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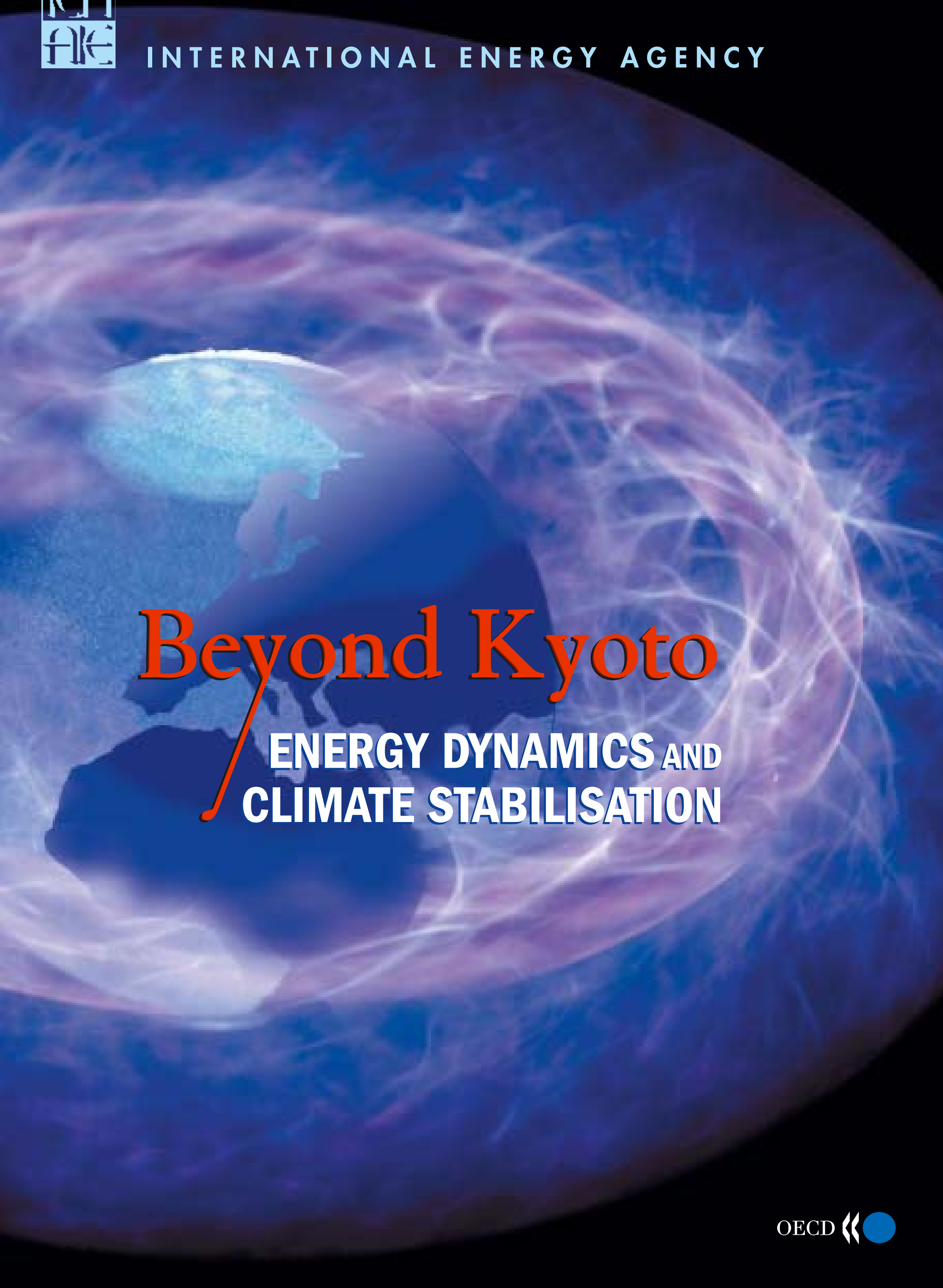

Beyond Kyoto

ENERGY DYNAMICS AND CLIMATE STABILISATION

OECD

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INTERNATIONAL ENERGY AGENCY

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The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-six* of the OECD's thirty Member countries. The basic aims of the IEA are:

- to maintain and improve systems for coping with oil supply disruptions;
- to promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations;
- to operate a permanent information system on the international oil market;
- to improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use;
- to assist in the integration of environmental and energy policies.

** IEA Member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, the Republic of Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the IEA.*

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), the Republic of Korea (12th December 1996) and Slovakia (28th September 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

FOREWORD

Climate change remains an important issue for all governments around the world. Efforts to reduce its future impacts will have important consequences for the energy sector.

Actions undertaken thus far are only first steps. Both the shortcomings and the achievements of current international agreements provide useful insights into what shape future agreements might take. Two questions, in particular, require attention:

- How to cope with the uncertainties that make it difficult to take firm decisions for the long term, even though near-term action makes sense only in a longer-term perspective; and
- How to create a global solution to this global problem in a world in which countries are at widely differing levels of development.

This book surveys the science and the energy policy choices of climate change. It assesses current commitments and technical change. It discusses burden-sharing and possible forms of future commitments, drawing on work undertaken both with the IEA's Standing Group on Long-Term Co-operation and with the Annex I Expert Group to the UNFCCC.

This book clearly identifies the relevant questions – and proposes solutions. Without prejudging countries' positions, it seeks to clarify the options. We look forward to continuing to provide a sound analytical foundation to the debate.

Robert Priddle,
Executive Director

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INTRODUCTION

Climate change is one of the most difficult challenges facing the world today. Preventing – or even significantly limiting – climate change will necessitate profound changes in the way we produce, distribute and consume energy.

Burning fossil fuels such as coal, oil and gas provides about three-quarters of the world's energy. However, when these same fuels are burned, they emit gases (the so-called "greenhouse gases") that are now recognised as being responsible for climate change. These fuels are ubiquitous. Fossil energy has fuelled industrial development, and continues to fuel the global economy. We each use energy in many forms every day: heating, cooking, lighting, TV, commuting, working, shopping.... Almost every activity requires energy. Beyond daily individual use, modern societies use even more energy for agriculture, industrial processes and freight transport. The primary greenhouse gas emitted through fuel combustion is carbon dioxide (CO_2). Land-use and land-use changes, notably deforestation, also involve emissions of carbon dioxide. Other greenhouse gases are also emitted during energy use, the most significant of which are methane (CH_4) and nitrous oxide (N_2O).

Improved global understanding of the potential consequences of climate change has led the international community to begin to address the problem. Following a series of scientific meetings during the 1980s where climate change was identified as a potential risk, in 1988 the World Meteorological Organisation and the United Nations Environment Programme established the Intergovernmental Panel on Climate Change (IPCC) to assess the state of understanding of the issue. In 1990, the United Nations General Assembly agreed to establish an Intergovernmental Negotiating Committee to develop an international framework for addressing climate change. The Committee completed its work in 1992, and in Rio de Janeiro, at the 1992 Earth Summit, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted by more than one hundred governments.

The Convention's ultimate objective is to stabilise greenhouse gas concentrations in the atmosphere. However, it provides only limited guidance as to how to accomplish this goal – and by 1997, the nations of the world had decided on a next step. In December 1997, at Kyoto in Japan, a Protocol to the UNFCCC was adopted that committed industrialised countries to individually and collectively limit their emissions, with specific national targets adopted for six of the key greenhouse gases. Further details on how to interpret the Protocol have been ironed out since Kyoto, facilitating its entry into force.

However, even with ratification of the Kyoto Protocol, commitments so far agreed only constitute a first step on a long road ahead. Achieving stabilisation of greenhouse gas atmospheric concentrations will ultimately require much deeper cuts in global emissions than those agreed in Kyoto. And cuts cannot be limited to emissions of industrial countries; to solve the problem, cuts must be made by all countries in the world. The difficulty in meeting this global obligation is underscored by the recent announcement by the United States regarding its intention not to participate in the Kyoto agreement.

The climate change problem is unique in at least three important ways: it is global in nature, it has an unusually long-term character, and both climate change itself and the effects of policies to mitigate it remain inadequately understood.

The global nature of the climate problem is well known. Emissions of greenhouse gases mix rapidly in the atmosphere – within weeks, they are spread around the globe. Furthermore, all countries release emissions; even the single largest (the United States) accounts for less than a quarter of the global total. Thus, no single country can address climate change alone. Even all the industrial countries, acting together, would only be able to forestall climate change – they could not stop it unless the developing nations also become engaged. It is thus clear that international co-operation is required. The need for such co-operation is heightened when issues of capacity to act are considered: industrial countries currently possess more advanced technical capacity and the financial resources needed to combat the problem. While developing nations have relatively low per capita emissions, few have the technical or institutional ability to work toward climate mitigation without international assistance.

Climate change is also a long-term issue. Greenhouse gases released into the atmosphere today will linger for decades (in the case of short-lived gases like methane) to hundreds of years (for carbon dioxide), to thousands of years (for long-lived gases like perfluorocarbons). Furthermore, the changes induced by these emissions are slow to manifest: the IPCC speaks of impacts such as global average temperature increases and sea level rise that will be progressive, taking decades or even centuries to show their full effects. Finally, mitigating climate change will require sustained efforts – that need to begin immediately but which will only produce results after a long time lag. The technical challenge for economic analysis is great. The usual analytic tools suggest that long-term damage has only a limited present value. However, the long-term nature of climate change presents an even more serious problem for the policy community: for most elected officials, political horizons are measured in years rather than in decades or centuries.

Knowledge gaps are also important: the exact rate and extent of climate change remain unknown, as does its likely regional or local consequences. Our still limited understanding of how the climate system operates, combined with the long-term nature of climate change, make it difficult for the scientific community to offer policy-makers strong recommendations on how aggressive their action needs to be to mitigate the problem. In this area, for example, the IPCC has consistently been unable (and unwilling) to make a recommendation concerning the appropriate level and timeframe for stabilising atmospheric greenhouse gas concentrations. Clearly, these questions require not only a scientific response, but also one based on society's values, including its attitudes to risk; ultimately, they remain political decisions.

The Convention on Climate Change essentially represents the world community's first effort to synthesise a response to the climate change problem. Its ultimate objective is relatively clear in intent – although not adequate for operational detail:

"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous

anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Thus, for example, the Convention did not specify the level or the timeframe. The Convention did, however, set a political direction for the near term. It committed industrialised country Parties to seek to return emissions to 1990 levels by 2000. The Kyoto Protocol committed countries to additional steps; under its binding provisions, industrial countries undertook, in most cases, to reduce emissions below 1990 levels by 2012. However, neither agreement provided an indication of how these near-term actions would fit into the longer-term goal – or even explicitly defined what that longer-term objective should be.

How might such decisions be taken – and what are the critical inputs into making them? To arrive at a fully "informed" decision, two completely different elements are required: information on the consequences of climate change at various concentration levels, and an assessment of the costs and benefits of mitigation and adaptation and residual damage at each level. This is not to say that such decisions could only be taken in the light of a full cost benefit analysis: such an analysis seems quite difficult, if not impossible, to perform. However, it is clear that costs cannot be excluded from the decision on how "dangerous" a greenhouse gas concentration level might be. Otherwise, the decision would be quite simple: since any rise in concentration increases the dangers of climate change, the only logical choice would be to stabilise concentrations at current levels – or even return to pre-industrial levels!

Unfortunately, such a decision appears impossible (at least in the short-term): it implies immediately halving global emissions and thus radically altering (and probably cutting) energy use. No matter how this burden is shared amongst countries, it is not an option that can be contemplated at any feasible price. Clearly, the UNFCCC negotiators recognised this. Their text indicates that mitigation must be rapid enough to avoid climate change risks, but also slow enough to avoid the economic disruption that could arise from energy shortages or the huge costs incurred in moving too rapidly from a fossil-fuel based energy system to a carbon-free energy system.

To assess the scope of the cost problem, we must look at some of the technology paths and potentials. For example, we would like to know what emission reductions would cost today, or in ten or even fifty years. Today's technological choices give us some insights. Nuclear power and renewable energy sources (such as hydro, wind and solar) could provide sufficient energy to the global economy with little or no carbon dioxide emissions. Fossil fuel power generation, if coupled with technologies that capture and sequester carbon from the waste stream, could also serve. However, while these technologies exist today, they are not competitive in most commercial markets when compared to traditional fossil fuel alternatives. Future costs are uncertain and depend in part on efforts to invent and deploy new technologies. Technical change arises in part from focused R&D efforts and, perhaps even more, from entrepreneurs' efforts to penetrate competitive markets.

Unfortunately, it may be impossible to put off acting until all the information is in. Like the climate system, the energy sector and energy consuming trends are characterised by significant inertia. This inertia suggests that in the short-term, any major mitigation action might be rather costly. On the other hand, the nature of the system's inertia also suggests that early action is necessary to avoid becoming locked-in to carbon intensive technologies or consumption patterns, and to foster technical change and R&D efforts to provide more no-carbon or low-carbon energy sources at some point in the future. It is also clear that as time passes, if too little or no action is taken, the range of long-term possibilities will narrow and climate change risks will increase in an irreversible manner. Balancing the risks of climate change in the future against costs today is difficult. It is for these reasons that so little progress has yet been made on a firm recommendation on a specific concentration level.

Are there ways out of this dilemma?

One alternative might be to aim at the lowest possible GHG concentration levels, at the same time placing a cap on the price society would have to pay to meet this level. This price could be reviewed over time as willingness to pay evolves.

An advantage of this approach is its compatibility with the least-cost solutions advocated by economic theory, in particular, with the "cap-and-trade" regimes that allow emissions reductions to be made in locations where the lowest cost potential is available. These mechanisms have been elaborated in the Kyoto Protocol, and there is widespread support for their continued use in any future regime. Such support is likely to be critical as efforts are made to broaden the emission mitigation framework beyond the industrialised world, and to achieve success in mitigating climate change.

A fundamentally different approach to determining the appropriate level of mitigation effort is to focus on the areas where policy action could simultaneously fulfil non-climate domestic policy objectives while reducing greenhouse gas emissions. Removing energy subsidies, cleaning the air, or improving mass transit systems usually belong to this category. Developing policy initiatives – without specific climate targets – could be the focus of such an effort. This policy approach could be attractive for developed countries as well as for developing countries, which, though vulnerable to climate change, have more urgent priorities such as poverty eradication, education challenges, sanitation, health, indoor and local air quality, and access to energy services.

Policies to address these concerns could have so-called "ancillary benefits" – that is, domestic policies aimed at achieving sustainable development might offer some global climate benefits. However, while this approach may be politically acceptable, it does not seem likely to promote the kind of radical shift in the energy economy that is needed to decarbonise the system – and thus, in isolation, may not fully meet the goal of combating climate change.

Some middle ground could be found between these alternatives. For example, while developing countries have shown great reluctance to taking on binding emissions limitation commitments, they have shown a considerable and growing interest in participating in the Clean Development Mechanism – a project-based approach to the concept of emissions trading, and the only Kyoto Protocol mechanism intended to extend mitigation efforts beyond developed countries. The Clean Development Mechanism also offers a means to promote technology transfer and investments between industrialised and developing countries. Alternatives that can build on this promising political interest may provide a possible path to a global agreement, where all countries take on some form of commitment to reduce emissions, and ultimately, participate in a global regime. Such a regime would also necessitate all developed countries accepting sufficiently stringent commitments, which could be facilitated if concerns about uncertain costs were dealt with, as suggested in this book.

Yet another alternative exists: one based on technological improvement and widespread penetration of alternative energy options. In itself, the idea of technological change is consistent with the approaches described above. They seek to promote change through pricing carbon; as the price increases, market mechanisms provide incentives for carbon producers to reduce emissions. Technological change as well as behavioural changes can result. However, a more direct approach may also be considered to induce more rapid technological change. Direct incentives such as R&D subsidies, as well as market guarantees for new technologies or public-private technology partnerships may generate emissions savings directly. While economic theory suggests that such an approach would be less comprehensive and efficient than those involving pricing or cap-and-trade instruments, it may be more politically palatable – and thus, in some cases, more likely to succeed.

Ultimately, it seems likely that all of these approaches will be needed. Operating in the uncertain world of future emissions and future costs, governments and private sector decision-makers need to explore all options. As the IPCC has put it:

"Climate change decision-making is a sequential decision-making process under general uncertainty. (....) The literature suggests a step-by-step resolution aimed at stabilising greenhouse gas concentrations. This will also involve balancing the risks of either excessive or insufficient action. The relevant question is not 'what is the best course for the next 100 years' but rather 'what is the best course for the near term given the expected long-term climate change and accompanying uncertainties'".

A successful international mitigation framework for the longer term (including for the period following the first commitment period outlined in the Kyoto Protocol) could benefit from closer adherence to this perspective. It is not too early to start considering the alternatives. The review and analysis contained in this book aim to promote this debate.

CLIMATE CHANGE AND DECISION-MAKING

REALITY OF CLIMATE CHANGE

Climate change is not science fiction. It's real, it's happening now and it will be with us throughout this century.

For almost 15 years, the Intergovernmental Panel on Climate Change (IPCC), which brings together hundreds of leading scientists from around the world, has regularly assessed our understanding of climate change. In its Third Assessment Report (IPCC, 2001), which was endorsed by the most important academies of science around the world, the IPCC confirmed both the reality and the threatening nature of climate change.

Human activities have been and are changing the composition of the earth's atmosphere, thus modifying the energy balance between the sun, the earth and outer space. Increasing the so-called "greenhouse effect" warms the earth – and changes the climate. Gases that are very minor constituents of the atmosphere play an important role in shaping the climate. They allow sunlight to enter the atmosphere and heat both the earth's surface and the atmosphere, but they do not allow the heat emitted in response by the earth – as infrared radiation – to escape from the atmosphere. This is the so-called greenhouse effect. Due to this effect, the average temperature on the earth's surface is about 15°C; without this effect it would be –18°C. However, human activities are increasing the concentration of such gases in the atmosphere. Carbon dioxide (CO_2), the most important long-lived gas, has increased 31 per cent since 1750. The atmospheric concentrations of other gases have also increased (see Box 1). This will warm the earth's surface and trigger climate changes.

During this century, the global average surface temperature is projected to increase by between 1.4 and 5.8°C. The projected rate of warming is much higher than that of the 20th Century and is without precedent throughout at least the last 10,000 years. In order to appreciate the magnitude of this temperature increase, it should be compared to the global mean temperature difference of perhaps 5 to 6°C from the middle of the last Ice Age to the present interglacial era.

Consequences will be detrimental to ecosystems and human societies

There is likely to be a rise in the global sea level (projected to reach between 9 and 88 cm by the year 2100, which would cause flooding in low-lying areas and other damage); shifting of climatic zones towards the poles by between 150-550 km (putting climatic stress on forests, deserts, wetlands and other unmanaged ecosystems); and posing threats to food security and health.

Natural systems can be especially vulnerable to climate change because of their limited capacity to adapt. While some species may increase in abundance or range, climate change can bring about both the extinction of some of the more vulnerable species and the loss of biodiversity. The geographical extent of the damage or loss, and the number of ecosystems affected – such as coral reefs and atolls, mangroves, boreal and tropical forests, polar and alpine ecosystems, prairie wetlands and native grasslands – will increase with the magnitude and rate of climate change. Increasing fire, drought, pest infestation, invasion of species, storms and coral bleaching could all disrupt ecosystems.

Agriculture and forestry, water resources, fisheries and human health are just a few of the human systems that are sensitive to climate change. Some regions and sectors could initially benefit from minor changes to the climate (fewer cold spells and therefore less heating required in winter, for example), but these benefits are expected to diminish as climate changes intensify. In contrast, many identified adverse effects are expected to increase both in extent and severity with the degree of climate change.

Regional adverse effects are projected to predominate throughout the world, particularly in the tropics and subtropics. Climate change will increase threats to human health, particularly in lower-income populations. Projected changes in climate extremes could have severe consequences, and their impacts are expected to fall disproportionately on the poor. Many human settlements will face an increased risk of coastal flooding and erosion, and tens of millions of people living in deltas, in low-lying coastal areas, and on small islands will be in danger of displacement. Resources critical to island and coastal populations such as beaches, freshwater, fisheries, coral reefs and atolls, and wildlife habitat would also be vulnerable.

Overall, the impacts of climate change will fall disproportionately upon developing countries and poor people in all countries, thereby exacerbating inequities in health and access to adequate food, clean water, and other resources. In addition, poverty and other factors make it difficult for most developing countries to adapt to climate change. Potentially, the capacity to adapt can reduce the adverse effects of climate change and can often produce immediate ancillary benefits, but it will not prevent all damage.

Projected climate change during this century has the potential to lead to future large-scale and possibly irreversible changes. Examples include the slowing down of the ocean circulation, large reductions in the Greenland and West Antarctic ice sheets, accelerated global warming due to carbon cycle feedbacks in the terrestrial biosphere, and the release of terrestrial carbon from permafrost regions and methane from hydrates in coastal sediments. The likelihood of such changes is difficult to predict but probably very low; however, it increases with the rate, magnitude and duration of climate change.

Global mean surface temperature increases and rising sea levels from ocean thermal expansion are projected to continue for hundreds of years after the stabilisation of greenhouse gas concentrations, even at present levels, albeit at a slower pace. Ice sheets will continue to react to climate warming and contribute to rising sea levels for thousands of years after climate has been stabilised. Climate models indicate that local warming over Greenland is likely to be one to three times the global average. Some ice sheet models indicate that local warming of more than 3°C, if sustained for millennia, would lead to virtually a complete melting of the Greenland ice sheet with a resulting sea level rise of about seven metres.

However, the extent of global warming and its specific local impacts remain uncertain. We do not know exactly what changes will occur in precipitation patterns, what kinds of extreme weather events might follow, or, more

Box 1

Greenhouse gas concentrations have increased

The most abundant long-lived greenhouse gas, carbon dioxide, represents only 370 parts per million (ppm), or 0.037 per cent of the earth's atmosphere. The atmospheric concentration of carbon dioxide (CO_2) has increased by 31 per cent since 1750. The present CO_2 concentration is higher than it has ever been throughout the past 420,000 years, if not the past 20 million years. The current rate of increase is unprecedented – at least for the past 20,000 years. During the past twenty years, about three-quarters of the anthropogenic (man-made) emissions of CO_2 in the atmosphere resulted from the burning of fossil fuels (for energy purposes). The rest is predominantly due to changes in land-use, especially deforestation. Currently, the ocean and the land together are absorbing about half of the anthropogenic CO_2 emissions.

The increase in methane (CH_4) concentration since 1750 is approximately 150 per cent, and that of nitrous oxide (N_2O) 17 per cent. Slightly more than half of current CH_4 emissions are human induced (e.g., use of fossil fuels, cattle, rice growing and landfills), while carbon monoxide (CO) emissions, mainly from fossil fuels, have recently been identified as contributing to increasing concentrations of CH_4. Concentrations of man-made gases that deplete the stratospheric ozone layer (CFCs) have been roughly stabilised, but although their substitutes and a few other synthetic gases (perfluorocarbons and sulphur hexafluoride – PFCs and SF_6) do not deplete the ozone layer, they are nevertheless greenhouse gases and their concentrations are increasing.

