Emissions from electricity and heat generation increased by 6 percent. Large increases in renewable energy supply will be required to meet the Kyoto targets, but the European Union is falling short of the investments needed to meet its own target of 20 percent provision by 2020.
- The United Kingdom has surpassed its Kyoto target of a 12 percent emissions reduction, but is off track to meet a national target to reduce emissions by 20 percent against 1990 levels. Most of the reduction was achieved before 2000 as a result of industrial restructuring and market liberalization measures that led to a switch from carbon-intensive coal to natural gas. Emissions increased in 2005 and 2006 as a result of switching from natural gas and nuclear to coal (chapter 3).
- Germany's emissions were 17 percent lower in 2004 than in 1990. Reductions reflect deep cuts from 1990 to 1995 following reunification and industrial restructuring in East Germany (over 80 percent of the total reduction), supplemented by a decline in emissions from the residential sector.
- Italy and Spain are far off track for their Kyoto targets. In Spain emissions have increased by almost 50 percent since 1990, with strong economic growth and increased use of coal power following droughts. In Italy, the primary driver of increased emissions has been the transport sector.
- Canada agreed under the Kyoto Protocol to target a 6 percent cut in emissions. In the event, emissions have increased by 27 percent and the country is now around 35 percent above its Kyoto target range. While greenhouse gas intensity has fallen, efficiency gains have been swamped by an increase in emissions from an expansion in oil and gas production. Net emissions associated with oil and gas exports have more than doubled since 1990.
- Japan's emissions in 2005 were 8 percent above 1990 levels. The Kyoto target was for a 6 percent reduction. On current trends it is projected that the country will miss its target by around 14 percent. While emissions from industry have fallen marginally since 1990, large increases have been registered in emissions from transportation (50 percent for passenger vehicles) and the residential sector. Household emissions have grown more rapidly than the number of households.
- The United States is a signatory to the Kyoto Protocol but it has not ratified the treaty. If it had, it would have been required to reduce its emissions to 7 percent below 1990 levels by 2010. Overall emissions have increased by 16 percent. By 2010 projected emissions are 1.8 Gt above 1990 levels on a rising trend. Emissions have grown across all major sectors despite a 21 percent decline in greenhouse gas intensity of the United States' economy, as measured by the ratio of greenhouse gas emissions to GDP.
- Like the United States, Australia did not ratify the Kyoto Protocol. Overall emissions have grown at around twice the rate that would have been required had the country participated, with emissions rising by 21 percent since 1990. High levels of dependence on coal-fired power generation contributed to large increases in the energy sector, with CO_2 emissions rising by over 40 percent.

Looking to the post-2012 period, the challenge is to forge an international agreement that engages all major emitting countries in a long term effort to achieve a sustainable carbon budget for the 21st Century. There is little that governments can do today that will have significant effects on emissions between 2010 and 2012: like oil tankers, energy systems have large turning circles.

What is needed now is a framework for beating dangerous climate change. That framework will have to provide a far longer time-horizon for policymakers, with short term commitment periods linked to medium-term and long term goals. For developed countries, those goals have to include emission reductions of around 30 percent by 2020 and at least 80 percent by 2050—consistent with our sustainable emissions pathway. Reductions by developing countries could be facilitated through financial and technology transfer provisions (chapter 3).

Source*:* EEA 2006; EIA 2006; Government of Canada 2006; IEA 2006c; Government of the United Kingdom 2007c; Ikkatai 2007; Pembina Institute 2007a.

per barrel. While prices may retreat, a return to the low levels of the late 1990s is unlikely. Some commentators interpret these market trends as evidence to support the 'peak oil' thesis—the idea that production is in long-run decline towards the exhaustion of known reserves.[71] In parallel to these market developments, political concern over the security of energy supplies has mounted in the face of growing terrorist threats, political instability in major exporting regions, high-profile disruptions in supply, and disputes between importers and exporters.[72]

Energy security and climate security —pulling in different directions?

The energy security background is important for climate change mitigation strategies. However, hopes that rising prices for fossil fuels will automatically trigger an early transition to a low-carbon future are likely to prove misplaced. Proponents of the 'peak oil' argument overstate their case. New supplies are almost certainly going to be more costly and more difficult to extract and deliver, raising the marginal price of a barrel of oil over time. Yet the world will not run out of oil any time soon: proven reserves could cover four decades of current consumption and much more may be discovered.[73] The bottom line is that there is more than enough affordable fossil fuel available to take the world over the threshold of dangerous climate change.

With current technologies, exploitation of even a small fraction of the Earth's vast reservoir of fossil fuels would guarantee such an outcome. Whatever the pressure on conventional oil sources, proven reserves of oil slightly exceed the volume used since 1750. In the case of coal, known reserves are around 12 times post-1750 use. Using just half of the world's known coal reserves during the 21st Century would add around 400 ppm to atmospheric stocks of greenhouse gases, guaranteeing dangerous climate change in the process.[74] The availability of fossil fuel reserves underlines the case for prudent carbon budget management.

Current market trends reinforce that case. One possible response to the rise in prices for oil and natural gas is a 'dash for coal'. This is the world's cheapest, most widely dispersed and most CO_2-intensive fossil fuel: for each unit of energy generated, coal generates around 40 percent more CO_2 than oil and almost 100 percent more than natural gas. Moreover, coal figures very prominently in the current and future energy profiles of major CO_2 emitters such as China, Germany, India and the United States. Experience in the transition economies points to wider problems. Consider the direction of energy policy in the Ukraine. Over the past 10 to 15 years coal has been steadily replaced by cheaper (and less polluting) imported natural gas. However, with the interruption of supplies from the Russian Federation in early 2006 and the doubling of import prices, the Ukrainian government is considering a shift back towards coal.[75] The case demonstrates the way in which national energy security may conflict with global climate security goals.

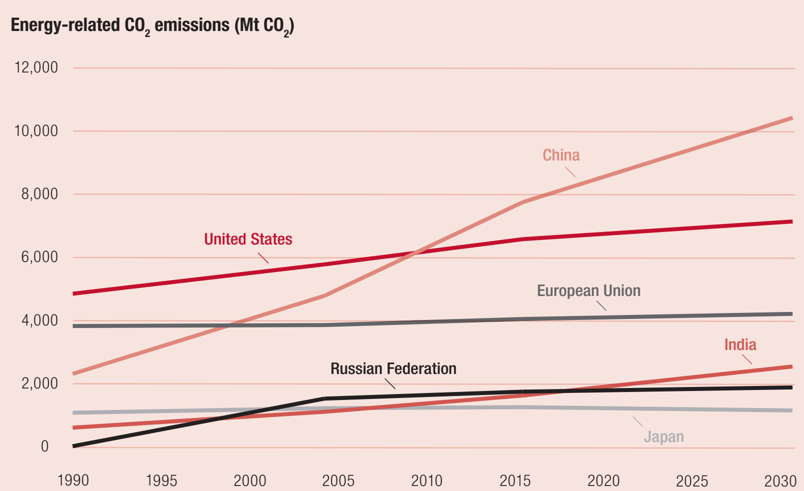
Energy demand scenarios confirm that rising fossil fuel prices are not pushing the world towards a sustainable emissions pathway. Demand is projected to increase by half between now and 2030, with over 70 percent of the increase coming from developing countries.[76] These projections suggest that the world will spend around US$20 trillion between 2005 and 2030 in meeting those demands. Much of that investment is still being directed towards carbon-intensive infrastructures that will still be generating energy—and emitting CO_2—in the second half of the 21st Century. The consequences can be assessed by comparing energy-related CO_2 emission scenarios developed by the International Energy Agency (IEA) and the IPCC with our sustainable emissions pathway simulations:

- Our sustainable emissions pathway points to a trajectory that requires a 50 percent cut in greenhouse gas emissions worldwide by 2050 against 1990 levels. The IEA scenario, in contrast, points to an increase of around 100 percent. Between 2004 and 2030 alone, energy-related emissions are projected to increase by 14 Gt CO_2, or 55 percent.

There is more than enough affordable fossil fuel available to take the world over the threshold of dangerous climate change

- While our sustainable emissions pathway points to an indicative target of cuts in the range of at least 80 percent for OECD countries, the IEA reference scenario indicates a 40 percent increase—an aggregate expansion of 4.4 Gt CO_2. The United States will account for around half the increase, taking emissions 48 percent above 1990 levels (figure 1.15).
- According to the IEA, developing countries will account for three-quarters of the increase in global CO_2 emissions, whereas our sustainable emissions pathway points to the need for cuts of around 20 percent by 2050 against 1990 levels. The projected expansion would represent a fourfold increase over 1990 levels.
- While per capita emissions will increase most rapidly in developing countries, convergence will be limited. By 2030, OECD emissions are projected at 12 tonnes of CO_2 per capita, compared with 5 tonnes CO_2 for developing countries. In 2015, per capita emissions from China and India are projected at 5.2 and 1.1 tonnes, compared with 19.3 tonnes for the United States.
- IPCC scenarios are more comprehensive than those developed by the IEA because they incorporate other sources of emissions, including agriculture, changes in land use, and waste, and a wider range of greenhouse gases. These scenarios point to emission levels of 60–79 Gt CO_2e by 2030, on a sharply rising trend. The lower end of this range is 50 percent above the 1990 baseline. One of the IPCC's non-mitigation scenarios has emissions doubling in the three decades to 2030.[77]

Figure 1.15 Business-as-usual CO_2 emissions on a rising trend



Source: IEA 2006c.

Drivers for increased emissions

As with any future scenario, these figures have to be treated with caution. They represent a best-estimate based on underlying assumptions about economic growth, population change, energy markets, technology and current policies. The scenarios do not chart a predetermined trajectory. What they draw attention to is the hard fact that the world is currently on an emissions trajectory that guarantees a collision between people and planet.

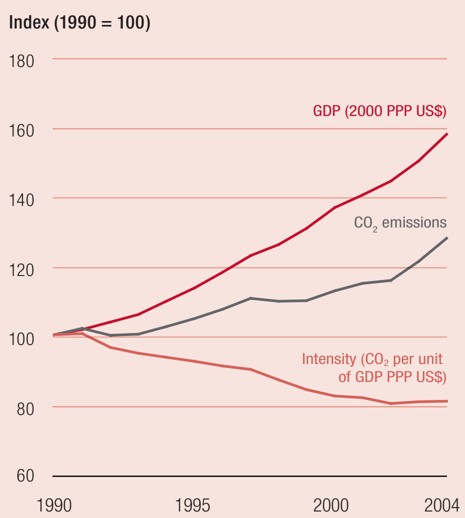
Changing trajectories will be difficult. There are three powerful drivers of rising emissions that will interact with technology, changes in energy markets and public policy choices.

- *Demographic trends.* Current projections point to an increase in world population from 6.5 billion today to 8.5 billion by 2030. At a global level, just standing still in terms of overall emissions will require 30 percent reductions in average per capita emissions—and standing still will not be enough to avoid dangerous climate change. Almost all the increase in population will take place in developing countries, where there are currently large unmet energy needs and lower levels of energy efficiency.
- *Economic growth.* Economic growth and the carbon intensity of growth—a function of energy mix and sectoral composition—are two of the most powerful drivers of emission trends. Any projections in this area are subject to uncertainty. Climate change itself could act as a brake on future growth, especially in the event of catastrophic sea-level

rises or unanticipated 'nasty surprises'. However, that brake may not be applied in the next few decades: most models do not expect climate to have significant effects on the drivers of world growth until towards the end of the 21st Century.[78] More immediately, the global economy is experiencing one of the longest periods of sustained growth in history. World GDP growth has averaged over 4 percent per annum for the past decade.[79] At this rate, output doubles every 18 years, pushing up demand for energy and emissions of CO_2 in the process. The amount of CO_2 generated by every dollar of growth in the world economy—the 'carbon-intensity' of world GDP—has been falling over the past two-and-a-half decades, weakening the link between GDP and carbon emissions. That trend reflects improvements in energy efficiency, changes in economic structure—with the share of carbon-intensive manufacturing falling relative to service sectors in many countries—and changes in the energy mix. However, the decline in carbon intensity has stalled since 2000, creating further upward pressure on emissions (figure 1.16).

- *Energy mix*. For the past quarter of a century, energy-related CO_2 emissions have grown less rapidly than primary energy demand. However, under the IEA scenario, the period to 2030 could see CO_2 emissions rise more rapidly than primary energy demand. The reason: an increase in the share of coal in primary energy demand. Emissions of CO_2 from coal are projected to increase by 2.7 percent a year in the decade to 2015—a rate that is 50 percent higher than for oil.

Figure **1.16** **Carbon intensity is falling too slowly to cut overall emissions**



Source: CDIAC 2007 and World Bank 2007d.

Achieving climate change mitigation on the scale required in the face of these pressures will require a sustained public policy effort backed by international cooperation. Current trends in energy markets alone are not going to push the world on to a low-carbon trajectory. However, recent market trends and concerns over energy security could provide an impetus towards a low-carbon future. With prices for oil and natural gas set to remain at high levels, the incentives for developing low-carbon energy capacity have moved in a favourable direction. Similarly, governments concerned about 'addiction to oil' and the security of energy supply have strong grounds for advancing programmes aimed at enhancing energy efficiency, creating incentives for the development and deployment of low-carbon technologies, and promoting greater self-reliance through renewable energy. We look in more detail at the mitigation framework in chapter 3. But the four building blocks for success are:

- Putting a price on carbon emissions through taxation and cap-and-trade systems.
- Creating a regulatory framework that enhances energy efficiency, sets standards for reducing emissions and creates market opportunities for low-carbon energy suppliers.
- Agreeing on multilateral international cooperation to finance technology transfers to developing countries supporting a transition to low-carbon energy sources.
- Developing a post-2012 multilateral framework to build on the first phase of the Kyoto Protocol, with far more ambitious targets for cutting greenhouse gas emissions.