Water vapour, while not emitted in any significant quantity through human activity, is the most abundant greenhouse gas. It is short-lived in the atmosphere, and its concentration mainly depends on temperature. Water vapour provides a strong positive feedback to the greenhouse effect, approximately doubling warming from what it would be from fixed water vapour content. Water vapour also amplifies other feedbacks, such as that of clouds, which could be positive or negative.

generally, what the regional consequences of climate change will be. To provide an example of our uncertainty, we only have to consider the range of warming predicted with a doubling of greenhouse gas concentrations (from 275 parts per million in the pre-industrial era, to 550 parts per million). The range is estimated by the IPCC to be from 1.5 to 4.5°C.

It is in face of this uncertain level – but certain damage – that we need to consider mitigation options. To do so, some additional information on the dynamics of the earth's system is necessary.

STABILISATION DYNAMICS

The United Nations Framework Convention on Climate Change (UNFCCC) – which is discussed in more detail in Chapter 3 – has as its main objective "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". Such a level "should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

An important point arising from the relatively long "lifetime"[1] of CO_2 in the atmosphere is that the stabilisation of CO_2 emissions at near-current levels would not lead to the stabilisation of CO_2 atmospheric concentrations. However, the stabilisation of emissions of shorter-lived greenhouse gases that have atmospheric sinks, such as CH_4 or N_2O, would lead, within decades, to the stabilisation of their concentrations. In contrast to methane and nitrous oxide, stabilising carbon dioxide concentration – at any level – requires the eventual reduction of net global CO_2 emissions to a fraction of their current levels.

How small that fraction should be remains uncertain. A balance between emissions and system uptake of CO_2 might be reached when emissions are reduced to approximately half of current levels. However, as the long-term

1 The lifetime of a gas, or its residence time in the atmosphere, is determined by its chemical composition and its reaction with other elements of the climate system. For carbon dioxide, there is no single agreed lifetime; many simplified models use a lifetime of approximately 100 years. For methane, the lifetime is approximately 12 years, while for some very long-lived gases such as perfluoromethane, the lifetime is more than 50,000 years.

release of CO_2 from the ocean into the atmosphere continues, to achieve the stabilisation of atmospheric concentrations would require even greater reductions. Thus, over the span of the next few centuries, emissions will need to decline to the level of persistent natural land and ocean sinks. This amount[2] is expected to be less than 0.2 GtC/y – a small fraction of current estimate levels of circa 8 GtC/y.

A key determinant in the final level of concentrations is the timing of reductions: the lower the chosen level for stabilisation, the sooner the reduction in global net CO_2 emissions needs to begin. More specifically, stabilising CO_2 atmospheric concentrations at levels of 450 ppm would require global anthropogenic CO_2 emissions to drop below 1990 levels within a few decades. To limit concentrations to 550 ppm would require global emissions to peak by 2030, and drop to below 1990 levels before 2100, and to limit concentrations below 1000 ppm would require reductions below 1990 levels within about two centuries. In each case, once 1990 levels had been reached, emissions would need to decrease steadily thereafter to ensure that concentrations had indeed been stabilised.

Table 1 shows projected total emissions for this century, approximate years in which global emissions would peak, and approximate years in which global emissions would fall below 1990 levels in order to achieve the stabilisation of atmospheric CO_2 concentrations at different levels from 450 ppm to 1000 ppm. These figures show some uncertainty reflecting the limited knowledge and understanding of the actual carbon cycle involving the atmospheric reservoir and uptakes and releases by land and ocean sinks. This uncertainty is magnified when climate feedback is integrated, which is likely to reduce natural uptakes. However, the main reason for the range of possible accumulated CO_2 emissions for each stabilisation level is the natural decay of carbon dioxide in the atmosphere.

Clearly, different emission pathways could lead to the stabilisation of atmospheric concentrations at identical levels. Rapid early reductions followed by steady, low-level emissions could have the same result as

2 CO_2 emissions are often expressed by the weight of their carbon content as this allows tracking the carbon quantities in various forms within the carbon cycle. 1 GtC = 1 gigatonne of carbon = 1 billion tonnes of carbon = 1 PgC = 1 petagramme of carbon. There is 1 g of carbon in 44/12 g of carbon dioxide. Conversely, there is 12/44 g C in 1 g CO_2. Hence, current CO_2 emissions are circa 30 Gt per year.

Table 1

What Different Levels of CO_2 Stabilisation May Require

WRE CO_2 Stabilisation profiles (ppm)	Accumulated CO_2 emissions 2001 to 2100 (GtC)	Year in which global emissions peak	Year in which global emissions fall below 1990 level
450	365 – 735	2005 – 2015	<2000 – 2040
550	590 – 1135	2020 – 2030	2030 – 2100
650	735 – 1370	2030 – 2045	2055 – 2145
750	820 – 1500	2040 – 2060	2080 – 2180
1000	905 – 1620	2065 – 2090	2135 – 2270

Source: IPCC TAR Synthesis Report, Table 6.1.

limited reductions in the near-term, followed by rapid and greater reductions in the future. However, it is likely that different emission pathways would also impose different climate consequences. Different emission time paths yield different time paths of temperature change. Differences in climate change impacts might be larger if some – unknown – thresholds in the climate system or at ecosystem levels were exceeded. However, climate change is driven by atmospheric GHG concentrations – not annual emissions.

Table 2

Global Warming Potentials

Gas		Lifetime (y)	GWP 20 y	GWP 100 y	GWP 500 y
Carbon dioxide	CO_2		1	1	1
Methane	CH4	12	62	23	7
Nitrous oxide	N_2O	114	275	296	156
Hydrofluorocarbons		0.3 – 260	40 – 9400	12 – 12000	4 – 10000
Fully fluorinated species		2600 – 50000	5900 – 15100	5700 – 22200	8900 – 32400
Ethers		0.015 – 150	1 – 12900	1 – 14900	<<1 - 9200

Source: IPCC TAR Synthesis Report, Table 6.1.

Box 2

How greenhouse gases compare: radiative forcing and global warming potential

In order to measure the influence a factor has in altering the balance of incoming and outgoing energy in the earth's atmosphere, scientists use the radiative forcing concept. It is expressed in Watts per square metre (Wm^{-2}). Radiative forcing due to an increase of the well-mixed greenhouse gases (GHG) from 1750 to 2000 is estimated to be 2.43 Wm^{-2}: 1.46 Wm^{-2} from CO_2; 0.48 Wm^{-2} from CH_4; 0.34 Wm^{-2} from halocarbons; and 0.15 Wm^{-2} from N_2O.

The depletion of the stratospheric ozone layer is estimated to have caused a negative radiative forcing (-0.15 Wm^{-2}) – in other words, a cooling – but the total amount of ozone (O_3) in the atmosphere is estimated to have increased by 36 per cent since 1750, corresponding to a positive radiative forcing of 0.35 Wm^{-2}. This is due primarily to anthropogenic emissions of several O_3-forming gases such as nitrogen oxides (NO_x), carbon monoxide (CO) and hydrocarbons (HC), which primarily arise from burning fossil fuels for energy purposes.

Fossil fuels and biomass burning are also the main sources of anthropogenic aerosols that tend to cool the planet. Direct radiative forcing are estimated to be -0.4 Wm^{-2} for sulphate, -0.2 Wm^{-2} for biomass burning aerosols, -0.1 Wm^{-2} for fossil fuel organic carbon and +0.2 Wm^{-2} for fossil fuel black carbon aerosols. In addition, aerosols have an indirect radiative forcing through their effects on clouds, the magnitude of which is uncertain.

Two natural factors, solar variation and volcanic aerosols, also influence climate. Radiative forcing due to changes in solar irradiance since 1750 is estimated to be about +0.3Wm^{-2}. Stratospheric aerosols from volcanic eruptions lead to negative forcing, which lasts a few years.

Global warming potentials (GWPs, see Table 2) measure the relative global warming contribution due to atmospheric emission of a kg of a particular greenhouse gas compared to emission of a kg of carbon dioxide, integrated over a chosen time period. They take into account not only the radiative properties of the gases, but also the removal of the substance from the atmosphere. GWPs are approximations. Radiative forcing of one greenhouse gas depends not only on its own concentration but also on other GHG concentrations, as their optical properties may overlap.

Finally, for the most important GHGs, the absorption of infrared radiation does not vary linearly with their abundance, but more slowly. Each kg adds a little less to the forcing than the previous one. For example, the doubling of pre-industrial CO_2 concentration would add 4 Wm^{-2} to the radiative forcing, and every further doubling of CO_2 concentration would add an additional 4 Wm^{-2}. GWPs would thus evolve over time.

One of the relatively well-understood elements of the climate system is the different effect different gases have on climate change. Thus, for example, while carbon dioxide is the most prevalent gas emitted through human activities, it is the least potent in terms of its warming potential. The GWP concept (albeit an imperfect political compromise) allows flexibility in tackling global warming by allowing reductions in all man-made greenhouse gases rather than just CO_2 – therefore reducing the costs of near-term quantitative targets (see, for example, Burniaux, 2000). Unfortunately, comparing the effects of different gases through an index (called the Global Warming Potential or GWP) may not be accurate under all circumstances, and its validity is reduced as far as long-term stabilisation is concerned.

Global mean surface temperature increases and rising sea levels from ocean thermal expansion are projected to continue for hundreds of years after the stabilisation of greenhouse gas concentrations, even at present levels, albeit at a slower pace. Ice sheets will continue to react to climate warming and contribute to rising sea levels for thousands of years after climate has been stabilised. Climate models indicate that local warming over Greenland is likely to be one to three times the global average. Some ice sheet models indicate that local warming of larger than 3°C, if sustained for millennia, would lead to virtually a complete melting of the Greenland ice sheet with a resulting sea level rise of about seven metres.

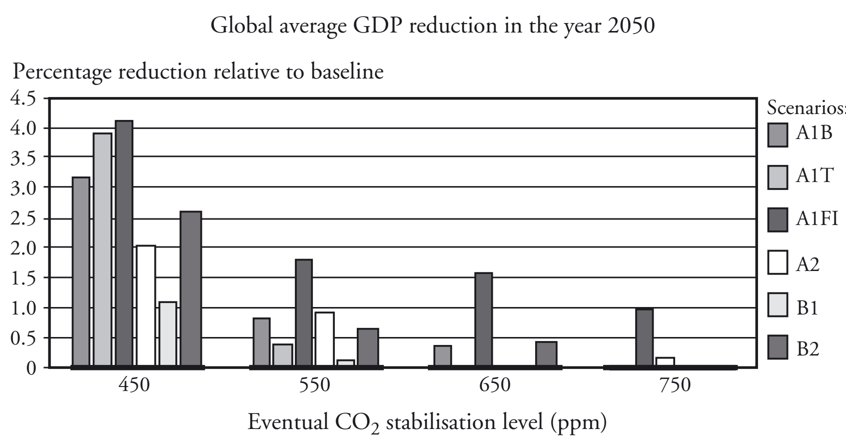
DECISION-MAKING UNDER UNCERTAINTY

Given the uncertainties surrounding both the earth's climate sensitivity (its reaction to a change in GHG concentrations)[3] and the availability and costs of present and future emission reductions, it is critical to identify a robust framework for decision-making. Such a framework should both facilitate decision-making for near-term decisions, and draw the necessary links between these near-term decisions and the long-term objective of the Convention.

Studies show that the costs of stabilising CO_2 concentrations in the atmosphere increase as the concentration stabilisation level declines. Different baselines can have a strong influence on absolute costs, as shown in Figure 1 (see also Box 3 in Chapter 2). While there is a moderate increase in costs when the target is decreased from a 750 to a 550 ppm concentration stabilisation level, there is a bigger increase in costs when it is decreased from 550 to 450 ppm – unless the emissions in the baseline scenario are very low, as shown in Figure 1. On the other hand, the IPCC

Figure 1

Indicative relationship in the year 2050 between GDP reduction and stabilisation level.



Source: IPCC, 2001. See Box 3 and Figure 5 for more information on the IPCC Special Report on Emission Scenarios (SRES)

3 Note the IPCC uses the term in a more precise way to define the long-term temperature change resulting from doubling pre-industrial CO_2 concentration.

provides evidence that detrimental climate impacts might increase more rapidly than GHG concentration levels. Impacts and risks associated with a 550-ppm stabilisation level might be significantly greater and more expensive than those associated with a 450-ppm stabilisation level.

Climate mitigation policies also have many unknown costs – and potential benefits. Uncertainties regarding benefits stem from uncertainties as to the earth's climate sensitivity, regional effects, valuation methods for future and/or non-market damage (for a discussion of these aspects, see e.g., Philibert, 1999; Neumayer, 1999 & 2001). Uncertainties relating to costs stem firstly, as is suggested in Figure 1, from uncertain business-as-usual emission trends that depend on uncertain economic growth and on possible changes in value and behaviour. They also result from uncertainties concerning not only the direct and indirect effects of policy instruments, but also the unpredictability of future relative prices of different energies, as well as the development and dissemination of low- or no-carbon energy technology. The wide range of cost estimates for achieving the modest targets of the Kyoto Protocol (see, e.g., Weyant & Hill, 1999) are a good illustration of the uncertainty about costs. This could be exacerbated in the future by rigorous commitments or alleviated by the experience gained from earlier emission reductions. It is not easy to determine which of these countervailing effects will dominate.

It is in this context that the IPCC observation that "*climate change decision making is essentially a sequential process under general uncertainty*" (IPCC, 2001) is particularly apt. Near-term decisions have to be taken while "desirable" levels of stabilisation remain indeterminate – and might remain so for decades. Decision-making processes have to deal with uncertainties including the risk of non-linear and/or irreversible changes; they must balance the risk between insufficient or excessive action. To do so, decision-makers must carefully consider the consequences (both environmental and economic), the likelihood of such consequences, and society's attitude towards risk. Such a sequential decision-making process is already enshrined in the UNFCCC, which requires regular reviews and assessments – followed by additional action, as needed, by the Conference of the Parties. In this context too, the Convention and its Protocol generally define the long-term goal (atmospheric concentration stabilisation), but only interim shorter-term targets (e.g., in the Convention, for a ten-year period, and in the Protocol for 15 years).

These uncertainties apply equally to emission pathways. Economic discounting (i.e., giving a low present value to long-term climate damage) and "autonomous" technical change tend to favour pathways with late emission reductions: it is worth waiting to make reductions because technical progress will make such reductions cheaper in the future. Delay also helps avoid premature lock-in to early versions of rapidly developing low-emission technologies. It allows a more natural – and cheaper – path in the retirement of capital stock, which is replaced at the end of its usable life instead of early, avoiding the high costs of stranded assets. However, the lack of clear signals for change in the short run might induce more inertia. Such inertia could subsequently prove very costly to reverse, a phenomenon known as the "lock-in" effect.

Conversely, an emphasis on "induced" technical change favours earlier reductions: early efforts will drive technical change (or push technical change in the direction of energy savings and lower-carbon energy techniques) and thus make further efforts cheaper. More rapid near-term action would also increase the range of choice possible in the ultimate stabilisation levels – the earlier the reduction, the more likely a lower final level could be achieved. This has indirect implications for both environmental and human risks, as well as potential costs associated with projected changes in climate. However, rapid changes in the short term may be extremely expensive due to the requirement to prematurely retire or modify capital stock.

It is difficult to choose between these paradigms – although it may ultimately prove unnecessary. In fact, the IPCC (2001, Synthesis Report) argues for a step-by-step resolution aimed at stabilising greenhouse gas concentrations. *"The relevant question is not 'what is the best course for the next 100 years', but rather 'what is the best course for the near term given the expected long-term climate change and accompanying uncertainties'".*

Let us consider what this would imply from a purely "scientific" viewpoint (the energy implications of the choices will be discussed in Chapter 2). While uncertainties make decision-making difficult in the long term, it is useful to evaluate the implications of a short-term policy that aims to keep all options open. It already appears to be impossible to return to pre-industrial CO_2 concentrations (275 ppm) – or even to stabilise atmospheric CO_2 concentration at 350 or 400 ppm. It is equally clear that the absence of any near-term action will progressively make stabilisation at "relatively" lower levels more and more difficult – if not impossible (unless near-total elimination of CO_2 emissions becomes technically feasible, or radical geo-engineering alternatives are developed and deployed). Thus, for example, without near-term action, the option of stabilising emissions at 450 ppm would disappear from the range of possible alternative end-points within a few decades. While a decision on any specific level is premature, retaining options does open the question of appropriate hedging strategies.

Most studies on possible hedging strategies belong to one of the following categories:

- Cost-effectiveness studies, which consider that at some point in time, a concentration level will be agreed, and will then have to be achieved at any cost;
- Cost-benefit approaches, which consider that, at any point in time, new information about costs and benefits might change the desirable level of mitigation and, ultimately, of desirable GHG stabilisation levels. This book follows this approach.

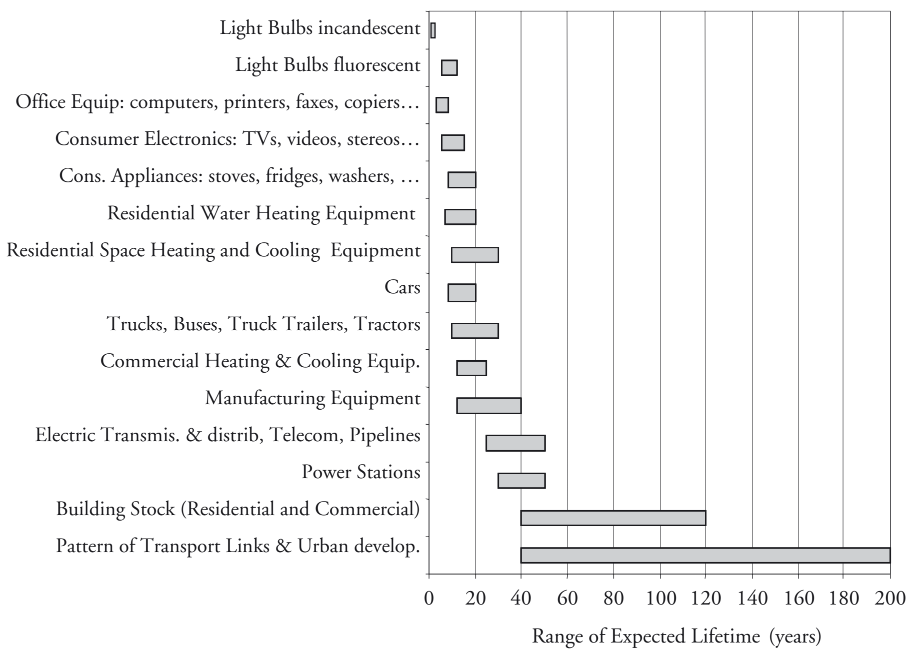
In both cases, the level of hedging suggested mainly depends on the probability given to the decision to reach a given concentration level (first approach) or to the likelihood that new information will emerge regarding climate change consequences or technologies (second approach). Ultimately, the risk premium is a political decision.

Inertia

One prominent feature of our energy system is inertia. Individual capital stock might have a lifetime extending from a few years for appliances, to decades for manufacturing or space heating and cooling equipment. Equipment in the energy sector is relatively long-lived – refineries, power stations, transmission lines or transformers and pipelines last up to 60 years or more (see Figure 2). Buildings may last centuries. The level of inertia is even more significant if one considers both the use and resources of the energy system. For example, urban patterns, which largely determine transport infrastructure, may develop over centuries – and are costly to reverse. Combined with the so-called "lock-in" effect, this might prevent markets from selecting the most effective means of achieving their goal.

Figure 2

Average Life-Spans for Selected Energy-Related Capital Stock



Note: Figures are intended to illustrate typical life-spans; there will always be exceptions. For example, some hydroelectric power plants are over 90 years old.
Source: Compiled from a range of sources by the IEA.

Inertia in energy systems calls for relatively smooth but early action. The economic costs of premature capital stock retirement suggest that changes may need to be gradually phased in over time. However, the large amount of planned or necessary replacement energy infrastructure to be installed in the coming decades suggests that clear signals need to be sent to decision-makers – if future efforts to move from a "business-as-usual" emission scenario are not to become prohibitively expensive and perhaps extremely difficult politically.

One way of dealing with this issue is to consider the rate of required changes in energy and/or carbon intensities (narrowly defined here as carbon per unit of energy produced) in various scenarios, and to compare them with historical rates. Using the IPCC scenarios as a basis, the stabilisation of atmospheric CO_2 concentration at levels below about 600 ppm is only possible with reductions in carbon intensity and/or energy intensity at rates greater than any that have been achieved in the past. Long-term historically recorded annual rates of improvement of global energy intensity and of carbon intensity are measured at approximately 1.0 to 1.5 per cent per year and 0.3 to 0.4 per cent per year respectively. To achieve stabilisation of CO_2 concentrations at about 600 ppm or below, carbon intensity reduction rates would eventually have to change by up to 1.5 per cent per year.

Historical average rates, however, hide some interesting lessons, such as the "de-coupling" between economic growth and energy consumption – and to an even larger extent, between energy growth and carbon dioxide emissions. Historic anomalies, such as the oil shocks, may partly explain these changes: the first and second oil-shocks in the late 1970s and early 1980s suggest that energy prices, further amplified by government policies, have a number of different effects on energy patterns with various time lags and dynamics.

Aiming at low concentration levels: costs matter

The choice of keeping open the option to stabilise CO_2 concentration at a relatively low level (such as 450 ppm) is not the same as ultimately deciding to achieve this level no matter the cost – or without taking into account the further development in our understanding of the science of climate and its impacts. A political decision might be taken with regard to an acceptable level – notwithstanding the inadequacies in the science and economic analysis: this is the approach taken by the European Union with its call for a cap at 550 ppm and a limit of 2°C increase in the temperature. However, although this proposal has been part of the negotiating dynamic for several years, the fact that it has not been picked up suggests the inherent political difficulty in negotiations like this. Innovative options considered in this book (see Chapter 6) follow the "step-by-step" approach advocated by the IPCC to establish an automatic review process in the timeframe of achieving short-term objectives. With dynamic targets for all countries, and/or price caps (for industrialised countries) and non-binding targets (for developing countries), effective realisation of commitments would be made dependent on actual abatement costs.

Such options might alleviate cost concerns that are exacerbated by cost uncertainty (both intrinsic and relative to economic growth uncertainty) and might thus help countries adopt sufficiently stringent commitments. Thus, one possible way of keeping all options open as long as possible would be to aim at defining near-term commitments compatible with stabilising CO_2 atmospheric concentrations at a low level (e.g., 450 ppm). This would then allow these near-term commitments to be relaxed if the costs of achieving them appear excessive. In this "relaxation" case, the long-term objective itself would be relaxed under a cost-benefit approach – unless new cheap possibilities that would justify a downward revision appear at a later stage.