Current trends in energy markets alone are not going to push the world on to a low-carbon trajectory

Policies for mitigating greenhouse gas emissions will require far-reaching changes in energy policy and behaviour

1.6 Why we should act to avoid dangerous climate change

We live in a deeply divided world. Extremes of poverty and prosperity retain the power to shock. Differences in religious and cultural identification are a source of tension between countries and people. Competing nationalisms pose threats to collective security. Against this backdrop, climate change provides a hard lesson in a basic fact of human life: we share the same planet.

Wherever people live and whatever their belief systems, they are part of an ecologically interdependent world. Just as flows of trade and finance are linking people together in an integrated global economy, so climate change draws our attention to the environmental ties that bind us in a shared future.

Climate change is evidence that we are mismanaging that future. Climate security is the ultimate public good: the world's atmosphere is shared by all in the obvious sense that nobody can be 'excluded' from it. By contrast, dangerous climate change is the ultimate public bad. While some people (the world's poor) and some countries stand to lose faster than others, everybody stands to lose in the long run, with future generations facing increased catastrophic risks.

Writing in the 4th Century BC, Aristotle observed that "what is common to the greatest number has the least care bestowed upon it". He could have been commenting on the Earth's atmosphere and the absence of care bestowed on our planet's capacity to absorb carbon. Creating the conditions for change will require new ways of thinking about human interdependence in a world heading for dangerous climate change outcomes.

Climate stewardship in an interdependent world

Tackling climate change confronts governments with difficult choices. Complex issues involving ethics, distributional equity across generations and countries, economics, technology and personal behaviour are at stake. Policies for mitigating greenhouse gas emissions will require far-reaching changes in energy policy and behaviour.

In this chapter we have looked at a range of issues that are important in framing the response to climate change. Four themes merit special emphasis because they go to the heart of the ethics and economics of any public policy framework for mitigation:

- *Irreversibility.* Emissions of CO_2 and other greenhouse gases are, for all practical purposes, irreversible. The duration of their residence in the Earth's atmosphere is measured in centuries. Similar logic applies to climate system impacts. Unlike many other environmental issues, where damage can be cleaned up relatively swiftly, the damage wrought by climate change has the potential to extend from vulnerable populations today across generations to the whole of humanity in the distant future.
- *Global scale.* The climate forcing generated through a build-up of greenhouse gases does not distinguish between nations, even if the effects differ. When a country emits CO_2 the gas flows into a stock that affects the whole world. Greenhouse gas emissions are not the only form of transboundary environmental pollution: acid rain, oil spillages and river pollution also create externalities that cross national borders. What is different with climate change is the scale and the consequence: that no nation state acting alone can solve the problem (even though some countries can do more than others).
- *Uncertainty and catastrophe.* Climate change models deal in probabilities—and probabilities imply uncertainties. The combination of uncertainty and catastrophic risk for future generations is a powerful

rationale for investment in risk insurance through mitigation.

- *Near-term human development reversals.* Long before catastrophic events due to climate change impact on humanity, many millions of people will be profoundly affected. It might be possible to protect Amsterdam, Copenhagen and Manhattan from rising sea levels in the 21st Century, albeit at high cost. But coastal flood defences will not save the livelihoods or the homes of hundreds of millions of people living in Bangladesh and Viet Nam or the Niger or Nile deltas. Urgent climate change mitigation would reduce the risks of human development setbacks over the course of the 21st Century, though most of the benefits will occur after 2030. Reducing human costs prior to that date will require support for adaptation.

Social justice and ecological interdependence

There are many theories of social justice and approaches to efficiency that can be brought to bear on climate change debates. Perhaps the most apposite was crafted by the Enlightenment philosopher and economist Adam Smith. In considering how to determine a just and ethical course of action, he suggested a simple test: "to examine our own conduct as we imagine any other fair and impartial spectator would examine it".[80]

Such a "fair and impartial spectator" would take a dim view of a generation that failed to act on climate change. Exposing future generations to potentially catastrophic risks might be considered inconsistent with a commitment to core human values. Article Three of the Universal

Special contribution — Our common future and climate change

Sustainable development is about meeting the needs of present generations without compromising the ability of future generations to meet their own needs. More than that, it is about social justice, equity and respect for the human rights of future generations.

Two decades have now passed since I had the privilege of chairing the World Commission on the Environment. The Report that emerged from our proceeding had a simple message that was captured in its title, *Our Common Future*. We argued that humanity was overstepping the limits of sustainability and running down the world's ecological assets in a way that would compromise the well-being of future generations. It was also clear that the vast majority of the world's population only had a small share in the overuse of our finite resources. Unequal opportunities and unequal distribution were at the heart of the problems we identified.

Today we need to reflect in detail on climate change. But is there any more powerful demonstration of what it means to live unsustainably?

The *Human Development Report 2007/2008* sets out what it describes as a 'carbon budget' for the 21st Century. Drawing upon the best climate science, that budget establishes the volume of greenhouse gases that can be emitted without causing dangerous climate change. If we continue on our current emissions trajectory, the carbon budget for the 21st Century will expire in the 2030s. Our energy consumption patterns are running up vast ecological debts that will be inherited by future generations—debts that they will be unable to repay.

Climate change is an unprecedented threat. Most immediately, it is a threat to the world's poorest and most vulnerable people: they are already living with the consequences of global warming. In our already deeply divided world, global warming is magnifying disparities between rich and poor, denying people an opportunity to improve their lives. Looking to the future, climate change poses risks of an ecological catastrophe.

We owe it to the world's poor and to future generations to act with resolve and urgency to stop dangerous climate change. The good news is that it is not too late. There is still a window of opportunity, but let's be clear: the clock is ticking, and time is running out.

Rich nations must show leadership and acknowledge their historic responsibility. Their citizens leave the biggest carbon footprint in the Earth's atmosphere. Moreover, they have the financial and technological capabilities needed to make deep and early cuts in carbon emissions. None of this means that mitigation has to be left to the rich world. Indeed, one of the most urgent priorities is international cooperation on technology transfer to enable developing countries to make the transition to low-carbon energy systems.

Today, climate change is teaching us the hard way some of the lessons that we attempted to communicate in *Our Common Future*. Sustainability is not an abstract idea. It is about finding a balance between people and planet—a balance that addresses the great challenges of poverty today, while protecting the interests of future generations.

Gro Harlem Brundtland
Chair of the World Commission on Sustainable Development
Former Prime Minister of Norway

The challenge is to sustain human progress today while facing the incremental risks created by climate change in the lives of a significant section of humanity

Declaration on Human Rights establishes that "everyone has a right to life, liberty and personal security." Inaction in the face of the threat posed by climate change would represent a very immediate violation of that universal right.

The principle of cross-generational equity is at the heart of the idea of sustainability. Two decades have now passed since the World Commission on Environment and Development brought the idea of sustainable development to the centre of the international agenda. The core principle is worth restating, if only to highlight how comprehensively it will be violated by a continued failure to prioritize climate change mitigation: "Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future."[81]

That vision retains a powerful resonance and an application to public policy debates on climate change. Of course, sustainable development cannot mean that every generation leaves the world's environment exactly as it found it. What need to be conserved are the opportunities for future generations to enjoy substantive freedoms, make choices and lead lives that they value.[82] Climate change will eventually limit those freedoms and choices. It will deny people control over their destinies.

Thinking about the future does not mean that we should think less about social justice in our lifetime. An impartial observer might also reflect on what inaction in the face of climate change might say about attitudes to social justice, poverty and inequality today. The ethical foundation of any society has to be measured partly on the basis of how it treats its most vulnerable members. Allowing the world's poor to bear the brunt of a climate change problem that they did not create would point to a high level of tolerance for inequality and injustice.

In human development terms, the present and the future are connected. There is no long term trade-off between climate change mitigation and the development of human capabilities. As Amartya Sen argues in his special contribution to this Report, human development and environmental sustainability are integral elements in the substantive freedom of human beings.

Tackling climate change with well-designed policies will reflect a commitment to expand the substantive freedoms that people enjoy today without compromising the ability of future generations to build on those freedoms.[83] The challenge is to sustain human progress today while facing the incremental risks created by climate change in the lives of a significant section of humanity.

There is a fundamental sense in which climate change challenges us to think differently about human interdependence. Greek philosophers argued that human affinity could be understood in terms of concentric circles stretching out from family, to locality, country and the world—and weakening with every remove from the centre. Enlightenment economists such as Adam Smith and philosophers such as David Hume sometimes used this framework to explain human motivation. In today's economically and ecologically more interdependent world, the concentric circles have become closer to each other. As the philosopher Kwame Appiah has written: "Each person you know about and affect is someone to whom you have responsibilities: to say this is just to affirm the very idea of morality."[84] Today we "know about" people in far-distant places—and we know about how our use of energy "affects"their lives through climate change.

Viewed from this perspective, climate change poses some tough moral questions. Energy use and the associated emissions of greenhouse gases are not abstract concepts. They are aspects of human interdependence. When a person switches on a light in Europe or an air-conditioning unit in America, they are linked through the global climate system to some of the world's most vulnerable people—to small-scale farmers eking out a living in Ethiopia, to slum dwellers in Manila, and to people living in the Ganges Delta. They are also linked to future generations, not only their own children and grandchildren but also to the children and grandchildren of people across the world. Given the evidence about the implications of dangerous climate change for poverty and future catastrophic risks, it would be a denial of morality to disregard the responsibilities that come with the ecological interdependence that is driving climate change.

The moral imperative to tackle climate change is rooted above all in ideas about stewardship, social justice and ethical responsibility. In a world where people are often divided by their beliefs, these are ideas that cross religious and cultural divides. They provide a potential foundation for collective action by faith group leaders and others (box 1.4).

The economic case for urgent action

Ambitious climate change mitigation requires spending today on a low-carbon transition. The costs will fall predominantly on today's generation, with the rich world facing the biggest bill. Benefits will be distributed across countries and

Box 1.4 **Stewardship, ethics and religion—common ground on climate change**

"We do not inherit the Earth from our ancestors, we borrow it from our children"

American Indian proverb

Sustainability was not a concept invented at the Earth Summit in 1992. Belief in the values of stewardship, cross-generational justice and shared responsibility for a shared environment underpin a wide range of religious and ethical systems. Religions have a major role to play in highlighting the issues raised by climate change.

They also have the potential to act as agents of change, mobilizing millions of people on the basis of shared values to take action on an issue of fundamental moral concern. While religions vary in their theological or spiritual interpretation of stewardship, they share a common commitment to the core principles of cross-generational justice and concern for the vulnerable.

At a time when the world focuses too often on religious difference as a source of conflict, climate change offers opportunities for inter-faith dialogue and action. With some notable exceptions, religious leaders could do more in the public sphere. One result is that there has been insufficient moral reflection on the issues raised by climate change. The foundations for inter-faith action are rooted in basic scriptures and current teaching:

- *Buddhism.* The Buddhist term for individual is *Santana*, or stream. It is intended to capture the idea of interconnectedness between people and their environment, and between generations. Buddhist teaching places an emphasis on personal responsibility to achieve change in the world through change in personal behaviour.
- *Christianity.* Theologians from a wide range of Christian traditions have taken up the issue of climate change. From a Catholic perspective, the Holy See's Permanent Observer to the UN has called for an "ecological conversion" and "precise commitments that will effectively confront the problem of climate change." The World Council of Churches has issued a powerful and compelling call to action rooted in theological concerns: "The poor and vulnerable communities in the world and future generations will suffer the most from climate change…The rich nations use far more than their fair share of the global commons. They must pay that ecological debt to other peoples by fully compensating them for the costs of adaptation to climate change. Drastic emission reductions by the rich are required to ensure that the legitimate development needs of the world's poor can be met."
- *Hinduism.* The idea of nature as a sacred construction is deeply rooted in Hinduism. Mahatma Gandhi drew on traditional Hindu values to emphasize the importance of non-violence, respect for all forms of life and harmony between people and nature. Ideas of stewardship are reflected in statements of Hindu faith on ecology. As the spiritual leader Swami Vibudhesha has written: "This generation has no right to use up all the fertility of the soil and leave behind an unproductive land for future generations."
- *Islam.* The primary sources of Islamic teaching about the natural environment are the *Quaran*, the collections of *hadiths*—discrete anecdotes about the Prophet's sayings and actions—and Islamic Law (*al-Sharia*). Because humans are seen as part of nature, a recurrent theme in these sources is opposition to wastefulness and environmental destruction. Islamic Law has numerous injunctions to protect and guard common environmental resources on a shared basis. The Quaranic concept of 'tawheed' or oneness captures the idea of the unity of creation across generations. There is also an injunction that the Earth and its natural resources must be preserved for future generations, with human beings acting as custodians of the natural world. Drawing on these teachings, the Australian Council of Islamic Councils has commented: "God entrusts humans to enjoy the bounty of nature on the strict condition that they take care of it…Time is running out. People of religion must forget their theological differences and work together to save the world from climatic ruin."
- *Judaism.* Many of Judaism's deepest beliefs are consistent with environmental protection. As one theologian puts it, while the Torah may give humanity a privileged place in the order of creation, this is not "the dominion of a tyrant"—and many commandments concern the preservation of the natural environment. Applying Judaic philosophy to climate change, the Central Conference of American Rabbis has commented: "We have a solemn obligation to do whatever we can within reason to prevent harm to current and future generations and to preserve the integrity of creation… Not to do so when we have the technological capacity—as in the case of non-fossil fuel energy and transport technologies—is an unforgivable abdication of our responsibilities."