Even with higher concentration targets, the more gradual transition from the baseline does not negate the need for early action. All stabilisation targets require future capital stock to be less carbon-intensive. This has immediate implications for near-term investment decisions. New supply options typically take many years to enter the marketplace. An immediate and sustained commitment to research and development is vital if low-carbon low-cost substitutes are to be available when needed.

CERTAINTY VERSUS STRINGENCY

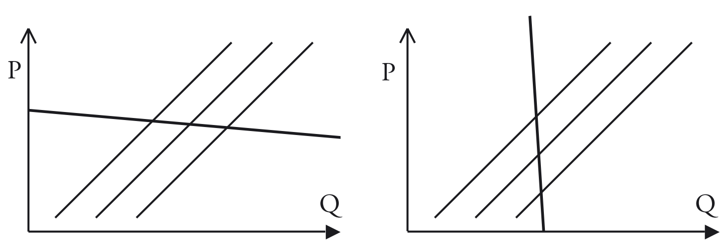
An analytical framework exists that can help weigh the respective values of certainty on emission levels (as offered by Kyoto-like, fixed targets) against a possible higher "stringency" or ambition in setting (lower) near-term targets.

Following Martin Weitzman (1974), environmental economists usually consider that, in the face of uncertain costs, the choice of economic instrument to tackle pollution problems should essentially be decided on the basis of marginal cost and benefit curves. Marginal benefits are defined here as the net present value attributed to avoid damages from the time the decision is taken until an infinite point in the future. If the marginal benefit curve is thought to be steeper than the marginal cost curve, then quantity instruments should be preferred. If, on the contrary, the marginal cost curve is steeper than the marginal benefit curve, then price instruments should be chosen.

If the marginal damage cost ("benefit") curve is steep, the damage rapidly increases with the level of pollution. It is then worth getting certainty about the level of pollution, rather than risk suffering too much environmental damage. If, on the contrary, the marginal benefit curve is flat, it means that the damage increases slowly with the level of pollution. In this case it is preferable to be certain about the marginal cost of abatement, rather than risk paying too high a price for too small an incremental environmental benefit. The rationale for this conclusion is illustrated in Figure 3.

Figure 3

Certainty versus Stringency



P stands for Price, Q for quantities of abatement. The origin marks the Business-as-Usual, uncontrolled level of emissions. The bold line indicates marginal damage costs (or abatement benefits), the three other lines indicate marginal abatement costs: in the middle the expected cost curve, on both sides two other possible outcomes.

Following this rule, it is possible to minimise the social cost of the unavoidable mistake that would be made in deciding on the level of either instrument (i.e., fixing the price or fixing the quantity). The uncertainty of the marginal benefits is independent of the choice of instrument, although it does have implications for its level.

Extreme cases make these results more intuitive: an extreme case of the first situation would be that of infinite damage, a catastrophe arising when concentrations exceed certain thresholds. With such a vertical benefit curve, a quantity instrument would be absolutely necessary (see Figure 3, right-hand side). An extreme case of the second situation would be that of constant marginal damage costs. With a flat horizontal marginal benefit line, fixing a tax at this exact level would ensure optimality regardless of the abatement cost curve. A price instrument would thus be the best choice (see Figure 3, left-hand side).

In the case of climate change, costs are related to emission reductions, while benefits are related to concentration changes. Given the importance of current CO_2 stock in the atmosphere, (730 PgC, compared to 8 PgC in annual anthropogenic emissions) concentrations change slowly. It is thus highly likely that in any short period marginal costs increase faster than marginal benefits. Studies[4] have suggested that, even taking due account of the likely effects on emission reductions in any one period on all subsequent periods, price instruments would be far preferable to quantity instruments. Although the economic parameters chosen in these studies might be challenged, this result seems quite robust. The preference for price instruments would be reversed only if climate change damages were enormously greater than currently anticipated, or if damages were to increase rapidly with increasing concentrations. This could happen in the case of a "nasty surprise": a strong, non-linear global climate change such as the melting of the polar ice caps, or the cessation of the large-scale ocean currents. The probability of such events occurring is currently estimated as "very low" by the IPCC, but could increase in the future with increased greenhouse gas concentration levels.

If extensive damage of this kind were thought to be likely, it would lead to preferences for a quantity instrument. However, it would also require short-term decisions to drastically reduce global emissions in order to keep CO_2 concentrations at roughly current levels. A sensitivity analysis assuming significant damage suggests this preference would apply when short-term cuts exceed 40 per cent (see Newell & Pizer, 2000). In other

4 Notably Newell & Pizer (2000), Pizer (1997, 2001), Hoel & Karp (2000, 2001). See Appendix for further explanation of this analytical background.

words, fixed quantity instruments would be compatible with very stringent short-term emission reductions. A threshold for the choice of a quantity instrument would seem to be approximately a 40 per cent reduction in emissions.

If short-term reductions are to be less drastic (i.e., if the special cases of non-linear damage are considered to be unlikely, and the damage is relatively independent of emissions over the near term), the theory strongly suggests that the instrument of choice should be a price instrument rather than a quantity cap.

This can be illustrated by considering what near-term global targets would be required for stabilisation at 450 ppm. If we look only at energy-related CO_2 emissions, the *World Energy Outlook* (IEA, 2002) projects a global emissions level in 2015 of about 9 GtC – slightly higher than the desirable peak considered in the IPCC range. Returning to the 1990 level of 5.8 GtC would thus necessitate a 36 per cent decrease from the 2015 level. According to the IPCC (see Table 1) such a level should be reached before 2040. This could be achieved through four 5-year commitment periods, where the target during each period would be for a 10 per cent reduction from the level of the previous period. Resulting emissions would then decline from 8.1 GtC in 2020, to 7.3 GtC in 2025, to 6.6 GtC in 2030, and finally, to 5.9 GtC in 2035. Three more periods with the same reduction rate[5] (in percentage points) would lead to emissions of 4.3 GtC in 2050, at the lowest range of emission levels assessed by Berk et al. (2001) as compatible with 450 ppm CO_2 concentration.

As the total reduction is lower than 40 per cent, the instrument of choice would be a price instrument. This conclusion seems even more robust when considered over the span of any individual commitment period – where reductions are on the order of 10 per cent. However, it could be argued that there is little difference between 36 and 40 per cent – and thus a fixed quantity cap – applied over a 25-year time horizon, could also be justified. While in this very stringent case economic theory might suggest

5 This is illustrative only. A constant –x% objective building from each period to the next represents a slowly decreasing rate of effort that may not be optimal. But aiming at a long-term level under a cost condition makes all short-term targets "illustrative only" and does not require an (impossible) optimality in setting the whole set of targets over time.

that either instrument could be used, there are significant political difficulties in the quantity instrument choice. The primary difficulty is one of application: there are few political institutions that have the capacity to levy a single commitment and adhere to it over the span of 30 years or more. An even longer period might be necessary: the time lag between taking on targets and the start of the first of these new commitment periods could last several years.

Connecting the arguments

How does this theoretical preference for price instruments relate to the suggested decision-making framework – to aim at a low GHG concentration level under cost conditions? The answer is simple: the amount of abatement actually undertaken under a price instrument would depend on abatement costs. If costs turn out to be higher than expected, the amount of abatement can be reduced. If they turn out to be lower than expected, the amount of abatement can be increased. Aiming at a low level under a price cap allows essentially the same thing – with some variations. These depend on the options retained for implementing this long-term emission path towards stabilisation through near-term quantitative commitments, as will be further discussed in Chapter 6.

While price instruments seem to be preferable from an economic perspective, quantity instruments have one key advantage from a political economy perspective. In particular, they allow for emissions reductions to be undertaken wherever they are cheapest – as long as the total quantity reduced remains unchanged. The potential for geographic flexibility in reductions allows dissociation between *where* emission reductions take place and *who* pays for them – the basis for international trade.

Thus, the concrete question (considered in the following chapters) is to define the options that would provide the benefits of both price and quantity instruments – seeking the best of both worlds.

CHOICES IN THE ENERGY SECTOR

THE PREDOMINANCE OF ENERGY-RELATED EMISSIONS

Energy-related greenhouse gas emissions are the dominant human contribution to climate change. The burning of fossil fuels is responsible for at least three-quarters of anthropogenic carbon dioxide (CO_2) emissions; fossil fuel production and use also emit methane (CH_4), nitrous oxide (N_2O), ozone-precursors, and black soot. Fossil fuels are also the main source of airborne aerosols that tend to cool the earth's surface; these aerosols can slightly offset the negative climate effects of GHGs. However, due to concerns for human health as well as impacts on the local and regional environment, industrialised and developing countries have increasingly been taking measures to remove aerosols from flue gases.

Approximately 20 per cent of all greenhouse gas emissions arise from activities outside the energy sector. Studies have shown (e.g., Burniaux, 2000; Reilly et al, 2000) that there are numerous cost-effective options for mitigating emissions from other sectors (e.g., CH_4 from waste management, agriculture and cattle, N_2O from agriculture, fluorinated gases from industries, or the increasing capture by natural sinks through changes in land use).

However, the breadth and depth of the necessary cuts to reach any stabilisation levels cannot but imply profound changes in energy production and use. Therefore, the choice of instruments and the timeframe for action will affect and be affected by changes in the energy sector.

Energy-related CO_2 emissions are estimated with some accuracy at 6.5 GtC/y (or 23,900 million tonnes CO_2) per year in 2000[6] out of a total estimated at 8 GtC. The *World Energy Outlook* (IEA, 2002a) foresees global energy-related CO_2 emissions of circa 7.4 GtC in 2010 and 8.7 GtC in 2020. The *International Energy Outlook* of the US DOE's

6 By both the IPCC (2001a) and the IEA (2002b) following the "reference approach".

Energy Information Administration (EIA, 2002) gives a higher figure for 2020 (9.9 GtC), while projections using the POLES model[7] (Criqui & Kouvaritakis, 2000) give 10.7 GtC for 2020.

As can be seen in Figure 4, according to IEA projections CO_2 emissions from the energy sector are increasing in both the developed and developing world. While the rate of increase is higher in non-Annex I countries, per capita emissions remain much lower – and converge only very slowly through 2030. The projected paths of greenhouse gas emissions reflect population growth and the expected continued increases in living standards and energy use; the trends are for more rapid increases in developing countries.

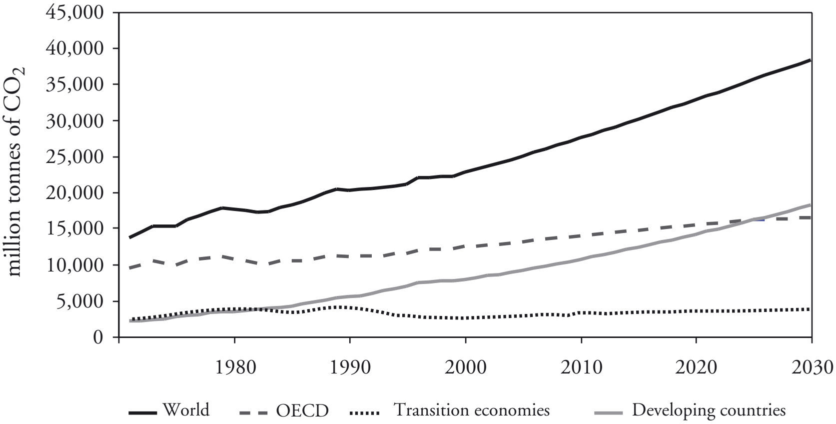
A number of conclusions can be drawn from such projections. First, the stabilisation of CO_2 concentrations will be impossible to achieve unless developing countries, as well as developed countries, take part. Second, unless additional action is taken, developed countries' aggregate emissions will continue to climb. Third, lower stabilisation levels require earlier integration of developing countries into the global mitigating framework. Fourth, the GDP levels projected for developing countries imply that capital resources to reduce emissions will be extremely scarce – and solutions must be found to finance emission reduction costs, particularly in the developing world.

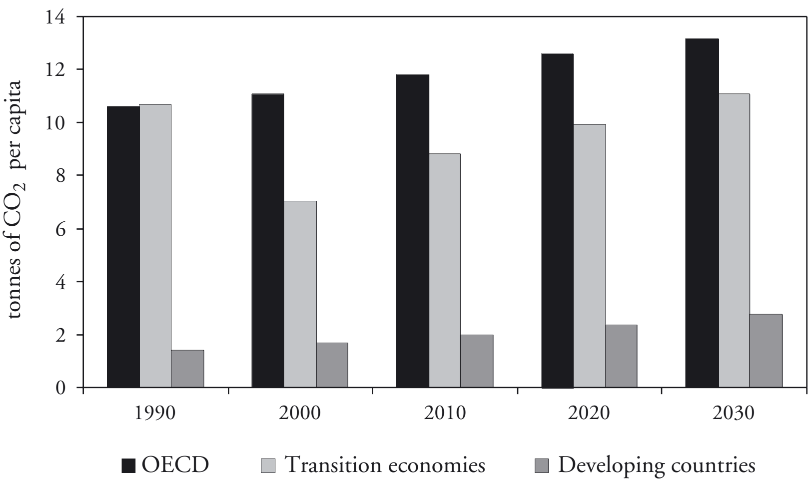
The 2002 *World Energy Outlook* projects that CO_2 emissions in 2030 will be 38 billion tonnes, or 10.4 GtC. Other models give a range of estimated CO_2 emission levels at the same date (e.g., the POLES model projects 13.4 GtC in 2030). The IPCC provides an even longer-term perspective. In its Special Report on Emissions Scenarios (SRES) released in 2000, the IPCC reviews a wide range of projections that extend through the year 2100. These scenarios do not assume any climate change mitigation policies, and thus illustrate long-term uncertainties in global emissions trends. While some lead "spontaneously" to stabilisation of CO_2 atmospheric concentrations at various levels, most do not (see Box 3).

7 POLES is a sectoral equilibrium model of world energy developed in the framework of the EC-DGXII Joule Programme.

Figure 4

World Energy-Related Carbon Dioxide Emissions





Source: IEA (2002a). Figure 4 shows trends in energy-related CO_2 emissions from OECD and Transition economies (Annex I) and developing countries (non Annex I). The second graph shows per capita emissions from the same regions.

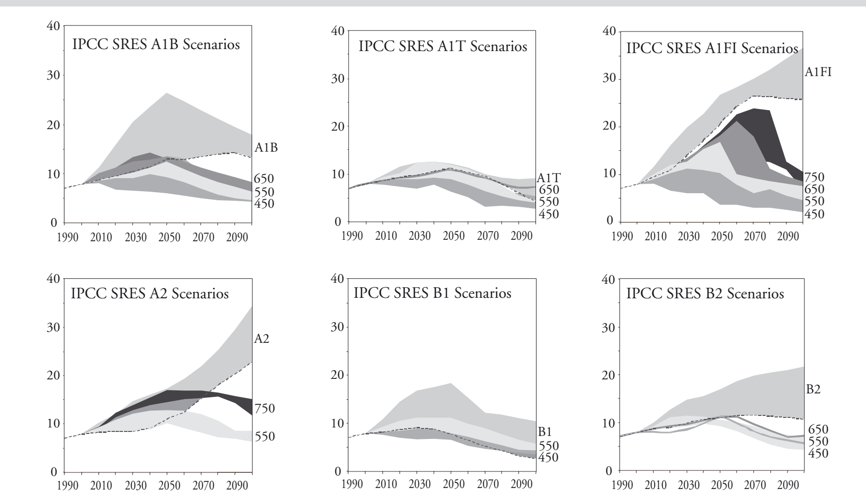
Box 3

IPCC emission scenarios

The IPCC scenarios incorporate a number of driving forces – from population dynamics to societal values and governance structures – that are expected to be relevant to future GHG emission levels. The scenarios are grouped into six illustrative groups, none of which include specific climate policy initiatives.

Figure 5

Comparison of reference and stabilisation scenarios. The six IPCC emission scenarios compared with CO_2 emission pathways leading to various concentration levels in 2100



Source: IPCC, 2001, Vol. 3, figure SPM-1.

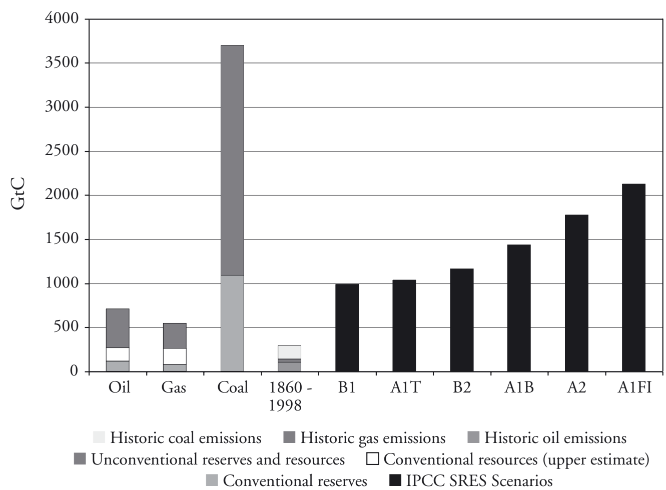
The four "A" illustrative scenarios emphasise economic development, while the two "B" scenarios emphasise sustainable development. In A1 and B1 scenarios, birth rates decrease after around 2050, while in A2 and B2 demographic growth continues unabated. The A1 scenarios are subdivided into three distinct groups illustrating alternative energy technology developments: A1F1 is fossil intensive, A1T assumes the full use of non-fossil energy sources, and A1B balances across all sources.

While each group includes several scenarios built on different models, the focus is on the so-called "illustrative" or "marker" scenarios selected as most representative of each family by the IPCC.

The most favourable climate scenarios – B1 and A1T – suppose relatively rapid energy efficiency improvements. In B1 (the "sustainable development" scenario), efficiency improves due to increased monetisation of activities such as childcare or housework. B1 also assumes lifestyle changes, such as increased public transportation. In A1T, energy efficiency improvements derive mostly from the penetration of new energy end-use technologies such as micro-turbines and fuel cells. Significantly, in both cases, the total cost of energy services (even including the cost of emission abatement allowing CO_2 concentration stabilisation at 450 ppm) remains lower than in scenarios where emissions rise more rapidly (Roehrl & Riahi, 2000). Under scenarios with higher emission levels, the total cumulative discounted costs of changes in the energy systems to stabilise concentrations would be extremely high.

Figure 6

Fossil Fuel Supply and Implications for Atmospheric Concentrations of Greenhouse Gases



Carbon in oil, gas and coal reserves and resources compared with historic fossil fuel carbon emissions 1860-1998, and with cumulative carbon emissions from a range of SRES scenarios and TAR stabilisation scenarios up until 2100.

Note: the unconventional gas resources do not include clathrates. *Source:* IPCC, 2001.

CO_2 constraint from a resource perspective

The IPCC TAR, as well as the IEA's *World Energy Outlook 2001* (IEA, 2001b) clearly demonstrate that fossil fuel resource constraints will not limit emissions during this century. In fact, the utilisation of all proven conventional oil and gas reserves would add only 200 GtC to the atmosphere – clearly less than the lower estimate for the total amount of carbon emissions leading to stabilising concentrations at 450 ppm (see Table 1 in Chapter 1). Burning all conventional oil and gas resources would add another estimated 332 GtC. Thus, the full use of the total resource base (i.e., the sum of all reserves and resources[8]) for conventional oil and gas would still remain in the range of CO_2 cumulative emissions compatible with stabilisation at 450 ppm.

However, the use of unconventional oil and gas reserves and resources could add another 440 GtC and 288 GtC, respectively, not taking into account the immense clathrate (gas hydrate) resources. The use of known reserves of coal would add more than 1,000 GtC, and potential resources another 2,605 GtC (see Figure 6). The fossil fuel resource base (total of reserves and resources, conventional and unconventional) represents a carbon volume of some 5,000 GtC. Their full use would lead to concentration levels closer to 2,000 ppm than to 1,000 ppm.

One clear implication of these statistics is that, in the long run, we cannot burn the entire resource base and still expect to stabilise concentrations at any reasonable level. Fuel switching between fossil fuels might play an important role – but this can only be transitional since in the long term, near elimination of CO_2 emissions will be needed. The stabilisation of CO_2 concentration will ultimately require phasing in much larger shares of zero or low carbon emitting energy sources, even though resource scarcity would not exist – and thus, fossil fuel prices, in the absence of policy intervention, could be expected to be relatively low. In turn, this suggests that energy efficiency improvements alone cannot lead to stabilising CO_2 concentrations – though they may bring large benefits.

8 The reserves are the fraction of resources that may be economically exploited in the future. The proven reserves are the recoverable reserves from known deposits. Resources are postulated from geologic information and theory to exist outside of known fields.

In all scenarios showing constrained emissions paths, a real departure from the baseline will have to begin during the next decade. Even under the low-emissions baselines (i.e., the B1 scenario), policy intervention will be needed – although in this case it may be possible to achieve stabilisation with relatively little action.

According to the IPCC (2001, Vol. 3, Chapter 3), sufficient technical options exist to hold annual global greenhouse gas emissions through 2010 to levels close to or even below those of 2000 — and even lower levels are possible by 2020. For energy-related CO_2 emissions alone, the technological potential exists for reductions of between 1,350 MtC/y and 1,900 MtC/y in 2010 and of 2,950 to 4,000 MtC/y in 2020. There are, however, conflicting views as to the costs of taking such actions.

Table 3 shows the estimates for energy-related CO_2 emissions in each IPCC TAR illustrative scenario, in 2020 and 2050. Not surprisingly, in

Table 3

Energy-related CO_2 Emission Pathways to Stabilising at 450 ppm compared with Different IPCC Scenarios and Other Projections, in GtC/y

YEAR SCENARIO GROUP	2010	2020	2030	2040	2050
path compatible with 450 ppm[a]	8.0	8.0	5.8	5.2	4.6
IEA-EIA/POLES	8.0/8.2	10.0/10.7	10.4/13.4	na	na
A1F1	8.7	11.2	14.6	18.7	23.1
A1B	9.7	12.1	14.0	15.0	16.0
A1T	8.3	10	12.3	12.6	12.3
A2	8.5	11.0	13.5	15.0	16.5
B1	8.5	10.0	11.2	12.2	11.7
B2	8.0	9.0	10.2	10.9	11.2

a. Figures for 2010 and 2020 have been taken slightly below that of the 2015 "peak". The figure for 2040 is a linear interpolation between those for 2030 and 2050. These numbers are illustrative only.

order to remain compatible with stabilisation at 450 ppm, the A1F1, A1B and A2 groups would require a wider range of, and more strongly implemented, technology and/or policy measures than the A1T, B1 and B2 groups. None of these scenarios, however, gets close to a return to 1990 emissions by 2030. Some are compatible with stabilisation – but at higher levels than 450 ppm.

Table 4 summarises the results of several studies and estimates potential greenhouse gas emission reductions in several sectors, taking into account possible overlaps between and within sectors. More than half of the potential comes from the aggregate effect of hundreds of technologies and practices for end-use energy efficiency in buildings, transport and manufacturing. Most of this potential may be tapped by 2020 with direct benefits – notably in the building and industry sectors (see IPCC 2001, Vol. 3, Chapter 3 – which largely draws on insights from the IEA Workshop on Technologies to Reduce Greenhouse Gas Emissions, IEA, 1999). This analysis suggests that a successful short-term climate programme must include the removal of barriers to energy efficiency improvements in the building and industry sectors.

The building sector

CO_2 emissions from fuels and electricity used in both residential and commercial buildings represent 98 per cent of all building-related GHG emissions. However, while developed countries have by far the largest CO_2 emissions from the building sector, energy use and related CO_2 emissions from buildings in developing countries, particularly in the Asia-Pacific region, have grown about five times faster than the global average since 1980.

By 2010, it is projected that 500 MtC CO_2 emissions from buildings could be avoided in developed countries (including EITs) at negative costs, while in developing countries more than 200 MtC CO_2 emissions could be saved at costs ranging from –US$200 to +US$50. Actions include improving building thermal integrity, reducing the carbon intensity of fuels used in buildings, and increasing the energy efficiency of appliances and equipment. It should be noted that these figures (provided by the IPCC) contradict the usual assumption that emission reductions are always cheaper in developing countries.

Table 4

Estimates of Potential Global Greenhouse Gas Emission Reductions in 2010 and in 2020 (Adapted from IPCC TAR SPM Table 1)

Sector (CO_2 Only)	Historic emissions in 1990 (MtCeq /y)	Historic Ceq annual growth rate 1990-1995 (%)	Potential emission reductions in 2010 (MtCeq /y)	Potential emission reductions in 2020 (MtCeq /y)	Net direct costs per tonne of carbon avoided
Buildings[a]	1,650	1.0	700-750	1,000-1,100	Most reductions are available at negative net direct costs.
Transport	1,080	2.4	100-300	300-700	Most studies indicate net direct costs less than US$ 25/tC but two suggest net direct costs will exceed US$ 50/tC.
Industry	2,300	0.4			More than half available at net negative direct costs. Costs are uncertain.
-energy efficiency			300- 500	700- 900	
-material efficiency			~200	~600	
Energy supply and conversion[b]	(1,620)	1.5	50-150	350-700	Limited net negative direct cost options exist; many options are available for less than US$ 100/tCeq.
Others[c]	1870-3420	n. a.	550-700	650-1050	
Total	6,900 – 8,400[d]		1,900 -2,600[e]	3,600 -5,050[e]	

a) Buildings include appliances, buildings, and the building shell. *b)* Included in sector values above. Reductions include electricity generation options only (fuel switching to gas/ nuclear, CO_2 capture and storage, improved power station efficiencies, and renewables). *c)* Includes Industry Non CO_2 gases, agriculture (CO_2 and Non CO_2 gases), waste (CH_4 only) and Montreal Protocol replacement applications. *d)* Total includes all sectors reviewed in IPCC 2001, Vol. 3, Chapter 3 for all six gases. It excludes non-energy related sources of CO_2 (cement production, 160MtC; gas flaring, 60MtC; and land use change, 600- 1,400MtC) and energy used for conversion of fuels in the end- use sector totals (630MtC). If petroleum refining and coke oven gas were added, global 1990 CO_2 emissions of 7,100MtC would increase by 12 per cent. Note that forestry emissions and their carbon sink mitigation options are not included. *e)* The baseline SRES scenarios (for six gases included in the Kyoto Protocol) project a range of emissions of 11,500– 14,000MtC Eq for 2010 and of 12,000– 16,000MtC eq for 2020. The emission reduction estimates are most compatible with baseline emission trends in the SRES-B2 scenario. The potential reductions take into account regular turn-over of capital stock. They are not limited to cost-effective options, but exclude options with costs above US$100/tCeq (except for Montreal Protocol gases) or options that will not be adopted through the use of generally accepted policies.

Again, according to the IPCC, the technical and economic potential for CO_2 emission reductions in the building sector extends to more than 1 GtC by 2020 and not less than 2 GtC by 2050. However, the availability of technologies to achieve such savings cost-effectively depends on significant R&D efforts.

Industry

Industry-related emissions accounted for 43 per cent of carbon released in 1995. Global industry emissions are slowly growing, while developed country industry emissions are slowly decreasing. As in the building sector, hundreds of sector-specific technologies combine to offer considerable scope for lowering CO_2 and other GHG emissions. The IPCC estimates the potential at 300-500 MtC in 2010 and 700-900 MtC in 2020 – of which a majority can be realised at net negative cost. Material efficiency improvements (including recycling, better product design and material substitution) could provide an additional 600 MtC emission reductions in 2020.

In general, Japan, South Korea and Western European countries have more energy efficient industries than developing countries, economies in transition and other OECD countries (notably the US and Australia). The latter offer the highest technical potential for energy efficiency improvements in the industry sector, though differences in economic potential may be smaller given the lower energy prices that often occur in the less efficient countries (IPCC, 2001, Vol. 3). IEA work on energy indicators (see Unander, 2001) suggests a variety of reasons for such differences – including energy pricing, geography, and local climate.

Transport

IPCC analyses suggest less optimistic prospects for the transport sector, which currently contributes about 20 to 25 per cent of global CO_2 emissions. Most evaluations suggest that technical improvements could slow the growth in emissions, but not reverse it. The primary problem in the sector is its very rapid growth rate. In fact, transport emissions could be even further exacerbated by the so-called “rebound effect” possibly arising from lower travelling costs (and thus, higher volumes) following technical improvements.

The IEA WEO (2002) "Alternative Policy Case" considers a range of policies that could help restrain OECD transport energy demand and CO_2 emissions after 2010 — but makes it clear that these policies would have only a limited near-term effect. It notes that effective policies are available for containing both passenger-vehicle and road-freight energy demand, although it suggests that the growth in demand for aviation fuel remains a major concern, and the increasing volume of passenger and freight-transport presents a long-term problem.

Electricity generation

Electricity generation accounted for 39 per cent of global carbon emissions in 2000. Baseline scenarios anticipate emissions of 3.5 GtC and 4 GtC for 2010 and 2020, respectively. The IPCC sets the potential for reductions at 350-700 MtC by 2020. Focusing on OECD Member countries, IEA's "Alternative Policy Case" predicts possible CO_2 emission reductions below reference scenarios of 4 per cent in 2010, 15 per cent in 2020, and 25 per cent in 2030 in these countries.

Prospects might be brighter in developing countries, where large investments in the power sector will be needed. China and India alone are expected to build up to 500 and 200 GW respectively of new power generation capacity, of which at least 350 and 125 GW will be new coal plants. These new plants will partially replace older ones, thus increasing the average energy efficiency of the sector. However, if new capacities were of an advanced super-critical design rather than the classical sub-critical design, their efficiency would be increased by a further seven percentage points and their CO_2 emissions reduced by about 15 per cent compared to current projections. Here, the critical issue may not be costs, but technology transfer, as even with low coal prices, subsequent fuel savings would pay for the incremental cost of investing in the most efficient technology.

Global potential for emission reductions in the power sector arises as much from fuel switching as from energy efficiency improvements. The distinction between these two categories is not clear-cut in the power sector, where the most efficient conversion rates are associated with the lowest carbon intensive fuel – natural gas. Combined cycle gas turbines have conversion efficiencies approaching 60 per cent for the latest models. Combined heat and power systems to meet space heating and manufacturing requirements can further raise efficiency – and are more conveniently fuelled by natural gas.

Energy efficiency improvements offer a number of other political benefits. Most importantly, they increase energy security. They are often employment intensive. They might generate ancillary environmental benefits such as improved air quality – although in some cases, particularly in developing countries, there remain more direct routes to such improvements. Finally, many are believed to be "free" or beneficial: energy savings necessitate up-front investments but often have short payback periods as they produce savings in energy expenses.

However, clear barriers hamper the dissemination of technologies and practices that could reduce GHG emissions. Market failures, such as distorted or incomplete prices, network externalities, misplaced incentives, vested interests, lack of effective regulatory agencies or information, lifestyles and behaviour, price volatility and uncertainties all inhibit action. Addressing and removing these barriers (even partially) is likely to require various specific policies and measures. Beyond "no costs" options, achieving larger energy-saving potentials will require extended policies and measures. If successful measures have already addressed market failures, it is likely that the most cost-effective way to further reduce GHG emissions will be to set a price, either directly with price-based instruments such as taxes, or indirectly through quantity-based instruments such as emissions trading.

Immediate benefits can be obtained from currently available energy efficiency technologies. However, to ensure continued efficiency improvements beyond 2020 will require further research and development.

FUEL SWITCHING

In the near term, while energy supply and conversion remains dominated by fossil fuels, switching from coal to oil or gas can play an important role in emission reduction. When energy efficiencies are unchanged, a shift from coal to oil implies a reduction in carbon emissions of 26 per cent, from oil to gas 23.5 per cent, and from coal to gas 43 per cent per unit of primary energy. Taking into account the estimated methane leakage in the production, transport and use of these various fuels would slightly reduce the gap between oil and gas and widen the gap between oil and coal.

As discussed above, use of the full gas resource base, including unconventional resources (but excluding clathrates), is compatible with stabilisation at 450 ppm. However, if all non-conventional oil resources were exploited, concentrations would rise above this level.

A number of factors are important in evaluating conventional versus non-conventional resources. In the case of gas, the distinction is not clear cut. Unconventional gas reserves are usually more costly to exploit, but their associated CO_2 emissions are still much lower per unit of energy than those of other fossil fuels. In some cases, as with coal-bed methane, recovery reduces methane emissions – with their larger-than-CO_2 global warming potential. However, the case for gas is not unequivocally positive: in some cases, (even in conventional gas), resources contain a high share of CO_2, sulphur or other toxic compounds that require large amounts of energy to clean – thus increasing the effective carbon intensity of these resources.

In contrast to gas, unconventional oil reserves are usually more carbon-intensive to exploit than conventional reserves. Technical improvements have already reduced exploitation costs and are likely to continue doing so in the future – but as other energy sources become more competitive, the price advantage for oil may decline. It is possible that the higher carbon intensity of unconventional oil resources may lead to delays in – or even the outright elimination of – efforts to exploit them in developed countries with GHG caps (see Pershing, 2000). This could refocus oil exploitation in OPEC and other developing countries, and while it might raise energy security concerns in many consumer countries, it could prove beneficial to countries with significant conventional resources.

A number of specific barriers exist for promoting a switch to low-carbon fossil fuels. The first is the availability and distribution costs of natural gas:

Box 4

Hydrogen and electricity

Hydrogen is often cited as the clean fuel of the future. In climate terms, it could provide the ultimate achievement: full decarbonisation of energy. However, hydrogen is not an energy source but an energy carrier – exactly like electricity.

Hydrogen offers some advantages over electricity, including independence from a grid and, perhaps, storage, although it lags electricity development by at least a century. Fuel cells are making progress and could replace batteries in portable electronics, internal combustion engines in cars and trucks and, to some extent, power plants (providing more distributed heat and electricity).

But how will this hydrogen be produced? An incremental route is through the "on-board" reforming of gasoline and methanol, a technique that has already been demonstrated in the transport sector. This solution does not yield full carbon benefits: it still produces CO_2 emissions. A more direct and cleaner path could be to derive hydrogen from natural gas and renewable energy. This approach would require public policies to solve the simultaneous need to modify the supply and demand sides of a hydrogen economy (Dunn, 2002). Some (optimistic) models have assessed this potential: according to Barretto et al. (2002), it is possible that in 2050 hydrogen could account for 25 per cent of the global final-energy consumption in the transport sector and 38 per cent of the residential/commercial sector. Under their scenario, steam reforming of natural gas and gasification of biomass would be the dominant technologies; they also see an increasing use of coal gasification and solar thermal in the hydrogen generating mix.

transporting natural gas is more expensive than transporting oil. Concerns may also arise for energy security and fuel costs – especially in countries that have abundant coal reserves. Finally, in many regions, an expanded use of gas beyond power production is likely to require huge infrastructure investments. This is particularly true in the developing world: while there are high densities of existing pipelines in North America and Europe, there are only low densities in Africa, Latin America and Asia.

Although 90 countries hold significant natural gas reserves, 70 per cent of world reserves are located in the former Soviet Union and the Middle East. The reserve/production ratio of 65 years globally is unevenly distributed, from 250 years for the Middle East to only 9 years for North America (IEA, 2001b). Thus, climate policies that promote fuel switching are likely to benefit natural gas exporters. The political and economic consequences of such policies need to be carefully evaluated.

Even more striking is the ratio of natural gas reserves to total energy consumption, as suggested by Siddiqi (2002). This ratio is lower than three years for some large countries with huge coal reserves such as China, India and the USA. In these cases, fuel switching towards natural gas is likely to aggravate rather than resolve energy security concerns.

A number of non-climate-related benefits contribute to offsetting some of the costs of fuel switching. Perhaps the most significant of these is the improvement in the local environment, particularly in air quality. This benefit has driven countries with large coal reserves to shift towards gas even where gas is not cheaper than coal. The most striking example is China, where switching to gas is an official policy that goes far beyond the use of the country's gas reserves. In its "dash to gas", China has aggressively developed LNG terminals and international pipelines, as well as sought to secure resources abroad (see also Box 8 in Chapter 4).

Conversely, a number of countries are switching away from zero-emitting sources to fossil fuels. This is the case in several OECD countries that are currently phasing out nuclear power; it is also the case in a number of developing countries that are expanding energy supplies (for example, in Brazil, where constraints on hydro power are prompting the development of thermal generation facilities). Still other countries, seeing considerable volatility in gas prices, are reconsidering the option to build new coal-fired thermal generation (e.g., the US).

Switching to gas-fired generation may, in the near-term, be limited by gas availability and costs. However, over the longer term, if a stringent GHG concentration level (such as 450 ppm) is to be met, even the emissions associated with gas consumption might be too high. Thus, fuel-switching options will also need to focus on non-carbon emitting technologies if

CO_2 emissions are to remain compatible with low and stabilised atmospheric concentrations.

NON-CARBON EMITTING ENERGY SOURCES

Although ranked third (after energy savings and fuel switching) in short-term potential for reducing global CO_2 emissions, non-carbon emitting energy sources are not new. For longer-term reductions associated with all stabilisation levels, these technologies become even more critical. Non-carbon energy sources are of two main types: nuclear energy and renewable energy sources. Both provide huge long-term technical potential – with pros and cons. A third way of producing non-carbon energy is to use fossil fuels with carbon recovery and storage. Each of these three options is discussed below.

Nuclear power

Nuclear power accounts for about 7.3 per cent of world total primary energy supply, a sharp increase since 1973 (when it provided a mere 0.9 per cent). However, this growth has stalled in recent years, mainly because lower fossil-fuel prices have made coal- and gas-fired generation more attractive economically, and also because of increasing public concern, heightened after the Chernobyl accident in 1986 (IEA, 2000a). The IEA projects that the nuclear sector will continue to lose its share in the world energy mix after 2005 as older plants are retired. Other than in Asia, relatively few new plants are being proposed or built.

The future of nuclear power will depend on whether it can meet several objectives simultaneously – reduced economic costs, convincingly safer operations, increased proliferation safeguards, and effective solutions to waste disposal. More capital intensive than its competitors, nuclear power is often disadvantaged in fully deregulated markets where the private sector demands higher rates of return than public discount rates. However, nuclear power remains competitive where natural gas infrastructures are not in place and in circumstances where coal has to be transported over long distances (e.g., in China).

Current "evolutionary" technical development efforts tend to build on experience gained with light water reactors to simultaneously reduce costs and increase safety, in particular by incorporating more passive safety features. More "revolutionary" designs might offer new solutions in the future, including less waste production (IEA et al., 2002). Nuclear fusion could be an option in the second half of this century if technical feasibility were demonstrated within a 20-30 year timescale.

Combustible renewable energy and waste

Combustible renewable energy sources, including waste, provide 11 per cent of world total primary energy supply – equal to its share in 1973. However, analysis suggests that biomass use may soon start declining. For health, local environmental and sometimes growing scarcity reasons, renewable combustibles are often replaced by more efficient fossil fuel sources in poor households in developing countries. Developments in technology may reverse these trends, particularly as more efficient uses of biomass find their way into the power sector, in particular through gasification. Another possible source of progress could be the development of household stoves with improved combustion (rather than enhanced thermal efficiency only) to reduce indoor pollution and health risks for users (RWEDP, 2000). In addition, increases in sinks (which simultaneously "gain time" in near-term mitigation policy) may provide additional longer-term resources for biomass use (see, e.g., Schlamadinger et al., 2001a; Read, 2002).

Hydropower

Hydropower provides 2.3 per cent of current global energy demand. Hydropower is expected to increase in absolute quantities over the next two decades, and its economic potential world-wide remains important. However, its development remains largely dependent on resolving public concerns about the environmental and social consequences of building large dams. Another important barrier is the increasing distance between still non-exploited resources and potential consumers. Progress in superconductivity could be a key for further development.

Other renewable energies

Other renewable energy sources such as wind, solar, geothermal and tidal energies provide only 0.5 per cent of global demand for energy. Wind energy is the fastest growing energy market but from a very narrow base.

However, these fuels hold considerable promise for the future. Solar energy received by the planet is about 9,000 times current energy consumption. Even though its technical potential is much less (and depends on factors such as land availability), lower estimates for supply exceed current global energy use by a factor of four. But the market potential for capture is currently low because of high costs, investment lead times and geographic variations. The diffuse, intermittent and non-dispatchable character of solar energy suggests it may remain a marginal technology unless storage becomes much cheaper. Again, progress in superconductivity could be a key, but other options exist, including hydrogen production.

With 1,538 GWh produced in 2000, solar electricity represents only 0.05 per cent of total electricity from renewable energy sources. Photovoltaic systems and concentrating solar-thermal power plants have approximately equal shares of that production. PV systems provide expensive energy but have niche markets that could expand from remote consumers (including a share of the estimated one and a half billion people without access to electricity) to integration into building structures. However, large reductions in costs are still needed for this source to compete with fossil-fuelled power plants.

Concentrating technologies may offer the best prospects for economically competitive large-scale production where solar resources are sufficiently intense. Nine plants in the Mojave Desert close to Los Angeles have provided 354 MWe of power since 1989. Concentrating technologies allows a back-up from fossil fuels or energy storage through heat transfer fluid that guarantees the continuity of power – an important requirement of utilities. They offer much cheaper electricity than PV – though at prices still higher than fossil fuels. However, similar plants could meet increasing electricity needs in large urban areas close to such resources; projects are currently underway in Egypt, India, Mexico and Morocco with financing by the Global Environment Facility (see Box 7 in Chapter 4), as well as in Iran, Israel, Jordan, South Africa, Greece, Spain and Italy. In the future, this technology might be used to produce hydrogen or other energy carriers. For example, direct natural gas reforming with solar concentrated heat could produce exportable hydrogen for other consuming regions while facilitating carbon recovery.

Wind power is the fastest growing energy source. In high wind areas, wind power is competitive with other forms of electricity generation. IEA estimates for 2020 project 1,200 GW of installed capacity, providing almost 3,000 TWh/year. Global economic potential estimates vary from 20,000 TWh/y to more than twice as much. While declining public acceptance of on-shore and high costs of offshore facilities are current constraints to the increase of wind power, further cost reductions are anticipated, e.g., through turbine efficiencies. As with other renewable energy sources, recent technical improvements in this sector suggest that research and development efforts are most valuable when they are combined with market deployment and learning-by-doing.

Other renewable energy applications include solar hot water, solar space heating, solar drying of agricultural crops, solar cooling, passive solar energy use in heating and cooling buildings, geothermal energy and marine energy – including wave, ocean current, ocean thermal and tidal. Some are already competitive – notably hot water and passive solar use in buildings. However, even collectively, these are not estimated to provide a significant share of the energy demand over the next twenty years. It may be, though, that commercial energy statistics hide some uses of solar energy (such as heating buildings) that tend to be merged with energy savings. Given the current and projected low levels of use, it will take considerable policy "push" to stimulate the growth of such technologies over the next thirty to fifty years.

Capture and storage

Various technologies are now available for CO_2 separation, transport and underground storage, although costs remain high, and the long-term environmental consequences are not entirely certain. Currently, these technologies are best suited to dealing with emissions of large point sources of CO_2, such as power plants and energy-intensive industries, rather than small, dispersed sources such as transport and heating.

Both pre- and post-combustion technologies exist for CO_2 capture. Post-combustion CO_2 capture uses amine solvents to scrub the flue-gases. The amine leaving the scrubber is heated to release high-purity CO_2 and is then re-used. However, the low concentration of CO_2 in the power-station flue-gases means that a very large volume of flue-gas has to be treated. Equipment is thus large – and large amounts of energy are required for solvent generation.

A pre-combustion capture technology avoids many of these problems – but necessitates that hydrogen becomes a more widely used energy carrier. Steam reforming of natural gas frees the hydrogen atoms in the fuel. A second step with more steam produces carbon dioxide and more hydrogen. The CO_2 is then separated from hydrogen. Part of the natural gas is used to fuel the process – itself requiring significant amounts of high temperature heat.

While it would also be possible to produce hydrogen from oil, or even coal, and capture and store carbon dioxide, this is less attractive than with gas that offers higher hydrogen to carbon ratio. More appealing may be the production of hydrogen from biomass – or electricity in association with carbon storage. If it is harvested in a sustainable manner, biomass use is "carbon-neutral" for the atmosphere and thus, preferable to fossil fuels. If hydrogen is produced from biomass and carbon captured and stored, then the whole cycle would pump carbon from the atmosphere. Each carbon tonne stored would have a double value.

IPCC estimates for storage capacities range from 1,500 to 14,000 GtC; this scale suggests that storage is not likely to be a major constraint on CO_2 removal and sequestration potential, provided current knowledge is improved and long-term storage guaranteed. Storage in the deep ocean would further extend this capacity but raises serious environmental concerns.

Cost estimates vary with techniques, as well as with transport distances. They range from \$25/tonne C to \$60 /tonne C, including storage. As with most technologies, there is scope to reduce costs in the future through technical improvements. If the CO_2 is used for enhanced oil or coal bed methane recovery, some of the costs will be offset – in fact the IEA Greenhouse Gas R&D Programme estimates that there could be a net benefit in some cases. Such a scheme is already operating at the Sleipner off-shore drilling platform operated by Statoil. Analyses have shown that stabilisation strategies at various levels are less costly when they include the option of capture and storage of CO_2.