Source*:* Climate Institute 2006; IFEES 2006; Krznaric 2007.

Do the costs and benefits of climate change mitigation support the case for urgent action?

time. Future generations will gain from lower risks and the world's poor will benefit from enhanced prospects for human development within our own lifetime. Do the costs and benefits of climate change mitigation support the case for urgent action?

That question was addressed by the Stern Review on *The Economics of Climate Change.* Commissioned by the United Kingdom Government, the Review provided a strong response. Using cost–benefit analysis based on long-run economic modelling it concluded that the future costs of global warming would be likely to fall between 5 and 20 percent of annual world GDP. These future losses could be avoided, according to the review analysis, by incurring relatively modest annual mitigation costs of around 1 percent of GDP to achieve greenhouse gas stabilization at 550 ppm CO_2e (rather than the more ambitious 450 ppm advocated in this Report). The conclusion: an overwhelming case for urgent, immediate, and rapid reductions in emissions of greenhouse gases on the grounds that prevention is better, and cheaper, than inaction.

Some critics of the Stern Review have reached different conclusions. They maintain that cost–benefit analysis does not support the case for early and deep mitigation. The counter-arguments are wide-ranging. The Stern Review and its critics start from a similar proposition: namely, that the real global damages from climate change, whatever their level, will be incurred far into the future. Where they differ is in their evaluation of these damages. The Stern review's critics argue that the welfare of people living in the future should be discounted at a higher rate. That is, it should receive less weight than allowed for in the Stern Review compared to costs incurred in the present.

Policy prescriptions emerging from these opposing positions are different.[85] Unlike the Stern review, the critics argue for a modest rate of emission reductions in the near future, followed by sharper reductions in the longer term as the world economy grows richer—and as technological capacities develop over time.[86]

The ongoing debate following the Stern review matters at many levels. It matters most immediately because it goes to the heart of the central question facing policymakers today: namely, should we act with urgency now to mitigate climate change? And it matters because it raises questions about the interface of economics and ethics—questions that have a bearing on how we think about human interdependence in the face of the threats posed by dangerous climate change.

Discounting the future—ethics and economics

Much of the controversy has centred on the concept of social discounting. Because climate change mitigation implies current costs to generate future benefits, one critical aspect of the analysis is about how to treat future outcome relative to present outcome. At what rate should future impacts be discounted to the present? The discount rate is the tool used to address that question. Determining the rate involves placing a value on future welfare simply because it is in the future (the rate of pure time preference). It also involves a decision on the social value of an extra dollar in consumption. This second element captures the idea of diminishing marginal utility as incomes rise.[87]

The argument between the Stern review and its critics over the costs and benefits of mitigation—and the timing of action—can be attributed in large measure to the discount rate. To understand why the different approaches matter for climate change mitigation, consider the following example. At a discount rate of 5 percent, it would be worth spending only US$9 today to prevent an income loss of US$100 caused by climate change in 2057. Without any discounting, it would be worth spending up to US$100 today. So, as the discount rate goes up from zero, the future damages from warming evaluated today shrink. Applied over the long time-horizon necessary for considering climate change impacts, the magic of compound interest in reverse can generate a strong cost–benefit case for deferred action on mitigation, if discount rates are high.

From a human development perspective, we believe that the Stern review is right in its central choice for a low value for the rate of pure time preference—the component of the discount rate that weighs the welfare of future generations in comparison with ours.[88] Discounting the well-being of those that will live in the future just because they live in the future is unjustified.[89] How we think about the well-being of future generations is an ethical judgement. Indeed, the founding father of discounting described a positive rate of pure time preference as a practice which is "ethically indefensible and arises merely from the weakness of the imagination".[90] Just as we do not discount the human rights of future generations because they are equivalent to ours, so we should accept a 'stewardship of the earth' responsibility to accord future generations the same ethical weight as the current generation. Selecting a 2 percent rate of pure time preference would halve the ethical weight given to somebody born in 2043 relative to somebody born in 2008.[91]

Denying the case for action today on the grounds that future generations with a lower weight should be expected to shoulder a greater burden of mitigation costs is not an ethically defensible proposition—and it is inconsistent with the moral responsibilities that come with membership of a human community linked across generations. Ethical principles are the primary vehicle through which the interests of people not represented in the market place (future generations) or lacking a voice (the very young) are brought into policy formulation. That is why the issue of ethics has to be addressed explicitly and transparently in determining approaches to mitigation.[92]

Uncertainty, risk and irreversibility—the case for catastrophic risk insurance

Any consideration of the case for and against urgent action on climate change has to start from an assessment of the nature and timing of the risks involved. Uncertainty is critical to the argument.

As shown earlier in this chapter, uncertainty under climate change is closely associated with the possibility of catastrophic outcomes. In a world that has more chance of going over 5°C than staying under 2°C, 'nasty surprises' of a catastrophic nature will become more probable over time. The impact of those surprises is uncertain. However, they include possible disintegration of the West Antarctic ice sheet, with attendant implications for human settlements and economic activity. Ambitious mitigation can be justified as a down paymenton catastrophic risk insurance for future generations.[93]

Catastrophic risks of the order posed by climate change provide grounds for early action. The idea that costly actions today should be deferred until more is known is not applied to other areas. In dealing with national defence and protection against terrorism, governments do not refuse to put in place investments today because they are uncertain about the future benefits of those investments, or the precise nature of future risks. Rather, they assess risks and determine on the balance of probabilities whether there is sufficient likelihood of severe future damage to take anticipatory action aimed at risk reduction.[94] That is, they weigh-up the costs, the benefits and the risks, and try to insure their citizens against uncertain but potentially catastrophic outcomes.

The case against urgent action on climate change suffers from wider shortcomings. There are many areas of public policy in which a 'wait-and-see' approach might make sense—but climate change is not one of them. Because the accumulation of greenhouse gases is cumulative and irreversible, policy errors cannot be readily corrected. Once CO_2e emissions have reached, say, 750 ppm, future generations will not enjoy the option of expressing a preference for a world that stabilized at 450 ppm. Waiting to see whether the collapse of the West Antarctic ice sheet produces catastrophic outcomes is a one-way option: ice sheets cannot be reconnected to the bottom of the sea. The irreversibility of climate change places a high premium on the application of the precautionary principle. And the potential for genuinely catastrophic outcomes in an area marked by large areas of uncertainty makes the use of marginal analysis a restrictive framework for the formulation of

In dealing with national defence and protection against terrorism, governments do not refuse to put in place investments today because they are uncertain about the future benefits of those investments, or the precise nature of future risks

The costs of delayed mitigation will not be equally spread across countries and people

responses to the challenge of climate change mitigation. To put it differently: a small probability of an infinite loss can still represent a very big risk.

Beyond one world—why distribution matters

There has also been a debate on the second aspect of the discount rate. How should we weight the value of an extra dollar of consumption in the future if the overall amount of consumption is different from today's? Most people who would accord the same ethical weight to future generations would agree that, if those generations were going to be more prosperous, an increase in their consumption should be worth less than it is today. As income increases over time, the question arises as to the value of an additional dollar. How much we discount increasing consumption in the future depends on social preference: the value attached to the additional dollar. The critics of the Stern review have argued that its choice of parameter was too low, leading in turn to what is, in their eyes, an unrealistically low overall discount rate. The issues relating to this part of the debate are different from those relating to pure time preference and involve projected growth scenarios under conditions of great uncertainty.

If the world were a single country with an ethical concern for the future of its citizens, it should be investing heavily in catastrophic risk insurance through climate change mitigation. In the real world, the costs of delayed mitigation will not be equally spread across countries and people. The social and economic impacts of climate change will fall far more heavily on the poorest countries and their most vulnerable citizens. Distributional concerns linked to human development greatly reinforce the case for urgent action. In fact, these concerns represent one of the most critical parts of that case. This point is widely ignored by those arguing about discount rates in 'one world' models.

Global cost–benefit analysis without distribution weights can obscure the issues in thinking about climate change. Small impacts on the economies of rich countries (or rich people) register more strongly on the cost–benefit balance sheet precisely because they are richer. The point can be illustrated by a simple example. If the 2.6 billion poorest people in the world saw their incomes cut by 20 percent, per capita world GDP would fall by less than 1 percent. Similarly, if climate change led to a drought that halved the income of the poorest 28 million people in Ethiopia, it would barely register on the global balance sheet: world GDP would fall by just 0.003 percent. There are also problems in what cost–benefit analysis does not measure. The value that we attach to things which are intrinsically important are not easily captured by market prices (box 1.5).

Distributional imperatives are often overlooked in the case for action on climate change mitigation. As with the wider debate on discounting, the weighting of consumption gains and losses for people and countries with different levels of income must be explicitly considered. There is, however, a key difference between the distribution issues relating to intergeneration distribution and those relating to distribution between current populations. In the former, the case for ambitious mitigation rests on the need to insure against uncertain but potentially catastrophic risk. In the latter case of distribution of income in our lifetimes, it rests in the 'certain' costs of climate change for the livelihoods of the poorest people in the world.[95]

Concern for distributional outcomes between countries and people at very different levels of development is not restricted to mitigation. Mitigation today will create a steady flow of human development benefits that strengthen in the second half of the 21st Century. In the absence of urgent mitigation, poverty reduction efforts will suffer and many millions of people will face catastrophic outcomes. Mass displacement due to flooding in countries like Bangladesh and mass hunger linked to drought in sub-Saharan Africa are two examples.

However, there is no neat dividing line between present and future. Climate change is already impacting on the lives of the poor and the world is committed to further climate change irrespective of mitigation efforts.

What this means is that mitigation alone will not provide a safeguard against adverse distributional outcomes linked to climate change—and that, for the first half of the 21st Century, adaptation to climate change must be a priority, alongside ambitious mitigation efforts.

Mobilizing public action

Through the work of the IPCC and others, climate science has improved our understanding of global warming. Debates on the economics of climate change have helped to identify choices over resource allocation. In the end though, it is public concern that will drive policy change.

Public opinion—a force for change

Public opinion matters at many levels. An informed public understanding of why climate change is such an urgent priority can create the political space for governments to introduce radical energy reforms. As in many other areas, public scrutiny of government policies is also critical. In the absence of scrutiny, there is a danger that high-sounding declarations of intent will substitute for meaningful policy action—a perennial problem with G8 commitments on aid to developing countries. Climate change poses a distinctive challenge because, perhaps more than in any other sphere of public policy, the reform process has to be sustained over a long time-horizon.

Powerful new coalitions for change are emerging. In the United States, the Climate Change Coalition has brought together non-government organizations (NGOs), business leaders and bipartisan research institutions. Across Europe, NGOs and church-based groups are building powerful campaigns for urgent action. 'Stop Climate Chaos' has become a statement of intent and a rallying point for mobilization. At an international level, the Global Climate Campaign is building a network that mobilizes across national borders, bringing pressure to bear on governments before,

Box 1.5 Cost–benefit analysis and climate change

Much of the debate over the case for and against urgent mitigation has been conducted in terms of cost–benefit analysis. Important issues have been raised. At the same time, the limitations of cost–benefit approaches have to be acknowledged. The framework is essential as an aide to rational decision making. But it has severe limitations in the context of climate change analysis and cannot by itself resolve fundamental ethical questions.

One of the difficulties with the application of cost–benefit analysis to climate change is the time-horizon. Any cost–benefit analysis is a study in uncertainty. Applied to climate change mitigation, the range of uncertainty is very large. Projecting costs and benefits over a 10- or 20-year period can be challenging even for simple investment projects such as building a road. Projecting them over 100 years and more is a largely speculative exercise. As one commentator puts it: "Trying to forecast costs and benefits of climate change scenarios a hundred years from now is more the art of inspired guesstimating by analogy than a science."

The more fundamental problem concerns what is being measured. Changes in GDP provide a yardstick for measuring an important aspect of the economic health of nations. Even here there are limitations. National income accounts record changes in wealth and the depreciation of the capital stock used in its creation. They do not capture the costs of environmental damage or the depreciation of ecological assets such as forests or water resources. Applied to climate change, the wealth generated through energy use shows up in national income, the damage associated with the depletion of the Earth's carbon sinks does not.

Abraham Maslow, the great psychologist, once said: "If the only tool you have is a hammer, every problem begins to look like a nail." In the same way, if the only tool used to measure cost is a market price, things that lack a price tag—the survival of species, a clean river, standing forests, wilderness—might look like they have no value. Items not in the balance sheet can become invisible, even though they have great intrinsic value for present and future generations. There are some things that, once lost, no amount of money can bring back. And there are some things that do not lend themselves to market pricing. For these things asking questions just through cost–benefit analysis can produce the wrong answers.

Climate change touches in a fundamental way on the relationship between people and ecological systems. Oscar Wilde once defined a cynic as "someone who knows the price of everything and the value of nothing". Many of the impacts that will come with unmitigated climate change will touch upon aspects of human life and the environment that are intrinsically valuable—and that cannot be reduced to the economics of the ledger sheet. That, ultimately, is why investment decisions on climate change mitigation cannot be treated in the same way as investment decisions (or discount rates) applied to cars, industrial machines or dishwashers.

Source*:* Broome 2006b; Monbiot 2006; Singer 2002; Weitzman 2007.

For all the progress that has been achieved, the battle for public hearts and minds is not yet won

during and after high-level intergovernmental meetings. As little as five years ago, most large multinational companies were either indifferent or hostile to advocacy on climate change. Now an increasing number are pressing for action and calling for clear government signals to support mitigation. Many business leaders have realized that current trends are unsustainable and that they need to steer their investment decisions in a more sustainable direction.