CURRENT COMMITMENTS

The international community has responded to the need to address climate change (see IEA 2002c). Ultimately, its actions aim to induce changes in greenhouse gas emissions, predominantly in the energy sector. Theory demonstrates the need for international co-operation; the climate change convention and the Protocol are built on this approach. These agreements, however, even if fully implemented, would have been unlikely to significantly reduce GHG concentrations. Furthermore, the details of implementation agreed by participant countries, as well as the extent of country participation (including US disengagement), have altered the effects of the agreements. However, they were always assumed to be iterative, with countries adopting additional steps. Developing these next steps requires an understanding of the existing agreements.

THE NEED FOR INTERNATIONAL CO-OPERATION

Mitigating global climate change, in theory, requires global co-operation. As Barret (1999) made clear, countries acting in isolation to mitigate climate change are likely to limit their efforts so that the marginal abatement cost they incur equals the marginal benefit they obtain from their own efforts. On the other hand, countries co-operating in mitigating climate change are likely to raise their level of effort so that their marginal cost equals the benefits that each of them receives from their concerted action. In a world of almost 200 countries, the difference is likely to be significant.

Sadly, a different paradigm operates: the prisoner's dilemma. In this framework, while collective welfare declines, individuals are better off if they "free-ride" – taking no action on their own, but benefiting from the actions taken by others. The unfortunate cumulative effect of this strategy was well described in a famous paper by Garrett Hardin (1968). The outcome is better known as the "tragedy of the commons" and in the case of climate change, implies significantly increased emissions.

Game theory suggests ways to escape the dilemma, such as relaxing the hypothesis of pure rationality of players, repeated games, and changes in the matrix of benefits and losses. Countries co-operating in mitigating climate change illustrate this; they may resist defection and free riding for a number of reasons; at the national level, these take the form of national pride, pressure from civil society, or willingness to build other countries' confidence in their "fair" behaviour. This last motive could be inspired by a clear perception of the collective future benefits of building international confidence in responding to climate change, or other benefits that may arise from international co-operation. In this respect, climate change might be thought of as a repeated game with players obeying different rules from the classic *homo œconomicus* of economic textbooks. Also, utilitarianism is not the only possible framework for explaining people's or states' behaviour.

However, incentives for defection are likely to persist and have to be considered when shaping future agreements. Thus, international agreements have sought to develop other incentives to stimulate performance: the Convention on International Trade of Endangered Species (CITES) and the International Whaling Convention (IWC) have successfully used trade sanctions against non-complying member countries and even non-member countries (Sand, 2001). The climate regime may not be able to apply these kinds of instruments, as their success was largely dependent on the isolation of the sanctioned countries. Such isolation has not been (and may never be) achieved in the climate context – and both the Convention and the Protocol recognise the right of Parties to withdraw.

Apart from aiming to raise the level of effort of individual countries, co-operation is also necessary to prevent the introduction of economically detrimental trade distortions and economically and environmentally detrimental "leakage" effects (further discussed below). It also contributes to enhancing the cost-effectiveness/environmental efficiency of countries' mitigation efforts. International co-operation will be needed to implement "win-win" projects or policies that cannot be undertaken by any country in isolation, due to concerns about economic competition. For example, projects that could simultaneously reduce pollutants with local and global effects but would raise the costs of internationally traded goods can only be undertaken in a world with internationally level playing fields.

Cost-effectiveness

Another important aspect of international co-operation to mitigate climate change is that it establishes a cost-effective regime. This is important from both economic and environmental viewpoints. Emission cuts of 50 per cent or more will be required to stabilise carbon dioxide atmospheric concentrations over the next century. Achieving concentration stabilisation is an ambitious long-term goal that requires progressively more stringent short-term emission targets.

Cost-effectiveness is usually considered as a means of minimising the costs of meeting a given environmental objective. However, if society's willingness-to-pay is somewhat limited, cost-effectiveness may be a way to achieve a better environmental outcome at a given cost. As the ultimate objective of the UNFCCC is not specified, and decisions are likely to be taken or revised sequentially, building cost-effectiveness into the international regime will help achieve GHG concentration stabilisation at lower levels.

Leakage

The need for global co-operation also arises from the risk of leakage, i.e., the part of emissions reductions in countries with a quantitative commitment that may be offset by an emissions increase in non-constrained countries. This can occur through relocation of energy-intensive production in non-constrained regions, by increased consumption of regional fossil fuels through a decline in the international price of oil and gas triggered by lower demand for these energies, and through changes in incomes and thus in energy demand due to better terms of trade. The risk of leakage is likely to increase with the stringency of the targets accepted by constrained countries.

Leakage may be offset by a more positive phenomenon: spillover effect. This occurs when technology is disseminated – and offers a particular advantage when less developed countries can leap-frog to new, advanced technologies without first adopting older and more polluting ones. In general, the level of environmental awareness increases, and energy intensity decreases as a country's per capita GDP increases. While the level of the intensity peak varies from one country to another, the spill-over effect results in the general lowering of global energy intensities (Martin, 1988).

THE UN FRAMEWORK CONVENTION ON CLIMATE CHANGE AND ITS KYOTO PROTOCOL

Numerous studies have closely examined both the UNFCCC and the Kyoto Protocol (see, for example, Grubb et al., 1999; Depledge, 2000; Bodansky, 2001). However, it may be useful to review a number of key issues in order to understand more clearly the implications for the next steps to address climate change. The agreements can be examined with respect to their success in addressing the three main elements described above – international engagement, cost-effectiveness and leakage. They can also be examined with respect to key elements of the decision, – and how these may be applied in future regimes: *i)* the establishment of goals (soft aims in the UNFCCC that were subsequently codified into legally binding obligations in the Protocol); *ii)* the differentiation in the level of commitments between countries; *iii)* the coverage of all greenhouse gases, including all sources and sinks; *iv)* the establishment of strong monitoring and review procedures; *v)* the rejection of specific common policy approaches and promotion of market mechanisms (emissions trading and project-based offsets); *vi)* the general, albeit non-specific, encouragement of co-operation in technology development and diffusion; and *vii)* the call for financial and technical support to assist developing countries.

International co-operation

The level of international co-operation in negotiating and ratifying the UNFCCC and its Protocol are remarkable. Unlike many earlier environmental agreements, both were negotiated under UN auspices, with full global participation. The ratification of the Convention by over 170 countries further attests to its global appeal.

However, in narrower terms, the agreement on the text masks deep and still persistent divisions in the process. To maintain consensus, these differences ultimately produced differentiated commitments – with developing countries undertaking no quantitative obligations, and developed countries assuming both a domestic emissions reduction burden and a financial commitment to assist developing countries. In some ways the Protocol deepened the divide: as long as commitments were non-binding, countries could accept the relative levels of status assigned. However, once commitments began to bite, countries began to argue vociferously that competitiveness concerns - including vis-à-vis those countries with no assigned targets – would make ratification costly, if not politically impossible. This was one of the arguments brought by countries within the EU that ultimately led to a "burden-sharing" arrangement. It was also a key argument used by the United States when it rejected the agreement at the beginning of 2001.

Other divisions also appeared early in the process, and have led to considerable difficulty in reaching a negotiated outcome. In particular, OPEC countries, faced with potential, though uncertain, damage if global efforts to reduce emissions result in a decline in oil and gas exports, fought to delay much of the negotiating process, seeking compensation for projected lost revenue[9].

Differentiated commitments

Perhaps the key structural element of both agreements is the differentiation made between countries (or groups of countries) with regard to commitments. While the Climate Convention requires all countries to limit their emissions of greenhouse gases, it recognises differences between them. The concept of differentiation is noted in the preamble of the Convention where it is acknowledged that the "global nature of climate change calls for the widest participation by all countries…in accordance with their common but differentiated responsibilities and respective capabilities and social and economic conditions". In the FCCC, four groups of Parties are recognised, and have different commitments:

- Annex II (those Parties with OECD membership at the time of adoption of the FCCC, which have both financial and technical assistance commitments as well as emission reduction commitments);
- Annex I (Parties in Annex II plus Parties in the former Soviet Union and in Eastern Europe; countries in this latter group have emissions limits, but are allowed flexibility in their "base year", and have no financial or technical assistance obligations);

9 It seems equally likely, however, that pricing carbon emissions would reinforce the market power of oil-exporting countries by putting non-conventional oil resources with heavier carbon content at a disadvantage (see Pershing, 2000).

- Non-Annex I, or developing countries (all Parties not in Annex I, which have generic reporting obligations but neither specific emissions targets nor financial or technical assistance obligations); and,
- Least developed countries (a group whose membership is not specifically defined, but which is a subset of the non-Annex I group and which has additional flexibility with respect to the timing of their first national communications).

Clearly, the concept of establishing categories of Parties that have obligations while excluding other Parties (even those with similar characteristics) was not new. Nearly identical groupings are established in the Montreal Protocol on Substances that Deplete the Ozone Layer, and in other environmental agreements. Conversely, some agreements do not use this form of differentiation at all, instead assuming that all Parties have obligations; these agreements differentiate not on whether commitments exist, but rather on their relative stringency. One example of this approach is the UN schedule of payments for the budget – to which all countries contribute, but at different levels.

Several arguments have been advanced to justify the requirement that developed countries act first. One of the most frequently cited has to do with leadership: until the wealthier and more technologically advanced Parties have adopted measures to mitigate emissions, developing countries see little justification to act. Furthermore, it is suggested that the more advanced nations will have to instigate much of the push for technological innovation that will support climate change mitigation, and, more importantly, advance the development of poorer populations.

Another argument in support of this position is based on responsibility for emissions: historically, most emissions of greenhouse gases have occurred in OECD countries, while developing countries have contributed significantly less. This perspective has even been included in the preamble to the Convention. However, a global shift in the current sources of emissions of greenhouse gases is underway – though current per capita emissions remain widely divergent. This shift is projected to continue in the future, as developing countries grow to meet their social and development needs.

The Kyoto Protocol further elaborates the concept of differentiation between countries. The primary manifestation of this concept is evident in the targets of developed country Parties: on the one hand, the EU has a collective target to remain 8 per cent below 1990 levels while the US has set 7 per cent, Japan and Canada 6 per cent, most Eastern European economies in transition 8 and 5 per cent; on the other hand, Russia and Ukraine have set targets at 1990 levels and Norway, Australia and Iceland's targets are respectively 1, 8 and 10 per cent above 1990 levels. As with the FCCC, which imposed no emissions targets on developing countries, the Protocol too focused emissions limitation obligations exclusively on the developed world.

A further differentiation is also implicit in the Protocol: Annex I Countries can create a "bubble", under which the total emission reductions required from participating countries might be redistributed among them. The European Union has reached such an agreement and has proposed to further differentiate its commitments as indicated in Table 5.

Table 5

The EU burden-sharing Agreement

Austria	-13%	Germany	-21%	Netherlands	-6%
Belgium	-6.5%	Greece	+25%	Portugal	+27%
Denmark	-21%	Ireland	+13%	Spain	+15%
France	0%	Italy	-6.5%	Sweden	+4%
Finland	0%	Luxembourg	-28%	United Kingdom	-12.5%

Both agreements sought to further differentiate between countries, providing specific remedies for perceived specific national circumstances. In this context, among the most critical articles in the Convention are 4.8 and 4.9 (also reflected in Kyoto Protocol articles 2.3 and 3.14) which accommodate countries whose national economic or natural characteristics make them vulnerable to climate change or the effects of its mitigation.

Cost-effectiveness

As described above, the general concept of cost-effectiveness is critical in maximising environmental benefits at the lowest possible cost. Both the Convention and Protocol sought to address this need through different means. In the case of the Convention, the absence of a legally binding commitment essentially ensured that no country would be obliged to pay any price to meet its commitment should it choose not to. While this voluntary goal led to minimal greenhouse mitigation, most of the changes that were made were at net benefit or cost-free.

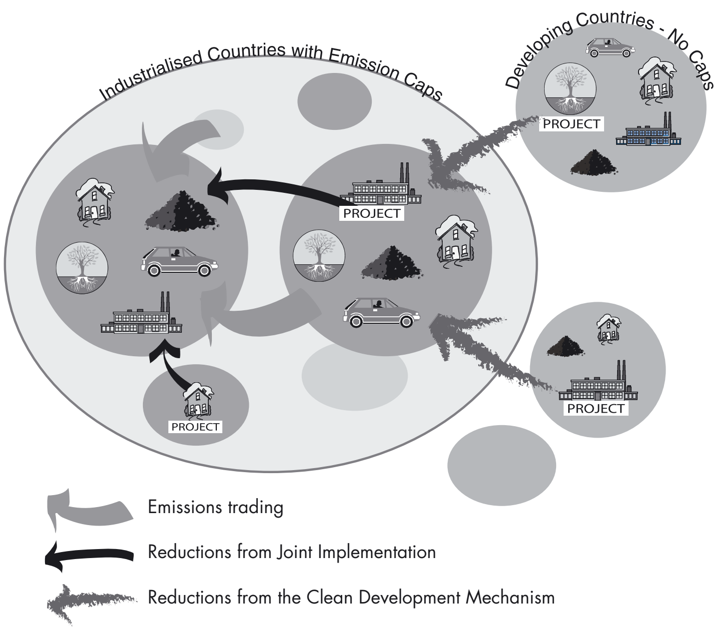
To further increase the cost-effectiveness of the agreement, it was specified that reductions could be undertaken in any gas, from any source, and through the enhancement of sinks. This form of flexibility assured that the lowest cost options would be pursued first. Appreciating the benefits of such a structure, the Kyoto Protocol also adopted this approach – in spite of a growing perception that there are considerable difficulties in monitoring and measuring reductions of some gases (particularly methane and nitrous oxide in the agricultural sector), and that substantial errors are inherent in assessing sinks of greenhouse gases.

In addition, beginning with the UNFCCC's "activities implemented jointly" (AIJ) and extending to the development in the Protocol of the three market-based mechanisms (emissions trading (ET), joint implementation (JI) and the Clean Development Mechanism or CDM), the use of efficient market mechanisms were incorporated into the agreements. Emissions trading (ET) is a mechanism that enables countries with legally binding emissions targets to buy and sell emissions credits among themselves. AIJ, JI and CDM are all forms of "project-based" activities; under rules established for these activities, a country may receive emissions credit for a specific emissions reduction project undertaken in another country. Projects fall under AIJ rules during the test phase; under JI rules when both countries have Kyoto commitments, and under CDM rules when one – or neither – country has a target but both are Kyoto Parties (see Figure 7).

However, the extent to which countries focused exclusively on cost-effectiveness was limited: many were concerned that unless prices for emissions were set at a relatively high level, there would be little if any incentive to develop the new technologies needed for longer-term reductions. In addition, there was concern that due to significant differences in the caps agreed in Kyoto, countries could ultimately "purchase" GHG credits and leave the world essentially with no net reductions in emissions. Constraints on a "perfect" trading market were thus envisioned.

Figure 7

The Kyoto Mechanisms



One of the most significant of these was the proposal to limit the use of these mechanisms so that countries would be restricted to using them to meet only 50 per cent of their reductions. While a quantitative limit was ultimately rejected, it still lingers in some countries' domestic programmes. Another form of constraint lay in the issue of eligibility: it was agreed that only those developed countries that were in compliance with detailed monitoring and reporting requirements would be eligible (although it may also be argued that stringent compliance structures are required for robust market operations). Separate restrictions were developed for project-based activities. CDM activities were required, on top of yielding additional emissions reductions, to meet undefined "sustainable development" criteria. In addition, a levy (at 2 per cent of the project's transferred emissions credits) was placed on all CDM projects. Finally, the open flexibility assigned to Parties in the use of sinks to offset emissions was capped: only certain sinks projects were allowed under the CDM, and the extent of total sinks projects could not exceed 1 per cent of a Party's emissions.

The Kyoto Protocol, notwithstanding its reduction commitments, may bear more than a passing resemblance to the non-binding UNFCCC: one interpretation of the process agreed by the Conference of the Parties (COP 7) at Marrakech in 2001 is that countries which do not accept the compliance provisions would not be bound by them. Thus, these Parties would bear no penalty if they did not meet the Protocol's commitments. This would essentially make the provisions non-binding – and similar to the non-binding 'aim' of the Convention itself.

Technology transfer, financial assistance and engagement of developing countries

It is clear from economic theory that the structure of differentiated commitments – particularly when the groups trade – can create market distortions and competitive imbalances. While a number of countries are contemplating national policies (e.g., tariff barriers or border-tax adjustments against goods from non-Parties or Parties with no GHG obligations), the Convention and Protocol also sought another route to address this problem. In particular, the emphasis was on raising the welfare of Parties with no obligations (developing countries).

While the expectation was that development was a goal in its own right, it was also anticipated that further development would allow these countries to take on commitments. Promoting development underpinned the long-term focus of the technology transfer and financial assistance provisions of both agreements (although these efforts to date have been relatively limited). Development policies were also presumed to have an ancillary benefit: most of the technology used in developing countries was assumed to derive from the Annex I Parties – providing a trade benefit even if the recipient did not take on a GHG target. This solution worked as long as the gap in required action between countries with targets and those without was relatively small and the technology and financial obligations not too onerous. However, for those countries that perceive themselves as obliged to take significant action while competitors are exempted, neither the current agreement (in the case of the US), nor future agreements may pass domestic scrutiny.

To date, there has been widespread resistance to allowing countries to "graduate" into the Annex I group. Proposals for modified targets – suggested by Argentina, Mexico and Korea – have not been taken up in the formal debate. Furthermore, with the emissions reductions obligations required of some countries to comply with Kyoto approaching 35 per cent below their baseline levels, the trade consequence of non-Party competition – and conversely, of leakage – have grown considerably.

LIKELY EFFECTS OF CURRENT COMMITMENTS

Direct effects on emissions

Though limited to developed countries, if the Kyoto Protocol had been fully implemented and its provisions relative to sinks discounted, its effects would have been substantial. According to IEA projections (IEA, 2000a), for energy-related CO_2 emissions a 5.2 per cent reduction below 1990 levels in 2008-2012 for Annex I countries would have turned into an average 22 per cent reduction against their baseline. While the growth in developing country emissions would collectively offset these gains, global emissions would nonetheless have been roughly equivalent to a 10 per cent reduction against the baseline.

The various provisions and interpretations agreed during the past year to seal the agreement (i.e., during negotiations in Bonn at the resumed 6th session of the COP and in Marrakech at COP 7) together have the effect of reducing the necessary level of actual emission reductions. In particular, according to IEA analysis, the decision to allow the use of existing "managed forests" as sinks reduces the overall reduction required of Annex I countries from about 5 per cent below 1990 levels to only approximately 3 per cent. If the United States is excluded from the calculation (and its

Box 5

The US withdrawal and the new US policy

In June 2001, the new Bush administration, while recalling the US commitment to the objective of the UN Convention on Climate Change, announced its intention not to ratify the Kyoto Protocol. This decision was based on a number of criticisms against the Kyoto Protocol, notably the cost incurred by the US to achieve its target, and the absence of legally binding quantitative targets for developing countries:

"The Kyoto Protocol is ineffective in addressing climate change because it excludes developing countries. (...) Developing countries can continue business as usual under the Kyoto Protocol, despite their rapidly growing emissions. (...) The Kyoto Protocol's targets are not based on science. Its targets and timetables were arrived at arbitrarily as a result of political negotiations, and are not related to any specific scientific information of long-term objective. The Kyoto Protocol targets are precipitous. (...) Meeting its target would require the United States to reduce its output of greenhouse emissions by one third in less than seven years. This would require U.S. firms to retire large amounts of capital stock prematurely, imposing substantial and unnecessary costs on the US economy. (...) Many analysts have pointed to trading as the only way that the United States could meet its Kyoto target. Yet few countries will have many excess tonnes to sell other than Russia and several other Eastern European countries that negotiated targets well above their expected emissions during the period 2008-2012. (...) Even if these countries met their (monitoring) requirements and were allowed to sell their emission allowances, U.S. purchases of allowances would amount to many billions of dollars of financial transfers annually – without achieving any meaningful greenhouse gas emission reductions or climate benefit." (The White House, 2001).

In February 2002, the US administration announced a new policy to tackle climate change. It is based on emissions intensity: units of greenhouse gas emissions per unit of GDP. Specifically, the proposal calls for reducing US emissions from 183 metric tonnes of emissions per million dollars GDP emitted today, to 151 tonnes of emissions per million dollars of GDP by 2012. The Administration plan states that this is a decrease of 18 per cent.

Intensity targets belong to the broader family of "dynamic targets" – targets indexed on the evolution of an economic indicator such as GDP – and constitute their simplest possible form. They present obvious advantages for climate change mitigation, a problem well stated in the Bush Administration document:

"The close connection between economic growth, energy use and GHG emissions implies that fixed appropriate emission limits are hard to identify when economic growth is uncertain and carbon-free, breakthrough energy technologies are not yet in place. Such targets are also hard to identify for developing countries where the future rate of emissions is even more uncertain. Given its neutrality with regard to economic growth, greenhouse gas intensity solves or substantially reduces many of these problems." (The White House, 2002)

IEA statistics show a 14.9 per cent decrease in carbon intensity of the US economy over 10 years (1990-2000), or about 1.5 per cent a year. Using the forecasts of the US Department of Energy's Energy Information Administration, US economic growth is projected to be 3 per cent per year, and carbon dioxide emission growth 1.5 per cent a year for the next ten years. Based on these statistics, the US would have a projected decrease in carbon intensity of energy-related CO_2 emissions of 15.5 per cent. The difference with the new commitment is rather small.

Apart from its intensity target, the proposed US policy embraces a number of policies and measures at the federal level. Moreover, there are a number of initiatives from the private sector, individual States and other local authorities that seek to reduce greenhouse gas emissions. It is hard to assess, however, if these policies and initiatives would be likely to bring emissions below the level represented by the main objective of the new US policy.

anticipated emission increases not counted), the reduction below 1990 levels is even less: approximately 2 per cent. Afforestation and reforestation activities, however, as well as agriculture changes, revegetation or sink activities under the CDM are not accounted for in these figures. If they were, they would further reduce the level of gross emission reductions necessitated by the Protocol after Bonn and Marrakech.

The US policy announced in February 2002 makes it possible to project likely US emissions in 2012. Assuming that the intensity target is met, US emissions for all six greenhouse gases under consideration within the Kyoto Protocol would be approximately 30 per cent above 1990 levels by 2012. Aggregating US emissions into the global totals reached under the Protocol suggests that cumulative Annex I emissions would be approximately 9 per cent above 1990 levels in 2012. This supposes extensive emissions trading with no banking[10]. Banking of, say, half of the potential surplus emission rights from Russia and Ukraine would bring the increase in Annex I emissions down to approximately 7 per cent.