Throughout history public campaigns have been a formidable force for change. From the abolition of slavery, through struggles for democracy, civil rights, gender equity and human rights, to the *Make Poverty History* campaign, public mobilization has created new opportunities for human development. The specific challenge facing campaigners on climate change is rooted in the nature of the problem. Time is running out, failure will lead to irreversible setbacks in human development, and policy change has to be sustained across many countries over a long period of time. There is no 'quick fix' scenario.

Opinion surveys tell a worrying story

For all the progress that has been achieved, the battle for public hearts and minds is not yet won. Assessing the state of that battle is difficult. Yet opinion surveys tell a worrying story—especially in the world's richest nations.

Climate change now figures prominently in public debates across the developed world. Media coverage has climbed to unprecedented levels. The film *An Inconvenient Truth* has reached an audience of millions. Successive reports—the Stern review being an outstanding example—have narrowed the space between popular understanding and rigorous economic analysis. The planet health warnings set out by the IPCC provide a clear basis for understanding the evidence on climate change. In the face of all of this, public attitudes continue to be dominated by a mindset that combines apathy and pessimism.

Headline numbers from recent surveys demonstrate the point. One major cross-country survey found that people in the developed world see climate change as a far less pressing threat than people in the developing world. For example, only 22 percent of Britons saw climate change as "one of the biggest issues" facing the world, compared with almost one-half in China and two-thirds in India. Developing countries dominated the ranking for countries whose citizens see climate change as the world's most worrying concern, with Brazil, China and Mexico topping the league table. The same survey found a far higher level of fatalism in rich countries, with a high level of scepticism about the prospects for avoiding climate change.[96]

Detailed national level surveys confirm these broad global findings. In the United States, climate change mitigation is now a subject of intense debate in Congress. However, the current state of public opinion does not provide a secure foundation for urgent action:

- Roughly four in ten Americans believe that human activity is responsible for global warming, but just as many believe that warming can be traced to natural patterns in the Earth's climate systems alone (21 percent) or that there is no evidence of global warming (20 percent).[97]
- While 41 percent of Americans see climate change as a "serious problem", 33 percent see it as only "somewhat serious" and 24 percent as "not serious". Only 19 percent expressed a great deal of personal concern—a far lower level than in other G8 countries and dramatically lower than in many developing countries.[98]
- Concern remains divided along party-political lines. Democrat voters register higher levels of concern than Republican voters, though neither locates climate change near the top of their list of priorities. On a ranking scale of 19 electoral issues, climate change registered 13th for Democrats and 19th for Republicans.
- Moderate levels of public concern are linked to perceptions of where risks and vulnerabilities are located. In a ranking of public concerns, only 13 percent of people covered were most concerned about impacts on their family or community, while half saw the most immediate impacts as affecting people in other countries, or nature.[99]

Caution has to be exercised in interpreting opinion survey evidence. Public opinion is not static and it may be changing. There is some positive news. Some 90 percent of Americans who have heard of global warming think that the country should reduce its greenhouse gas emissions, regardless of what other countries do.[100] Even so, if "all politics is local", then current public risk assessments are unlikely to provide a powerful political impetus. Climate change is still perceived overwhelmingly as a moderate and distant risk that will primarily impact people and places far away in space and time.[101]

Evidence that European opinion is far ahead of American opinion is not corroborated by opinion survey evidence. More than eight in every ten European Union citizens are aware that the way they consume and produce energy has a negative impact on climate.[102] Yet only half say that they are "to some degree concerned"—a far higher share express concern about the need for Europe to have greater diversity in energy supply.

In some European countries, public attitudes are marked by an extraordinary degree of pessimism. For example, in France, Germany and the United Kingdom the share of people agreeing with the statement that "we will stop climate change" ranges from 5 to 11 percent. Alarmingly, four in every ten people in Germany thought that it was not even worth trying to do anything, most of them on the grounds that nothing can be done.[103] All of this suggests a strong case for a greater emphasis on public education and campaigning.

The evidence from opinion surveys is worrying at several levels. It raises questions first of all about the understanding of people in rich nations about the consequences of their actions. If the public had a clearer understanding of the consequences of their actions for future generations, and for vulnerable people in developing countries, the imperative to act might be expected to register far more strongly. The fact that so many people see climate change as an intractable problem is another barrier to action because it creates a sense of powerlessness.

The role of the media

The media have a critical role to play in informing and changing public opinion. Apart from their role in scrutinizing government actions and holding policymakers to account, the media are the main source of information for the general public on climate change science. Given the immense importance of the issues at stake for people and planet, this is a role that carries great responsibilities.

The development of new technologies and globalized networks has enhanced the power of the media across the world. No government in a democracy can ignore the media. But power and responsibility have not always gone together. Speaking in 1998, Carl Bernstein said: "The reality is that the media are probably the most powerful of all our institutions today and they, or rather we [journalists], too often are squandering our power and ignoring our obligations."[104] That observation has a powerful resonance for the debate on climate change.

There are very large variations in the way that the media within and across countries have responded to climate change. Many journalists and many media organs have performed an extraordinary service in keeping public debates alive and deepening knowledge. However, the flip side has to be acknowledged. Until recently, the principle of 'editorial balance' has been applied in ways that have served to hold back informed debate. One study in the United States[105] found that the balance norm resulted in over half of articles in the country's most prestigious newspapers between 1990 and 2002 giving equal weight to the findings of the IPCC and of the climate science community, and the views of climate sceptics—many of them funded by vested interest groups. Continued confusion in public opinion is one consequence.[106]

Editorial balance is a laudable and essential objective in any free press. But balance between what? If there is a strong and overwhelming 'majority' view among the world's top scientists dealing with climate change, citizens have a right to expect to be informed about that view. Of course, they also have a right to be informed about minority views that do not reflect a scientific consensus. However, informed judgement

The media have a critical role to play in informing and changing public opinion

Dangerous climate change is a predictable crisis that comes with an opportunity

is not helped when editorial selection treats the two views as equivalent.

Media coverage of climate change has suffered from wider problems. Many of the issues that have to be addressed are enormously complex and inherently difficult to communicate. Some media reporting has clouded public understanding. For example, there has been a far stronger focus on catastrophic risk, than on more immediate human development threats—and in many cases the two dimensions are confused.

Over the past two years the quantity of climate change coverage has increased and the quality has improved. But in some areas media treatment continues to hold back informed debate. Sharp peaks in attention during weather-related disasters or around the launch of key reports are often followed by lengthy troughs in coverage. The tendency to focus on emergencies today and apocalyptic future events obscures an important fact: that the most damaging medium-term effects of climate change will take the form of gradually intensifying pressures on highly vulnerable people. Meanwhile, the responsibility of people and governments in rich countries for these pressures is a heavily under-represented theme. One consequence is that public awareness of the importance of support for adaptation measures to build resilience remains limited—as does international development assistance for adaptation.

Conclusion

The science of climate change has established a clear and reasonable target for international action. That target is a threshold for average temperature increases of 2°C. The Stern review has provided a powerful economic rationale for action. The proposition that the battle against climate change is affordable and winnable is one that has achieved powerful traction with policymakers.

The argument for long-run insurance against catastrophic risk and the human development imperative provide powerful rationales for action. Mitigation of climate change poses real financial, technological and political challenges. But it also asks profound moral and ethical questions of our generation. In the face of clear evidence that inaction will hurt millions of people and consign them to lives of poverty and vulnerability, can we justify inaction? No civilized community adhering to even the most rudimentary ethical standards would answer that question in the affirmative, especially one that lacked neither the technology nor the financial resources to act decisively.

Dangerous climate change is a predictable crisis that comes with an opportunity. That opportunity is provided by negotiations on the Kyoto Protocol. Under a revitalized post-2012 multilateral framework, the Protocol could provide a focal point for deep cuts in emissions, allied to a plan of action on adaptation that deals with the consequences of past emissions.

Appendix table 1.1 Measuring the global carbon footprint—selected countries and regions

Top 30 CO_2 emitters	Carbon dioxide emissions[a]: Total emissions ($Mt\ CO_2$) 1990	Total emissions 2004	Growth rate (%) 1990–2004	Share of world total (%) 1990	Share of world total (%) 2004	Population share (%) 2004	CO_2 emissions per capita ($t\ CO_2$) 1990	CO_2 emissions per capita 2004	CO_2 emissions or sequestration from forests[b] ($Mt\ CO_2$ / year) 1990–2005
1 United States	4,818	6,046	25	21.2	20.9	4.6	19.3	20.6	-500
2 China [c]	2,399	5,007	109	10.6	17.3	20.0	2.1	3.8	-335
3 Russian Federation	1,984 [d]	1,524	-23 [d]	8.7 [d]	5.3	2.2	13.4 [d]	10.6	72
4 India	682	1,342	97	3.0	4.6	17.1	0.8	1.2	-41
5 Japan	1,071	1,257	17	4.7	4.3	2.0	8.7	9.9	-118
6 Germany	980	808	-18	4.3	2.8	1.3	12.3	9.8	-75
7 Canada	416	639	54	1.8	2.2	0.5	15.0	20.0	..
8 United Kingdom	579	587	1	2.6	2.0	0.9	10.0	9.8	-4
9 Korea (Republic of)	241	465	93	1.1	1.6	0.7	5.6	9.7	-32
10 Italy	390	450	15	1.7	1.6	0.9	6.9	7.8	-52
11 Mexico	413	438	6	1.8	1.5	1.6	5.0	4.2	..
12 South Africa	332	437	32	1.5	1.5	0.7	9.1	9.8	(.)
13 Iran (Islamic Republic of)	218	433	99	1.0	1.5	1.1	4.0	6.4	-2
14 Indonesia	214	378	77	0.9	1.3	3.4	1.2	1.7	2,271
15 France	364	373	3	1.6	1.3	0.9	6.4	6.0	-44
16 Brazil	210	332	58	0.9	1.1	2.8	1.4	1.8	1,111
17 Spain	212	330	56	0.9	1.1	0.7	5.5	7.6	-28
18 Ukraine	600 [d]	330	-45 [d]	2.6 [d]	1.1	0.7	11.5 [d]	7.0	-60
19 Australia	278	327	17	1.2	1.1	0.3	16.3	16.2	..
20 Saudi Arabia	255	308	21	1.1	1.1	0.4	15.9	13.6	(.)
21 Poland	348	307	-12	1.5	1.1	0.6	9.1	8.0	-44
22 Thailand	96	268	180	0.4	0.9	1.0	1.7	4.2	18
23 Turkey	146	226	55	0.6	0.8	1.1	2.6	3.2	-18
24 Kazakhstan	259 [d]	200	-23 [d]	1.1 [d]	0.7	0.2	15.7 [d]	13.3	(.)
25 Algeria	77	194	152	0.3	0.7	0.5	3.0	5.5	-6
26 Malaysia	55	177	221	0.2	0.6	0.4	3.0	7.5	3
27 Venezuela (Bolivarian Republic of)	117	173	47	0.5	0.6	0.4	6.0	6.6	..
28 Egypt	75	158	110	0.3	0.5	1.1	1.5	2.3	-1
29 United Arab Emirates	55	149	173	0.2	0.5	0.1	27.2	34.1	-1
30 Netherlands	141	142	1	0.6	0.5	0.2	9.4	8.7	-1
World aggregates									
OECD [e]	11,205	13,319	19	49	46	18	10.8	11.5	-1,000
Central & Eastern Europe & CIS	4,182	3,168	-24	18	11	6	10.3	7.9	-166
Developing countries	6,833	12,303	80	30	42	79	1.7	2.4	5,092
East Asia and the Pacific	3,414	6,682	96	15	23	30	2.1	3.5	2,294
South Asia	991	1,955	97	4	7	24	0.8	1.3	-49
Latin America & the Caribbean	1,088	1,423	31	5	5	8	2.5	2.6	1,667
Arab States	734	1,348	84	3	5	5	3.3	4.5	44
Sub-Saharan Africa	456	663	45	2	2	11	1.0	1.0	1,154
Least developed countries	74	146	97	(.)	1	11	0.2	0.2	1,098
High human development	14,495	16,616	15	64	57	25	9.8	10.1	90
Medium human development	5,946	10,215	72	26	35	64	1.8	2.5	3,027
Low human development	78	162	108	(.)	1	8	0.3	0.3	858
High income	10,572	12,975	23	47	45	15	12.1	13.3	-937
Middle income	8,971	12,163	36	40	42	47	3.4	4.0	3,693
Low income	1,325	2,084	57	6	7	37	0.8	0.9	1,275
World	22,703 [f]	28,983 [f]	28	100 [f]	100 [f]	100	4.3	4.5	4,038

NOTES

a Data refer to carbon dioxide emissions stemming from the consumption of solid, liquid and gaseous fossil fuels and from gas flaring and production of cement.

b Data refer only to living biomass—above and below ground, carbon in deadwood, soil and litter are not included. Refer to annual average net emissions or sequestration due to changes in carbon stock of forest biomass. A positive number suggests carbon emissions while a negative number suggests carbon sequestration.

c CO_2 emissions for China do not include emissions for Taiwan, Province of China, which were 124 $Mt\ CO_2$ in 1990 and 241 $Mt\ CO_2$ in 2004.

d Data refer to 1992 and growth rate values refer to the 1992–2004 period .

e OECD as a region includes the following countries that are also included in other subregions listed here: Czech Republic, Hungary, Mexico, Poland, Republic of Korea and Slovakia. Therefore, in some instances, the sum of individual regions may be greater than the world total.

f The world total includes carbon dioxide emissions not included in national totals, such as those from bunker fuels and oxidation of non-fuel hydrocarbon products (e.g., asphalt), and emissions by countries not shown in the main indicator tables. These emissions amount to approximately 5% of the world total.

Source: Indicator Table 24.