For the EU to meet Kyoto commitments (if they were to comply exclusively through domestic action), energy-related carbon dioxide intensity has to go from 102 tonnes per million dollars of GDP to 75.5 – a 26 per cent decrease. Japan must meet a similar level of intensity decrease: using IEA projections for GDP increases in the Pacific region as a proxy for Japan, energy-related CO_2 intensity would need to decrease by about 30 per cent from 2000 levels if they are to comply with Kyoto exclusively through domestic action. Given that Japanese energy intensity has essentially remained unchanged between 1990 and 2000, this represents a formidable shift indeed. If the US were to meet its Kyoto objectives without sacrificing GDP growth, its emissions intensity would need to decline by approximately 40 per cent. Of course, as Kyoto offers the potential for emissions trading, changes in intensity could be significantly lower than suggested from these examples.

Direct effects on concentration levels and climate change

Soon after Kyoto, Bert Bolin, then chairman of the Intergovernmental Panel on Climate Change, published an assessment of the likely effects of the agreement on CO_2 concentration levels in 2010 (Bolin, 1998). This assessment revealed that a full implementation of the Protocol would avoid the emissions of 4 to 6 Pg of carbon dioxide out of 140 Pg likely to be emitted during the 1990-2010 period. On concentration levels, while

10 Kyoto Protocol Article 3.13 allows countries to carry over parts of their assigned amounts in one commitment period for use in subsequent commitment periods – which is usually referred to as “banking”.

business-as-usual trends are expected to raise CO_2 concentration from circa 370 ppm today up to 383 or 384 ppm, the full implementation of the Kyoto Protocol would have limited this rise to 382 ppm. Thus, even with full compliance and US participation, the agreement would have had only a limited effect on the underlying concentrations. After the Bonn and Marrakech decisions and, more importantly, the US withdrawal from the Protocol, current commitments will bring very little change in the GHG concentration levels by the year 2012. No significant modification in radiative forcing and climate consequences might be reasonably expected at that time. This is all the more true since the inertia in climate response is amplified by the thermal inertia of the oceans that tend to "hide" and delay committed climate change.

It was clear from the signing of the Protocol, however, that it would only represent the very first step on a long road toward reducing global emissions and stabilising GHG concentrations. Thus, a better test of the efficacy of the agreement is whether the next steps can be negotiated – and if negotiated, can be met. A process through which an international, legally binding regime is established and implemented would, over the longer term, have considerable potential to mitigate climate change.

A carbon price?

Numerous estimates have been proposed to assess the costs of the Kyoto targets for the countries involved. All show that the costs are likely to differ substantially across regions. As an example, the analysis undertaken for the *World Energy Outlook 2000* (IEA, 2000a) suggested that aggressive transport and power generation policies would, even in combination, be insufficient to meet the Kyoto commitments if OECD nations act alone. However, the same model, using the Kyoto mechanisms, and assuming a full trading regime among all Annex I countries, could reduce total costs by 89 per cent with a marginal cost of around \$32 per tonne of CO_2.

IEA analysis also suggests that the withdrawal from further participation in the Protocol by the United States (with approximately 35 per cent of the developed world's emissions) makes the Kyoto targets easier to achieve for other countries. Without competition from the United States as a buyer in a world market for emissions credits, the trading price is likely to fall to less than US$5 per tonne of CO_2 – and possibly further as a result of the decisions on sinks adopted in Bonn and Marrakech.

Actual costs may depend largely on the policies adopted by those countries that are likely to have assigned amounts (i.e., allocated emission rights under the Protocol) higher than their projected domestic emissions, such as Russia and Ukraine. If these countries were to make use of the "banking" provision of the Protocol in an attempt to maximise their revenues from international emissions trading (i.e., holding credits for use in subsequent periods), the carbon price would rise on international markets. Another possibility is that some of the countries likely to be buyers on these international markets for their domestic emission abatement costs would restrict themselves voluntarily to "protect" their domestic policies and measures and prevent carbon price from reaching a "too low" price.

Overall assessment

The UN Convention on climate change has created a dynamic for addressing climate change at a global level, recognising "common but differentiated responsibilities" by all countries. While most countries have taken steps to address climate change, more has been achieved, so far, in raising awareness than in bringing about reductions in emissions: globally, energy related CO_2 emissions climbed by nearly 10 per cent between 1990 and 1999. Overall growth in emissions from developing countries has been particularly significant, although their per capita emission levels remain low. Technically, the Convention's aim to stabilise emissions in developed countries as a whole has been met, due to the significant decline in emissions in Russia and Eastern Europe (the so-called Economies in Transition) which has effectively offset the collective growth in OECD countries.

Under the Kyoto Protocol, only industrialised countries have made quantitative commitments to limit or reduce their emissions. Emissions from these countries represent 58.5 per cent of 2000 global energy-related CO_2 emissions. With the announced US withdrawal, the share of 2000 global emissions controlled by the Kyoto Protocol falls below 35 per cent. The Protocol is similarly limited in terms of longer-term commitments: the targets that have been adopted only apply for the period 2008 to 2012.

The Kyoto Protocol has introduced (at a level unprecedented in prior multilateral environmental agreements) the concepts and mechanisms for flexibility in implementation. This may be critical for further negotiations for two reasons. The first is that the cost-effectiveness they drive may be essential for adopting further commitments compatible with the stabilisation of greenhouse gas concentrations. The second is that they permit the dissociation of actual reductions from the allocation of emission rights, or assigned amounts. From a perspective of procedural equity this is important, as there is no reason that a cost-effective allocation would necessarily be perceived as fair by all. Conversely, there is no particular reason for an acceptable allocation to be spontaneously cost-effective.

One of the strengths of the Kyoto Protocol is that it allowed differentiation, not only between large groups of countries, like the Convention itself, but also between individual countries. One of its weaknesses may be that it was set up without any clear rules or guidelines to establish differentiated commitments – but purely on the basis of political negotiations.

Financial contributions under the Convention have been managed by the Global Environment Facility (GEF), operating under the aegis of the World Bank, the United Nations Development Program, and the United Nations Environment Program. Total contributions to the fund so far have amounted to approximately $3.6 billion, of which approximately $1 billion have been devoted to climate change (the GEF also supports the preservation of biodiversity, the protection of the stratospheric ozone layer, and other environmental activities). These funding mechanisms, further augmented as a result of the Bonn and Marrakech accords, have started to help capacity building and disseminate clean technologies. Such resource transfers may be expected to help develop and disseminate low-carbon or carbon-free technologies. However, there is no link between these initiatives and any efforts that might be mounted in the Annex I countries to address the same technologies.

The Convention and the Protocol (as interpreted by the Bonn agreements and Marrakech Accords) provide a framework for debating future international co-operation. However, they provide only a very limited step toward achieving the Convention's ultimate objective.

The next step is to extend emission reduction efforts beyond 2012 – and to include those countries currently without commitments. Unfortunately, neither the Protocol nor the Convention provides much guidance in these two areas. No clear rules were followed in developing the differentiation levels, so they do not serve as guidelines for ratcheting them up. Even the underlying Framework Convention provides limited guidance: while calling for the stabilisation of GHG concentrations at a level that would prevent dangerous interference with the climate system (a level that is still undefined), it provides no guidance on targets or goals beyond the year 2000. Similarly, the amendment procedures needed to broaden participation in the agreement may be overwhelmingly constricting – and make any enlargement of the group of participating countries extremely difficult.

However, the current structure has a number of features that seem valuable, and could be critical elements in any future accord. It is comprehensive and allows for flexibility between sectors, gases, emission sources and sinks. Its multi-year commitment and its banking provision not only protect countries against unexpected short-term changes in emission patterns from economic or climatic surprises, but also allow the reduction of carbon price volatility that could discourage emission-reducing investments, in the same way as energy price volatility already discourages energy-saving investments (see, e.g., Hasset & Metcalf, 1993; Awerbuch & Deehan, 1995)[11].

Moreover, the negotiations that preceded and followed the Protocol's adoption have introduced a wide audience to emissions trading and its advantages of near-term cost-effectiveness and long-term environmental effectiveness. Through the Clean Development Mechanism, they have also introduced the idea to experts and decision-makers in developing countries that they could enter into a global mitigation framework at little or no cost – with benefits for the local environment, economic growth and technology transfer. Certainly, project-based mechanisms and emissions trading should remain part of any future agreement based on quantitative

11 Nordhaus (2002), however, notes that banking in the sulphur oxides emissions trading regime in the USA has not prevented price volatility.

targets. However, the question remains as to whether Kyoto-like targets, i.e. fixed and legally binding quantitative commitments, are best suited for developing countries – or even for industrialised countries – in the near future. Some adaptations to the already negotiated framework may help broaden the action against climate change.

INDUCING CHANGE

Stabilising CO_2 and other greenhouse gas atmospheric concentrations – at whatever level – will require changes in the way we produce and consume energy products and services. These changes may be partly behavioural but will be mainly technical (see Box 6). By technical change we include here the development of new technologies, their dissemination in the marketplace, and technology transfer between countries.

It is possible to induce technical and behavioural change through the use of a number of policy instruments (see, e.g., IEA, 2000c). However, ascertaining the effectiveness of those instruments – and therefore judging the stringency with which they need to be applied – requires a clear understanding of how such change is induced, and whether there are specific directions in determining which technologies to promote.

LEARNING-BY-DOING

The view that technology deployment in the marketplace – not only research and development efforts – is a key element to speed up technical change, is borne out by lessons from past technological developments[12]. They reveal that the costs of technologies decrease as total unit volume rises. The metric of such change is the "progress ratio", defined as the reduction of cost as a consequence of the doubling of cumulative installed technology. This ratio has proven roughly constant for most technologies – although it differs significantly from one technology to another. However, the fact that the progress ratio is usually constant means that technologies learn faster from market experiences when they are new than when they are mature. The same absolute increase in cumulative production has a more dramatic effect at the beginning of a technology's deployment than it has later on (see IEA, 2000b). This is why new techniques, although more costly at the outset, may become cost-effective

12 It is also backed by recent developments in economic growth theory known as the Schumpeterian view on economic growth and technical change. The essential characteristic of this view is the occurrence of a succession of innovations in one or more sectors, resulting from research activities and made more rapid through a business stealing effect. See, e.g., Mulder et al, 2001.

Box 6

Technical and behavioural changes

The respective roles of these changes are a matter of debate. The canonical example of purely behavioural change is "switching off the lights when leaving a room" – while technical changes could be replacing incandescent lamps by more efficient compact bulbs or inserting a sensor in the lightning circuit that will automatically shut off the light when the room is empty. Some of the interactions are complex: for example, labelling of appliance efficiencies may modify consumer behaviour – which in turn creates competitive pressures for the development of more efficient technologies.

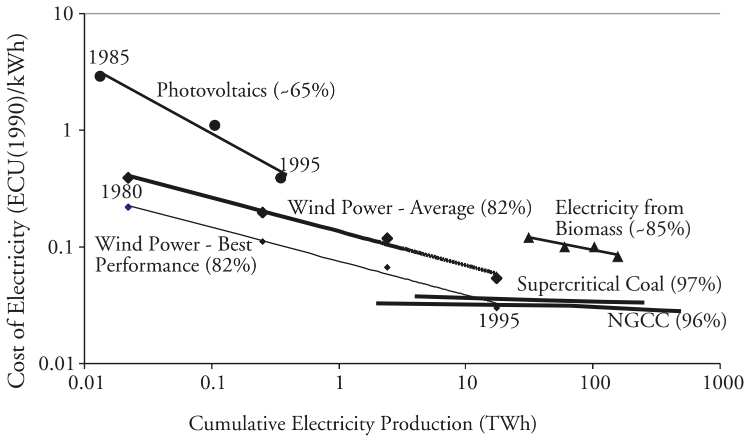
There are many cases where technical and behavioural changes are interlinked. For example, the choice of riding a bicycle rather than driving a car or taking public transport for short distances may be thought of as purely behavioural or individual. But this choice may also stem from a determination of the relative safety of the two choices – which itself depends on the building of bicycle paths. The case for using a mass-transit system may be affected by parameters such as its proximity, frequency, comfort, safety, and cost. In some cases technical and behavioural components are even more closely linked. To choose to buy a "hybrid" car, twice as energy efficient because it associates a small thermal engine with an electric one, currently implies accepting that driving faster than certain speeds is only possible for short periods.

Another problem is the "rebound effect" – when technical changes reduce the costs of an activity, leading to increases in that particular activity. For instance, more-efficient cars might be able to travel longer distances at lower cost – but the lower cost may induce drivers to use their cars more frequently and for longer trips – offsetting some of the efficiency gains. The increase in real income derived from increases in efficiency can also be used for other activities – some of which may themselves lead to increases in emissions.

Some policies are designed to induce technical change (e.g., funding for R&D), while others are primarily focused on behavioural changes (e.g., daylight saving time in winter and summer; awareness campaigns; etc.). Still other policies seek to influence both (e.g., taxes).

Figure 8

Electric Technologies in EU 1980-1995



Numbers in parenthesis are estimates of progress ratios. They indicate the change in cost when market size doubles. Thus, for example, if the size of PV markets double, the cost of PV electricity is reduced to 65% of its previous value. *Source:* IEA, 2000b

over time if they benefit from sufficient dissemination. Figure 8 below shows this phenomenon in the power-generating sector.

In many cases, niche markets allow the deployment required to drive sufficient cost reductions to make the technologies commercial in other arenas. However, policies can speed up – or slow down – this penetration. In some cases, new technologies may be locked out; in others, certain technologies can be advantaged and outpace their competitors.

Projecting forward using concepts of learning-by-doing is risky; there is a clear indication that some mature technologies no longer follow the progress ratio of their early development. However, the concept does seem to be robust for many of the new technologies such as renewable energy. Using these ratios, it is possible to gain some idea of how competitive advantages may change with time. For example, in photovoltaics, a break-even point with fossil fuels might be expected around 2025 if historical growth at 15 per cent per year continues. Much of the progress in PV growth is supported through niche markets – in remote places where photovoltaics are already the most cost-effective solution. In the case of wind power, market deployment has increased in a number of countries where policies drive consumers to pay extra for wind power. The US in the

1980s, and Denmark in the 1990s were the main leaders, and more recently Germany, Spain and India have seen extensive growth in wind generation. These extra prices constitute "learning investments" – cumulative costs for supporting new technology.

This "learning-by-doing" concept of technical change provides a strong argument in favour of global early action (see Grubb, 1997, OECD, 1999). However, it does not provide guidance on how to induce change – i.e., what policies to adopt to make new, climate-friendly technologies fully economically competitive.

CO-ORDINATED POLICIES AND MEASURES

A number of questions arise when considering the tools to promote technical change.

Is the manner of inducing change necessarily a matter for international negotiation? If a global agreement is reached on targets, the choice of how to induce that change might well be better left to purely domestic decisions, and based on specific national circumstances. In fact, this is the choice that was made during the course of the UNFCCC and Kyoto negotiations: the international community established only an "indicative" list of policies and measures under Article 2 of the Kyoto Protocol, and set no requirements for any country on how to achieve the agreed targets.

Of course, the caps that were agreed by individual countries act as significant incentives to create new technology options. This occurs directly – when governments, in seeking to meet their targets, mandate the use of new technologies such as renewable power. It also occurs indirectly: the mere existence of a cap imposes a commodity scarcity – and under market structures, imposes a price. Technology responds to price mechanisms.

However, there may be other means to induce change.

The value of co-ordinated policies and measures has been the subject of a long-standing debate amongst countries. While it has not formally adopted such a policy structure, the Conference of the Parties recognises its possible value: Article 2 of the Kyoto Protocol requires co-operation between industrialised countries "to enhance the individual and combined effectiveness of their policies and measures". The consideration of the ways and means to co-ordinate certain policies and measures devolves to the Meeting of the Parties to the Protocol if it decides that it would be beneficial to do so.

Clearly, there are a number of policies and measures that could benefit from international co-ordination – or that could simply be made possible through it. International markets for goods such as automobiles or appliances become fragmented if each country sets its own emission or energy efficiency standards, and this fragmentation has a cost. Conversely, the promotion of new, low- or no-carbon emitting energy technologies could greatly benefit from concerted efforts to expand current markets. However, beyond these obvious advantages to international co-operation, the debate on co-ordinated policies and measures has also involved an (albeit partially hidden) debate on the value of co-ordinated price policies, and in particular on carbon taxes.

Co-ordinated carbon taxes

Taxing carbon is one way to charge for carbon emissions, and thus encourage their reduction. Taxes give price signals to economic agents through markets, while leaving each of them free to reduce emissions – or pay for them. As revenue raising would not (presumably) be the main purpose of such tax policies, carbon taxes could enable reductions to be made in other taxes or charges and facilitate some other policy goal – such as reducing unemployment. This "double dividend" would thus reduce the cost of the climate policy. A number of European countries have already introduced carbon taxes as one of the policy tools to meet national emissions targets.

As extensively discussed in the literature (see Cooper, 1998; Nordhaus, 2002; OECD, 1999; etc.), co-ordinated carbon taxes could offer an alternative form for an international agreement. Economically, such an agreement would be as cost-effective as one based on quantitative targets with emissions trading: cost-effectiveness is obtained by equalising marginal costs of abatement efforts within and between countries. In fact, all economic general equilibrium models use taxes to simulate efficient policy actions! Finally, given the main feature of the climate change problem – in particular the fact that abatement costs are linked to current emissions, while abatement benefits are linked to much slower concentration changes – prices ought to be preferred to quantity instruments, as discussed earlier[13].

However, the idea of co-ordinating global efforts through co-ordinated implementation of pure price instruments has proven unsuccessful in the course of climate negotiations. In particular, countries are reluctant to accept the "intrusion" into their domestic policies that such a scheme would necessitate. Carbon taxes seem politically difficult to introduce, and often incur opposition, including from energy-intensive industries, whose profitability is often better preserved through some free allocation of tradable permits. Moreover, co-ordinated carbon taxes do not provide an efficient means to incorporate countries with very different levels of willingness-to-pay into a single, integrated framework. In this respect, carbon taxes would do little to help extend existing agreements to new countries, even though such an extension would increase the agreement's cost-effectiveness and reduce the risks of leakage. Finally, it is not clear that taxes are universally effective in reducing emissions. For example, in situations of market power (such as that existing in oil markets), widespread carbon taxes might be offset through the willingness of the monopoly powers to reduce their share of the rents – leaving the level of end-use prices unchanged.

An agreement to promote backstop technologies

Low- or no-carbon emitting energy technologies have many characteristics of a public good – especially when the carbon externality is not reflected in prices. As an alternative to both the international cap and the GHG pricing mechanism, one possible way of promoting technical change could be a concerted effort to promote a small number of selected "backstop" technologies – those that offer a great potential for providing energy with no or few carbon dioxide emissions. These could include, for example, carbon storage and recovery in the power sector and/or

13 In Chapter 1 and in the Appendix.

liquefaction of coal, off-shore wind power technologies, concentrating solar technologies, safe nuclear technologies, and fuel cells.

The focus of such an effort would be on accelerating the "learning-by-doing" process that might bring technologies more rapidly into the market, and ultimately make them fully competitive. Such an approach could be valuable particularly for those technologies that are still high on the learning curve, e.g., for technologies that have no niche markets, or are not competitive under current economic conditions.

Promoting such technologies by "internalising the externality cost" would be the perfect answer from an economic standpoint. However, for political economy reasons, such pricing policies could be difficult to implement. A second-best solution would be to subsidise clean technologies directly. The insufficient market production of public goods is the canonical justification for subsidies. It is fair to say, however, that countries with a development policy for new technologies usually enjoy direct benefits in terms of industry competitiveness – as is currently the case for the US, Danish and German wind power industries.

However, within a global agreement, countries are likely to provide more subsidies than they would in isolation: basic research and development, with relatively long payback periods (although high benefits) can best be supplied co-operatively. Numerous examples of such co-operative ventures are provided by the IEA's "implementing agreements"– more than 40 international collaborative energy research, development and demonstration projects[14]. Other examples can be found with the Climate Technology Initiative or the Global Environment Facility – in particular its operating programme n°7.

There is little doubt that more could be done in this respect. New international agreements focusing on climate backstop technologies could, *inter alia*, aim at linking together existing technology promotion efforts – for example, those introduced by the G8 strategy to promote renewable energy sources, and the still embryonic technology transfer mechanisms under the Climate Convention. Such links might provide a more organised and aggressive strategy to speed up the development and

14 See the IEA website: www.iea.org and more specifically www.iea.org/techno/index.htm

Box 7

The GEF and "backstop technologies"

One of the objectives of the seventh Operational Programme of the Global Environmental Facility (GEF) is the reduction of greenhouse gas emissions from anthropogenic sources by increasing the market share of low greenhouse gas-emitting technologies. The focus is on technologies that have not yet become widespread, least-cost alternatives in recipient countries, but where technical (and economic) potential exists for specified applications. The objective is to be achieved through tools such as purchase agreements, and the aim is to increase installed capacity – thereby improving learning, and taking advantage of economies of scale. Ultimately, it is anticipated that energy costs will decline to commercially competitive levels, rendering further GEF assistance unnecessary. Several backstop technologies for both supply and demand sides are to be considered. Initially, following consultations with the GEF Scientific and Technical Advisory Panel, the following supply-side technologies are to be emphasised:

(a) Photovoltaics for grid-connected bulk power and distributed power (grid reinforcement and loss reduction) applications;

(b) Advanced biomass power through biomass gasification and gas turbines;

(c) Advanced biomass feedstock to liquid fuels conversion processes;

(d) Solar thermal-electric technologies in high insulation regions, initially emphasising the proven parabolic trough variant for electric power generation;

(e) Wind power for large-scale grid-connected applications;

(f) Fuel cells, initially for mass transportation and distributed combined heat and power applications; and

(g) Advanced fossil fuel gasification and power generation technologies, initially to include integrated coal gasification/combined cycle technologies.

Other solar thermal technologies (central receivers or parabolic dishes) or other fuel cell technologies (molten carbonate, solid oxide, and proton exchange membrane) may be considered for programmatic support in the future.

dissemination of these technologies than that offered by independent national efforts.

Might such a technology approach be an effective alternative to global GHG caps or GHG pricing policies? The problem is primarily one of timing. As discussed in Chapter 1, to keep all future concentration options open requires prompt and aggressive near-term action. In the near term, it is unlikely that major new technology development and penetration can be accomplished without substantial costs. Most analyses suggest that the main near-term alternative for abatement is energy savings – and "hundreds of technologies" in all areas, according to the IPCC, are required to provide these savings. Launching separate technology agreements in each of these areas would be a daunting and probably unsuccessful process.

A separate problem with such an approach lies in the difficulty in choosing which technologies to select for subsidisation. History has shown that governments are often less effective at "picking winners". However, such a concern could be overcome if the selection process was made by the market – with governments offering purchase agreements for technologies that meet certain specified criteria – rather than picking specific technologies.

Notwithstanding these potential drawbacks, a number of recent proposals have been made for technology-based international agreements as successors to the Kyoto Protocol. Scott Barrett (2001) suggests the negotiation of a new agreement focusing on R&D funding. While such an agreement might complement the current Kyoto Protocol, Barrett maintains that over time it could fully replace it. Under his proposal, base-level contributions would be determined on the basis of both ability and willingness to pay, and could be set according to the United Nations scale of assessments. To provide incentives for participation, each country's contribution to the collaborative effort would be contingent on the total level of participation. The research emphasis would be on electric power and transportation. This would be a "push" programme for R&D – a dimension absent from the Kyoto approach.

However, Barrett also proposes a complementary "pull" incentive to encourage compliance and participation. He suggests that the most attractive approach would be to agree on common standards for technologies identified by the collective R&D effort, and established in complementary protocols. As examples, energy efficiency standards could be established for automobiles, requiring the use of new hybrid engines or fuel cells, or standards for fossil fuel fired power plants might require capture and storage.

A standards-based approach was also advocated by Edmonds & Wise (1999). Under their hypothetical protocol, any new fossil fuel electric power plant and any new synthetic fuels plant installed in industrialised countries after 2020 would be required to capture and dispose of any carbon dioxide from its exhaust stream or conversion processes. Developing countries would undertake the same obligations when their per capita income equals the average for industrialised countries in 2020 in purchasing power parity terms.

The proposal is built on the idea that given the finite oil and gas resources, the climate change problem would be solved if coal could be displaced. Part of the merit of this idea lies in its simplicity – it may be easier to "sell" to politicians than the complex structures of taxes, or cap-and-trade regimes that are currently in vogue with analysts. In addition, such a proposal does not take on the entirety of global industry – but only focuses on a single sector – and one that collectively, within OECD countries, employs a relatively small total number of people.

However, the Edmonds and Wise proposal would need to overcome a number of significant hurdles: there are likely to be huge difficulties in getting a global agreement that would require either abandoning coal or exploiting it only with additional costs; this will be particularly problematic in countries that have vast reserves – and even more so in countries with no immediate alternative power options. Even for countries that do not use coal in their power mix, the increased demand for alternative fuels once coal had been displaced would be certain to drive up electricity costs – at least until a backstop technology had been developed. Edmonds & Wise themselves recognise that the cost of achieving a given concentration level with such a protocol would be 30 per cent higher than the economically efficient cases of taxes or tradable permits. This estimate may even be too low, as the structure of the agreement would not encourage some of the most cost-effective energy efficiency improvements. In addition, while the number of coal miners may constitute a small proportion of the population, efforts to disadvantage them through government action have proven extremely difficult to introduce. In the UK, efforts to close down money-losing coal mining operations took decades. In Germany, in spite of the multi-billion-dollar/year cost, coal subsidies are maintained to provide jobs to a very small mining community, and coal capacity is seen as an important contribution to national energy security goals.

While the near-term potential for a narrowly focused technology agreement does not seem to provide an adequate "solution" to the climate problem, the same may not be true over the longer term. Ultimately, solving the problem will require huge reductions in emissions – essentially decarbonising the world's energy system. Current technologies are not available to do this on the scale required. Options such as large-scale capture and storage (see Chapter 2), or enormous reductions in costs and increases in capacity of nuclear or renewable energy would be needed to meet this goal. Massive R&D investments would seem to be critical over the longer term – and inasmuch as these can be enhanced through international co-operation, agreements may indeed provide the critical missing element to a successful next step.

In sum, the adoption of more comprehensive and aggressive international agreements to promote world-wide a handful of backstop energy technologies with large potential would add a "push" to the research and development of these technologies. This could be extremely valuable in the absence of a global agreement that directly or indirectly imposed a price on carbon emissions - but is unlikely to fully substitute for such an agreement.

ANCILLARY BENEFITS AND SUSTAINABLE DEVELOPMENT

While inducing technical change directly is the focus of considerable attention, solutions to the climate change problem may also come about from indirect efforts. These may take two forms: *i)* benefits in other areas as a result of action to mitigate climate change, and *ii)* benefits to climate change from policies in other areas. Both may be referred to as 'ancillary benefits".

The lure of ancillary benefits provides significant incentives for policy action on climate change both in developing and developed countries. Analyses of ancillary benefits from OECD countries' policies to mitigate climate change indicate that they could offset as much as 30 per cent of mitigation costs. Such analyses assess, *inter alia*, air pollution and related human health effects of GHG mitigation measures. Other OECD work assesses the extent of ancillary benefits in selected developing countries (Brazil, Chile, and China) in close consultation with national experts (OECD, 2000). Local air and water pollution has long been associated with urban areas in many developing countries. The use of coal and non-commercial energies accounts for a high share of energy use, giving rise to acute levels of indoor and ambient air pollution. Increasing energy efficiency, switching from coal to gas or electricity, and promoting clean uses of renewable energy sources could simultaneously reduce local air pollution and greenhouse gas emissions.

Other types of ancillary benefits exist, though they have been studied less extensively. Reducing emissions from the transport sector, for example, could lead to policies aimed at increasing different modes of transport other than the use of the private car, thereby reducing congestion, traffic noise and road accidents, and facilitating personal mobility. Switching away from imported fossil fuels toward domestic renewable resources could add an energy security benefit to health and environment benefits, as well as increasing energy efficiency in all sectors.

Another important arena for such ancillary benefits is that of energy subsidy removal. Subsidies entail costs, and often fail to achieve their intended goals, such as facilitating access to energy services by the poor. This is often the case in the power sector: subsidies often go to the high- or middle-income populations that have access to electricity, but deprive utilities of the necessary resources to extend their grids and build new generating capacities.

IEA and OECD studies (see, e.g. IEA, 1999 and IEA, 2000a) have examined the implications of subsidy removals in the energy sector and conclude that considerable CO_2 emissions reductions would accrue from such policies. For a sample of eight countries – China, India, Indonesia, Iran, Kazakhstan, Russia, South Africa and Venezuela – energy subsidy removal could lead to an average of 15 per cent reductions in CO_2 emissions from business-as-usual. Cumulatively, from these eight countries alone, global emissions would be reduced by more than 4 per cent.

However, caution must be exercised in removing subsidies. In some cases, they support cleaner fuels or cleaner appliances. For example, some countries subsidise gas or kerosene lamps or stoves, providing immense health benefits. While the climate benefits of the alternatives (often combustible waste or biomass) may be superior, the new fuels provide direct and immediate health benefits, particularly in countries where indoor air pollution is one of the major factors contributing to morbidity and mortality in women and children.

Studies have pointed to a large number of relevant policy actions being taken in developing countries (Reid & Goldemberg, 1998). Many of these policies have been adopted for reasons independent of climate change – but have had enormous emissions reduction benefits, as illustrated by the case of China (see Box 8). A similar trend also seems to be developing in India, where CO_2 emissions have almost stabilised since 1997.

There is a general consensus that ancillary benefits should be taken into account in considering climate policies – as they might reduce their costs. However, climate policies might also have ancillary costs (beyond direct abatement costs). An example already mentioned is the risk of constraining the removal of biomass fuels burned in an unhealthy fashion. In countries with large coal reserves but low gas resources, fuel switching might reduce, not increase, energy security. Ancillary benefits must then be compared to similar benefits that would arise from more direct policies. Local environmental benefits could be significant if a more efficient design is chosen for a coal-fired power plant, in the absence of an end-of-pipe device. However, if SO_x and particulate emissions are the primary concern, scrubbers and filters would provide a higher level of abatement – but the benefits from improved energy efficiency would be scaled down.

Ancillary benefits have many links to the concept of sustainable development and in particular its environmental dimension (see, e.g., Biagini, 2000; IEA 2001c). Sustainable development, however, cannot ignore the global benefits of mitigating policies. As the IPCC (2001,

Box 8

China reduces CO_2 emissions

Chinese CO_2 emissions peaked in 1996 at 3.2 Gt CO_2 and have declined every year since then, although China's GDP has continued to grow. While questions have been raised as to the precise extent of the reductions (they may be exaggerated due to methods of calculating emissions, particularly from coal), the de-coupling between economic growth and CO_2 emissions seems real and impressive. China is the world's largest coal consumer, and second in CO_2 emissions after the USA. Energy-efficiency improvements are the most probable explanation; Chinese policy, combined with a degree of market opening, has led to a pronounced decline in energy intensity (albeit from initially quite high levels). Price reform and liberalisation, subsidy removal, pollution taxation and legislation tightening can be expected to continue to foster additional improvements. Furthermore, thousands of small (and inefficient) coal mines and small industries have closed down for economic and environmental reasons – and most of the industry growth has occurred in recent years in newly-built, more-efficient, cleaner and larger plants.

It is hard to guess, however, whether this emission reduction will continue, or whether, with some of the larger inefficiencies eliminated, emissions will again become coupled to GDP (for a discussion, see Sinton & Fridley, 2000).

Synthesis Report) notes, local, regional and global environmental issues often combine in ways that jointly affect the sustainable meeting of human needs. Several environmental issues – air pollution, biodiversity, land degradation and desertification, fresh water degradation – are linked with climate change *via* both common biogeochemical and socio-economic processes. These interactions offer opportunities to capture synergies in developing response options, enhancing benefits and reducing costs. Moreover, approaches that exploit synergies between environmental policies and key national socio-economic objectives like growth and equity could help mitigate and reduce vulnerability to climate change, as well as promote sustainable development. The application of supply- and demand-side energy-efficient technologies, for example, simultaneously reduces various energy-related environmental impacts and can lower the pressure on energy investments, enhance energy reserves and facilitate access to energy services. The same would probably apply to sustainable transport or land-use policies, with many other ancillary benefits.

Policy implications are less clear. Ancillary benefits might help countries adopt or strengthen climate commitments – but may not be sufficient for the majority of developing countries to take on stringent targets such as those adopted under Kyoto by the Annex I Parties. For these countries, the concept of possible climate benefits from non-climate policies might be more attractive.

The multiple and complex linkages between climate change and sustainable development require policy integration at all levels (Beg et al., 2002). This does not necessarily mean that the climate change negotiating process should be merged into the broader sustainable development agenda. Mitigating climate change requires urgent and specific action: its solution cannot be made dependent on solving all other pressing needs. Unless we are prepared to accept high atmospheric CO_2 concentrations, we cannot afford to wait for action to be taken – and this cannot wait until all other development problems have been solved in developing countries. The threat of climate change certainly strengthens the sense of responsibility, and reinforces public opinion on the importance of supporting developing countries. Beyond its environmental benefits, co-operating to solve climate change at a global level might also become an opportunity for sustainable development, and help build more confidence in international relationships.

PROMISES AND LIMITS OF FINANCIAL ASSISTANCE AND THE CLEAN DEVELOPMENT MECHANISM

The effort to induce technical change has several components, including both the development and the diffusion of technologies. While the preceding discussion has focused mostly on development, it is also useful to consider policy instruments that may foster dissemination. Over the past few decades, the primary policy tool to promote the spread of technology to the developing world has been financial assistance – either through grants or through preferential or concessional loans. In the course of climate negotiations, a new instrument has also been added: the Clean Development Mechanism (CDM).

Financing under the Convention and the Protocol now takes a number of different avenues. The Global Environmental Facility is the main "financial mechanism" of the Convention, though it also addresses biodiversity, international waters and ozone depletion, and finances project in economies in transition as well as in developing countries. Since its inception, the GEF has given $1 billion for climate change projects and leveraged more than $5 billion in co-financing. Usually, GEF funds are linked to other loans from multilateral institutions (e.g, the IBRD or the ADB); they are also linked to projects financed with national or bilateral funds. More than half has been devoted to renewable energy projects in 47 developing and transitional countries. While GEF funds have increased slightly over time, they are not considered adequate to address climate issues.

The Marrakech Accords instituted three new funds: *i)* a Special Climate Change Fund under the Convention to provide additional assistance for adaptation, technology transfer, energy, transport, industry, agriculture, forestry, and waste management, and broad-based economic diversification; *ii)* a Least Developed Country Fund, also under the auspices of the Convention, to support these countries, primarily in their effort to adapt to climate change; and *iii)* a Kyoto Protocol Adaptation Fund to finance adaptation to climate change; this last fund is to be financed by the CDM levy as well as voluntary contributions.

What these funds will be able to deliver remains an open question. They have been created in a context of declining funding of official development assistance (ODA) and, more generally, in a context of increasing scarcity of public spending in most OECD countries. Many observers believe that while they will help to finance capacity building at national levels, they will never be large enough to finance the bulk of costs associated with the profound changes in the energy sector required to promote development while reducing global emissions.

Concerns about the adequacy of funding, an interest in lower-cost opportunities for Annex I emissions reductions, and an interest in engaging non-Annex I Parties in actions to mitigate climate change largely drove the negotiators at Kyoto to create the Clean Development Mechanism, one of the most innovative features of the Kyoto Protocol. While the GEF and other Funds rest on public financing, the CDM is intended to facilitate the financing of emissions reductions in developing countries and technology transfer from the private sector.

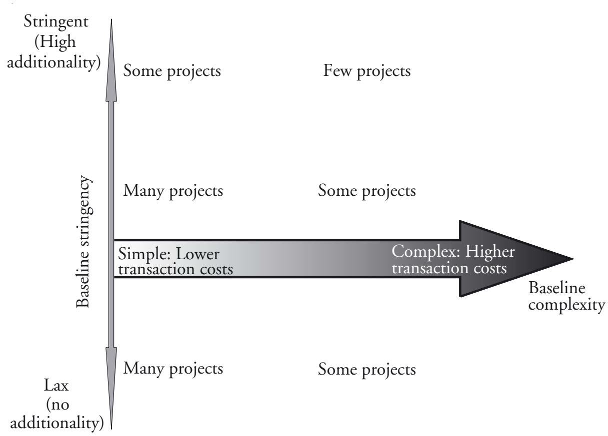
The CDM's objective is to assist developing countries in achieving sustainable development. At the same time, it aims to contribute to the ultimate objective of the Convention, in part by assisting industrialised countries in achieving compliance with their quantified emission limitation and reduction commitments. The main difficulties in making the CDM work arise from the twin issues of "additionality" and "baselining". To obtain "certified emission reductions" – that is, new emission rights – from investments in developing countries, investors must demonstrate that emission reductions are "additional to any that would occur in the absence of the certified project activity". Ways and means to determine that additionality and to establish relevant "baseline" emission scenarios that would allow calculating the amounts of emission rights that could accrue from each project have been – and still are – subject to intense research and debate.

However, for the purposes of considering the next steps to mitigate climate change, only a few key issues are relevant: whether the CDM will work; whether the number of projects flowing through the CDM pipeline will be large enough to affect developing country emissions; and whether the CDM mechanism can establish sufficient incentives to promote the development and dissemination of new technology.

The jury is still out on how effectively the CDM will work. Proposals to restrict the number of projects accepted (through legitimate fears that some projects might not actually contribute to "real" reductions) are frequently made by Parties. Ultimately, if too few projects are allowed through, the net environmental benefits will be lower – even if each individual project is environmentally better. If, on the other hand, too many of these projects "would have happened anyway", not only will the global level of emissions increase above agreed levels (Bernow et al., 2001) but, perhaps more importantly, truly additional projects that would expand niche markets for new technologies may be crowded out (see Figure 9).

Figure 9

Possible effect of baseline stringency and complexity on project numbers and a project's environmental additionality (from OCDE/IEA, 2000)



Information from economic models does provide some context for assessing the environmental and financial potential of the CDM regime. In simple terms, CDM can be modelled as emissions trading with some transactions costs. Thus, models that examine the benefits of global trading can provide some estimate of both the volume of CO_2 reductions that would be generated through projects, and the financial revenues such projects would generate for clean technology.

Model results of a "perfect" CDM system suggest annual revenues of about $10 billion/year (presuming US participation). While this represents only about 10 per cent of current foreign direct investment in the developing world, it is likely that a significant share of the investment would be in the energy sector – and could certainly influence the types of technology choices made.

Unfortunately, while total investments may be large, the CDM value of most projects would be relatively small. Some of the most innovative projects may need more than a small carbon price adder to make them commercial – so CDM by itself may not promote market penetration of expensive options without other price supports. These considerations partly explain the decisions at Bonn and Marrakech to develop simplified rules for small-scale projects, notably in the fields of energy efficiency and renewable energy sources. Small projects can hardly afford transaction costs and would benefit from simplified procedures, while any environmental risks in promoting such projects would be minimal.

Another quite different approach to the CDM process has yet to be legally tested in the political arena of the UNFCCC. Under this interpretation, policies may be defined as CDM projects – and governments could get CDM credit for adopting them as long as the results could be quantified, and additionality was verifiable. An example of such a programme might be an effort by a city to put in new bus lanes, or set renewable energy targets. If the GHG reductions from these plans could be assessed, the credits they generate could be offered on the international market. In such a case, the CDM process would have characteristics more closely related to the emissions trading regime – and could bring significant benefits both in terms of technology development – and in terms of engaging developing countries in the climate mitigation effort. A possible additional advantage of CDM projects under a so-called "unilateral" scheme would be – as with emissions trading – that the host country could get a share of the "surplus" – the difference between local abatement cost and international permit price.

Technology development and diffusion is a relatively slow process. However, it is clear that it is critical to solving the climate change problem – and that we must take full advantage of all the means at our disposal to facilitate its further and more rapid evolution and widespread penetration. In both the near and long term, countries will continue to have higher environment and development priorities than climate change. This is particularly true for developing countries, where the immediate needs for food, water and health pre-empt other secondary and longer-term questions. However, policy tools do exist to promote the technologies that will be needed to mitigate climate change, even when it may not be a high priority issue. Governments, particularly governments in industrialised countries, can reap both direct and indirect benefits from undertaking such policies.

FUTURE COMMITMENTS: TIMING, ALLOCATION AND STRUCTURE

At Kyoto, assigned amounts were set in a largely political process with little underlying analysis of its implications – and even less transparency. The magnitude of the overall commitment, and the differentiation that resulted from the process have been questioned by a number of commentators. Berk and den Elzen (2001), for example, noted that "*In order to secure the participation of all developed countries, the negotiations have resulted in a situation where countries that bargained hard got exceptional allowances, while others committed themselves to lower targets than they were originally willing to accept. Thus, without accepted principles and rules for determining a fair differentiation of commitments, negotiations resulted in a watering down of the overall emission reduction target and weakened the principle that all developed countries should lead by reducing their emissions.*"

While it is likely that in the next "round" of climate negotiations political processes will again have the final word, it is possible that an agreement on some rules, guidelines or principles to establish future assigned amounts will facilitate this political process. Three different but related questions should be considered:

- Timing: when should (or could) additional countries take on commitments?
- Allocation: how to share emission reductions – or emission "rights" (or assigned amounts in the Kyoto Protocol language)?
- Form: is a Kyoto-like fixed legally-binding target the best option for developing countries or even for industrialised countries – and should differentiation of commitments extend from setting the numbers to shaping the nature of targets?

The discussion on timing and differentiation dates back to even before the signing of the UN Convention. This long-standing debate overflows into formal negotiations from hotly debated philosophical issues as well as economic and environmental concerns. However, the equally important question of the form has been raised only recently.

TIMING

As earlier discussions have made clear, to keep open the options for stabilising GHG concentrations, all countries, including all developing countries, must ultimately participate in efforts to reduce emissions. The lower the level of acceptable concentrations, the more rapidly cuts must be introduced – and the greater the participation required to ensure success.

While ultimately developing countries must engage (and if significant climate change is to be avoided, such engagement must come soon), the specific timing of their acceptance of emissions reduction obligations is more difficult to ascertain. Resolving this question will require considering both how the overall obligations for reduction are to be shared among countries, and the capacity of countries to take action.

A number of arguments exist as to why developing countries should take on commitments early. These include:

– reducing global emissions – and thus, the climate change to which developing countries are the most vulnerable;

– early adoption would accelerate the attainment of ancillary benefits (in new technology and often cleaner local environments) brought by many GHG reduction initiatives; and,

– increased foreign direct investment (FDI) and official development assistance (ODA) – a growing share of which is now coupled to climate – and even more of which might flow if commitments were undertaken.

However, developing countries have responded with corresponding (and other) objections:

– near-term actions might make subsequent action more costly;

– developing countries may take local pollution abatement efforts anyway, but do not wish to be bound by climate commitments;

– they have little confidence that foreign assistance would be forthcoming: the declines in levels over the past few decades leave little room for optimism;

– developed countries should act first.

While each of these objections leads to counter-arguments, the political debate is extremely divisive. Some additional analytic rigour, may, however, open other possibilities. Accommodating concerns while moving the system forward argues for a significant level of differentiation in obligations.

The Climate Convention already provides for "timing differentiation" in two aspects: *i)* it allows countries with economies in transition to establish their own base year (and countries have chosen years ranging from 1987 to 1990), and *ii)* it allows least developed countries flexibility in choosing the year for their initial communications. The Kyoto Protocol provides for further timing differentiation by allowing countries to choose whether to use 1990 or 1995 for the base year for CFC substitutes.

There are many different schemes that could be used to determine the timing for future agreements. One way to assess timing parity would be to use the Convention process itself as a model: given that approximately 15 years will have elapsed between the time the Convention entered into force and the time that Annex I Parties would need to have binding commitments, a similar timeframe might be applied to developing countries. Thus, a subsequent negotiation might assign new Party commitments to begin 15 years from the conclusion of the new negotiations. Other existing environmental agreements have used such timing differentiation mechanisms. For example, the Montreal Protocol on Substances That Deplete the Ozone Layer provided for a ten-year lag between the requirements for developed and developing country actions.

Another alternative is to phase in a country's commitment once it has reached a certain level of development. This might be expressed in general terms such as GDP per capita or in more climate relevant terms such as CO_2 or GHG emissions per capita. It is clear that, in general terms, such a distinction was used in deciding how to allocate classifications in the Convention: while no specific index was chosen, OECD countries were grouped together with commitments, while other countries had fewer, or none. Arguably, on both GDP and emissions grounds, they were among the top-ranked countries in the world, and using almost any index, would have been obligated to undertake actions. The other countries included in Annex I of the Convention were part of Eastern Europe or the FSU – and for political reasons insisted that they be classified at the same level as OECD Members. On emissions grounds, these countries too would rank near the top of a global list. For the purposes of adopting commitments, all other countries were exempt.

However, while the ranking of countries may have been accurate at a specific point in time, it is clear that such rankings are ephemeral at best. Today, about twenty-five non-Annex I countries have per capita emissions above those of the lowest Annex I Party, about forty such countries have a per capita GNP (on a purchasing power parity basis) above that of the lowest Annex I Party (see ranking on per capita CO_2 and GDP in Tables 6 and 7). Thus, either a periodically updated list may be necessary, or a switch to an entirely different regime.

Claussen and McNeilly (1998) further codify the differentiation concept for the climate process. Using three criteria – standard of living, historical responsibility and opportunity – to rank countries into groups, they assign to each an informal "timing": the first group "must act now", the second group "should act now, but differently", while the third group "could act now". While the potential concrete implications of this different grouping of countries are not specified, it is worth noting that the first group includes some non-Annex I countries – but does not include all Annex I countries.

Berk and den Elzen (2001) have assessed the compatibility of such "multi-stage" approaches with low CO_2 concentration objectives (a concentration goal of 450 ppm under the A1 emissions scenario – a member of the IPCC Special Report on Emission Scenarios family, see Box 3 and Figure 5 in Chapter 2). They assume that developing countries will take on targets when their per capita income reaches half the 1990 Annex I per capita income. When they reach three-quarters of 1990 Annex I per capita income, it is assumed that developing countries will join the Annex I group. Within this group, the emission reduction burden

Table 6

Countries Ranked on Per Capita Energy-related CO_2 Emissions (2000, tonnes per person)

Rank	FCCC Party	CO_2 per capita	Rank	FCCC Party	CO_2 per capita
1	Qatar	59.99	32	Kazakhstan	8.26
2	Kuwait	31.53	33	New Zealand**	8.26
3	United Arab Emirates	23.66	34	Austria**	7.74
4	USA**	20.57	35	Iceland**	7.69
5	Bahrain	20.44	36	Poland*	7.58
6	Luxembourg**	18.24	37	Norway**	7.48
7	Australia**	17.19	38	Italy**	7.38
8	Canada**	17.13	39	Libya	7.34
9	Netherlands Antilles	15.23	40	Slovenia*	7.27
10	Brunei	14.95	41	Spain**	7.13
11	Saudi Arabia	12.58	42	Slovakia*	7.01
12	Belgium**	11.73	43	South Africa	6.91
13	Trinidad and Tobago	11.63	44	Turkmenistan	6.59
14	Czech Republic*	11.56	45	France**	6.18
15	Netherlands**	11.13	46	Ukraine*	6.08
16	Ireland**	10.88	47	Portugal**	5.96
17	Finland**	10.59	48	Sweden**	5.86
18	Singapore	10.45	49	Malta	5.84
19	Russia*	10.34	50	Switzerland**	5.80
19	Estonia*	10.22	51	Belarus*	5.55
21	Germany**	10.14	52	Hungary*	5.51
22	Israel	10.01	53	Venezuela	5.32
23	Oman	9.82	54	Bulgaria*	5.23
24	Chinese Tapei	9.69	55	Uzbekistan	4.64
25	North Korea	9.51	56	Islam. Rep. Iran	4.59
26	Denmark**	9.38	57	Malaysia	4.56
27	Republic of Korea	9.17	58	Former Yugoslavia	4.31
28	Japan**	9.10	59	Macedonia	4.14
29	United Kingdom**	8.89	60	Croatia*	4.06
30	Cyprus	8.36	61	Bosnia Herzegovina	3.86
31	Greece**	8.31	62	Romania*	3.85

Source: Data from IEA. * indicates Annex-I membership, ** indicates Annex-II membership

Table 7

GNP per capita 2000, Purchasing power parity (international dollars)

1	Luxembourg**	45,470	32	New Zealand**	18,530
2	Liechtenstein	... a	33	Slovenia*	17,310
3	United States **	34,100	34	Korea	17,300
4	Bermuda	... a	35	Portugal**	16,990
5	Switzerland**	30,450	36	Greece**	16,860
6	Norway**	29,630	37	Malta	16,530
7	Iceland**	28,710	38	Bahamas	16,400
8	Cayman Islands	... a	39	Barbados	15,020
9	Belgium**	27,470	40	Bahrain	*14,410* a
10	Denmark**	27,250	41	Czech Republic*	13,780
11	Canada**	27,170	42	Argentina	12,050
12	Japan**	27,080	43	Hungary*	11,990
13	San Marino	... a	44	Saudi Arabia	11,390
14	Austria**	26,330	45	Slovak Republic*	11,040
15	Netherlands**	25,850	46	St. Kitts and Nevis	10,960
16	Monaco**	... a	47	Seychelles	... a
17	Ireland**	25,5270	48	Antigua and Barbuda	10,000
18	Australia**	24,970	49	Mauritius	9,940
19	Germany**	24,920	50	Estonia*	9,340
20	Brunei	*24,910* a	51	South Africa	9,160
21	Singapore	24,910	52	Chile	9,100
22	Finland**	24,570	53	Poland*	9,000
23	France**	24,420	54	Uruguay	8,880
24	Sweden**	23,970	55	Mexico	8,790
25	United Kingdom**	23,550	56	Malaysia	8,330
26	Italy**	23,470	57	Trinidad and Tobago	8,220
27	Cyprus	20,780	58	Russian Federation*	8,010
28	U. Arab Emirates	*19,410* a	59	Costa Rica	7,980
29	Israel	19,330	60	Croatia*	7,960
30	Spain**	19,260	61	Belarus*	7,550
31	Kuwait	18,690	62	Brazil	7,300

Table 7 (continued)

GNP per capita 2000, Purchasing power parity (international dollars)

63	Botswana	7,170	71	Tunisia	6,070
64	Latvia*	7,070	72	Colombia	6,060
65	Turkey	7.030	73	Iran	5,910
66	Lithuania*	6,980	74	Venezuela	5,740
67	Grenada	6,960	75	Dominican Republic	5,710
68	Namibia	6,410	76	Panama	5,680
69	Romania*	6,360	77	Equatorial Guinea	5,600
70	Thailand	6,320	78	Bulgaria*	5,560

Source: Data from World Bank
Notes: a: 2000 data not available; ranking is approximate. Figures in italics are the most recent estimates for 1998 or 1999. * indicates Annex-I membership, ** indicates Annex-II membership

is shared proportionally with their per capita contribution to CO_2-induced temperature increase – following the Brazilian Proposal (Brazil, 1997). Other countries follow their baseline emissions.

Modelling these assumptions using the FAIR model[15] leads to the conclusion that the emission pathway leading to stabilisation at 450 ppm is abandoned in 2020 – even if Annex I country emissions were below zero. The reason is that major developing countries like China and India would only start participating after the middle of this century. Stabilisation at 550 ppm remains possible, but would leave very little emission space for the whole Annex I. As a result, write Berk and den Elzen, "*In the case of stringent climate goals, a per capita income threshold for participating in global emission reduction efforts may result in too long a delay in the participation of non-Annex I regions to meet these goals.*"

As long as the delay in emissions reductions from all nations, including developing countries, continues, the world cannot hope to remain on a low concentration path. It is therefore vital that mechanisms be found to

15 Framework to Assess International Regimes for differentiation of future commitments. Berk & den Elzen suggest de-carbonisation targets or carbon intensity targets that represent one form that "indexed" or dynamic targets could take. However, the form of the target does not influence the result; it is entirely dependent on the assumed timing.

accelerate the phase-in of commitments – if not for all countries, than at least for the large emitters. Establishing a global regime that benefits the whole world – including developing countries – could be a partial solution to this goal.

Ultimately, reducing the issue of differentiation to no more than a question of the delay in the timing of developed and developing country action is likely to be unsatisfactory. Other means, including differentiation in assigned amount levels, or in the form of commitments, may better address developing country concerns and speed up the point at which global emissions begin to decline.

ALLOCATION

There are two basic ways of considering this issue: resource-sharing and burden-sharing. The first of these raises the question of how to allocate global emission rights in a manner compatible with the objective of the Convention. The second concerns how to allocate the efforts needed to depart from business-as-usual emission trends and associated climate risks. While these two opposite paradigms might lead to rather different outcomes, the search for an outcome acceptable by all parties tends to narrow the range of concrete possibilities.

Resource-sharing and equal per capita emission rights

In the context of this approach, the "resource" in question is the ability of the carbon cycle to absorb man-made CO_2 and other greenhouse gases so as to keep their concentrations constant. This defines a level of global emissions compatible with the objective of the Convention. Under a resource allocation scheme, this global amount of emissions would then be allocated to countries, or perhaps to individuals. Both options have adherents in the climate negotiating community.

However, there might be many reasons for per capita emission levels to differ from one country to another, such as climate, natural resources, etc. (see, e.g., Neumayer 2002). Thus, a fair distribution might need to take account of certain national circumstances with global benefits, such as whether a country refines oil, or produces energy-intensive materials (steel, cement, etc.), or extracts clean natural gas (with overall emission reductions but local emission increases). However, differences in economic structure account for far less of the variability in carbon intensity in the industry sector than the energy intensity of the underlying economy (as revealed in "mine-yours" comparisons, Schipper et al, 2001).

Some potentially improbable outcomes might emerge under a strict per capita allocation system. For example, Denmark would pay Norway (or Argentina would pay Brazil) forever for the zero-carbon content of their exported hydropower – even after a safe world level of emissions is reached.

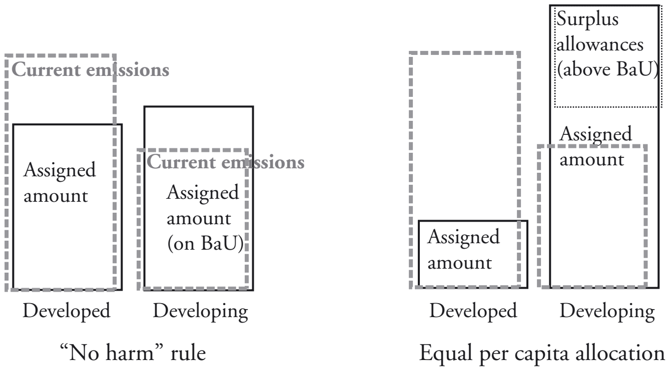
An equal per capita distribution would imply large wealth transfers from the North to the South. Industrial countries would have much less than they are accustomed to using, developing countries much more. If there were no emissions trading under such an allocation, it would prove enormously inefficient economically: no emission reductions would be undertaken in developing countries, where they are likely to be cheaper. Instead, the entire obligation, and hence the reductions, would all take place within industrialised countries, where costs would not be expected to be the cheapest. High costs would in all probability generate resistance to stringent targets – if indeed they were accepted at all.

If emissions trading is allowed, the system becomes more efficient. However, developing countries still receive more emissions allocations than they can possibly use, and industrialised countries much less. Industrialised countries would need to buy surplus emission rights in developing countries. This may have perverse consequences and have a critical impact on the stringency of the targets. This is illustrated in Figure 10. In the case where a significant amount of hot air (surplus emissions rights) is assigned, the majority of the compliance would be in transfers of payments – and not in "real" emissions reductions. As the marginal costs of "real" reductions theoretically drive the price for hot air, and given a likely limit on "willingness to pay", the negotiated outcome would probably be of limited stringency.

It is far from clear whether, in spite of their superficial attractiveness, per capita allocations would indeed be equitable. There is no guarantee that

Figure 10

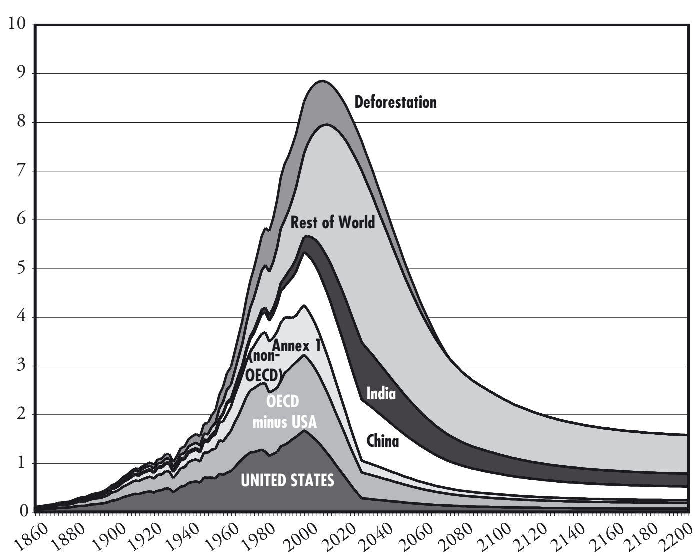
Possible effects of an equal per capita allocation



Respective assigned amounts of developed and developing countries, in solid lines. The dotted lines indicate current emissions of the two groups. In this purely illustrative figure, an illustration of a no-harm rule is shown on the left. Assigned amounts for developed countries represent an absolute reduction (of 25 per cent), while those for developing countries represent an absolute increase (of say, 30 per cent), which is close to business-as-usual (BaU) trends. On balance, there is a 7.5 reduction in global emissions. On the right, an illustration of an equal per capita allocation is given for the same global reduction. The amount of rights that developed countries must buy is more than four times that of actual reductions – and so is the price they should accept to pay.

Figure 11

Contraction and Convergence (CO_2 emissions in GtC)



Source: Global Commons Institute, 2000.

the developing countries receiving surplus permits would be those that suffer the most from climate change. The adaptation fund created by the Marrakech Accords seems to be designed to serve this purpose. Furthermore, while the allocation on a per capita basis might be the intent, the actual practice is more likely to be an allocation to the government on the basis of population – and there is little evidence that state-to-state transfers always yield economic growth and development. It is more probable that this distribution of rights will depress economic growth in the North and thus also in the South. As a result, the situation of the poor in developing countries may worsen.

Contraction and convergence

Given the obvious shortcomings of an immediate "equal per capita" allocation of emission rights that would be compatible with scenarios leading to stabilising GHG concentrations at low levels, their proponents usually see it as a longer-term objective (see, e.g., Agarwal & Narain, 1998; Meyer, 2000). Allocation for near-term targets would thus be an interpolation between current emission levels and a longer-term equal per capita allocation (see Figure 11). Others recognise that per capita allocation does not fully account for differing national circumstances, and suggest that a better solution to the allocation problem would be to mix per capita and other criteria (see, e.g., Aslam, 2002).

This view is partly reflected in the Marrakech Accords (Decision 15/CP7) that states that Annex I Parties shall implement domestic action "*with a view to reducing emissions in a manner conducive to narrowing per capita differences between developed and developing country Parties while working towards achievement of the ultimate objective of the Convention*". If this is the case for domestic action, it may, *a fortiori*, also be the case for emission allocations.

Berk and den Elzen (2001) suggest distributing emission allowances with a global CO_2 emission profile for stabilising CO_2 concentration at 450 ppm, with a linear convergence in per capita emission rights either in 2030 or in 2050. In the case of convergence as early as 2030, allocations for countries like China and India remain constantly above baseline needs, while for industrialised countries reductions by 2030 would be in the range of minus 60 per cent (Western Europe) to minus 75 per cent (North America).

In comparison with the "multi-stage" approach (see above), Berk and den Elzen find that the "*convergence regime offers the best opportunities for exploring cost-reduction options as all parties can fully participate in global emission trading. There may be excess emission allowances (hot air), but this will not affect the effectiveness nor the efficiency of the regime, only the distribution of costs. Second, there will be no so-called carbon leakage.*" However, it should be noted that these advantages are those of any scheme allowing immediate global participation in emissions trading – and not necessarily those of the suggested distribution.

This "contraction and convergence" proposal has some of the shortcomings of an equal per capita allocation – although to a lesser extent – notably creating hot air that should be bought back by industrialised countries. Such an approach might be superior to the "multi-stage" approach in delivering the desired concentration level, as it requires that actual emission reductions begin in developing countries before they reach a given threshold.

However, as with all longer-term commitments, there is a problem in ensuring that future governments in these countries will feel bound by such agreements after they cease to deliver surplus allowances but instead become constraints. In actual practice, this discussion may be entirely moot: developing countries are currently refusing to take on fixed and binding commitments, and no proposal for short-term generous allocation seems to have much likelihood of being accepted. The fear

Box 9

An application of the Triptych Approach:
The European Union and Kyoto

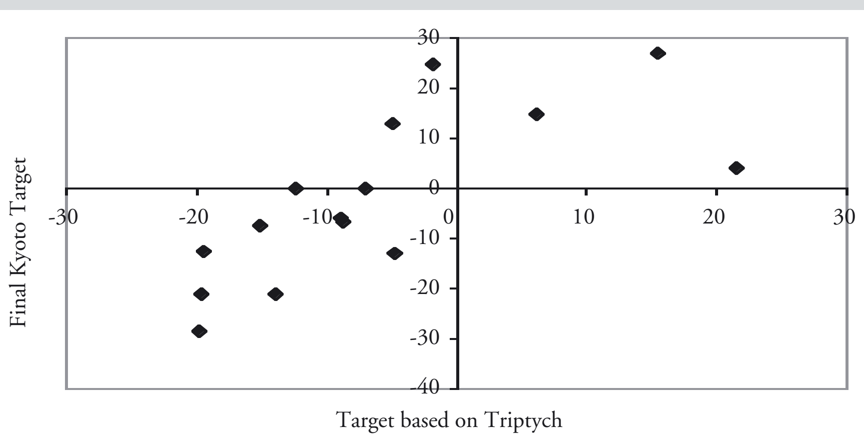
One form of such an analysis was undertaken by the European Union prior to determining the level of its own internal burden sharing. In its assessment (the "Triptych Approach"; described in Phylipsen et al., 1998), levels were determined by dividing emissions into three parts (electricity generation, heavy industry, and domestic sectors), and then establishing targets for each sector and for each country – which were then aggregated to determine a national objective.

Electricity generation emissions were assumed to be highly country specific (largely as a function of different initial fuel sources), but targets limiting growth to less than 1 per cent per year were established. While heavy industry emissions also differed, such differences were smaller than for electricity; in this area, countries agreed to the same fixed emission reduction factor. Finally, it was agreed that countries should move to a per capita convergence with respect to domestic sectors – and a figure of 20 or 30 per cent below 1990 levels in the year 2030 was established for purposes of analysis. Aggregating these sectors provided a range of reductions for European Union members.

As can be seen in Figure 12, there is a reasonable correlation between the reductions derived from this analysis and the first internal burden-sharing agreement reached within the EU following Kyoto. Differences seem to emerge from a consideration of new data, the additional stringency of the targets agreed in Kyoto, and some internal negotiations.

Figure 12

Relationship between EU member country triptych targets and finally-adopted Kyoto targets under burden-sharing arrangement



Source: based on Phylipsen et al., 1998 (with this as with other proposals for current commitments, no matter how weak) is of a progressive "ratcheting" process leading at some future point in time to real constraints on their economic development – and even worse, that such constraints would begin to take effect long before they reach current industrialised countries' levels.

There are a large number of other proposals offering possible solutions to the global burden-sharing issue. Groenenberg et al., 2000, for example, suggest extending the "Triptych approach" that has been used to support the EU burden-sharing agreement to enlighten global burden-sharing negotiations (Box 9). The Triptych approach distinguishes the energy-intensive industry sector, the power sector and the domestic sectors. Another example is the "multi-convergence" approach suggested by Sijm et al. (2001). It combines elements of the "multi-stage" approach, the "Triptych approach" and contraction and convergence.

Burden-sharing and "no harm" rule

Another way of framing the whole issue is that of "burden-sharing" or "cost-sharing". Using this approach, the overall cost of compliance is assessed, and this cost is allocated between countries. A number of approaches have been provided in the literature to evaluate the overall cost – essentially of decarbonising the global economy. As noted in the preceding discussion, the issue of "when" such decarbonisation is achieved will affect the overall levels of atmospheric concentration; it will also affect the cost.

Other alternatives have been suggested to address these issues. One is the "no-harm" rule (after Edmonds et al., 1995), where poor people would have to pay nothing. If objectives were set on the uncontrolled emission baselines for most developing countries, after "win-win" actions have been realised, then any further (and implicitly costly) actions would be financed by industrialised countries through emissions trading (Philibert & Pershing, 2001). Efforts to keep permit allocation as close as possible to their real (and growing) needs while ensuring that they don't have to pay might be reflected in options such as "dynamic targets" and "non-binding targets". Thus, a right to develop would be given to those in developing countries. They would benefit from such an allocation if they could sell permits at an international price for emission reductions that were cheaper. This is not grandfathering: allocation for industrialised countries would decrease over time and would increase for developing countries (to some extent and a certain level of development), but current situations would not be ignored.

Emissions trading: the need for new options

In fact, independent of the allocation regime, the prospects for an equitable solution to the burden-sharing problem are enhanced through the use of emissions trading. Economically efficient allocation would allow cuts to take place where they cost less: (presumably) in developing countries. Numerous modelling exercises (see, e.g., Weyant & Hill, 1999; Babiker & Eckaus, 2000; Rose & Stevens, 2001) have shown how a global trading regime would reduce the overall costs of achieving a given climate target. Global trading could then, in the long run, allow the achievement of more ambitious environmental objectives.

Jean-Marc Burniaux and Paul O'Brien (OECD, 1999) compare three different scenarios for global participation, that lead to three different levels of GHG concentrations by 2200:

- "Kyoto forever": Annex I Parties limit their emissions at the levels specified in the Kyoto Protocol, other countries are not constrained. Atmospheric concentrations would not be stabilised under this scenario;
- "740 ppm", representing a doubling from current concentration;
- "550 ppm", roughly twice the concentration at pre-industrial times.

A comparison of the global economic cost over a 2010-2050 horizon provides striking results: Annex-I countries would spend as much to achieve a "Kyoto forever" emission objective without trading – no stabilisation of concentrations – as they would to reach stabilisation of concentrations at 550 ppm if global emission trading were made possible. Furthermore, most of the scenarios for allocation targets that involve trading deliver net economic (i.e., trading) benefits to non-Annex I regions, from a scenario where they would take no action to reduce their GHG emissions.

Emissions trading allows negotiators to focus on equity criteria rather than on efficiency criteria in making the initial allocation. The best possible outcome for any party in this process is to have to support zero cost – that is, to be allowed to emit greenhouse gases at the same rate as it might have in the absence of any need to address climate change. In cases where ability to pay, or responsibility for the effect of climate change effects is the determining factor, it is fair that most developing countries would not have to pay for mitigating climate change. However, in cases where polluter pays rules apply, all countries would need to take steps.

Developing countries, however, have also expressed a different kind of concern about emissions trading – or even the Clean Development Mechanism. Mwandosya (2000), reflects a common argument in the negotiations: if cheaper options (often called low-hanging fruit) in the reduction of emissions existing in developing countries are sold through the mechanisms, once developing countries take on their own commitments, only the more expensive options for reductions would then be available to them. However, cheap emission reduction options in developing countries arise in large part from the fact that they are building their infrastructures anew. Were they to do so following high-emission paths, most of these cheap options would simply no longer be available.

The task is to find solutions that balance the principles of equity in a way that induces acceptability. To date, the UNFCCC represents one example of success; with the withdrawal of the US from the Kyoto Protocol, it is clearly less effective as a paradigm. Next steps must build on successes as a way forward.

Box 10

Meanings of equity and acceptability

It is often said that equity is the key to acceptability. This is probably true in general terms, but it may be useful to distinguish between distributive justice and procedural equity. Regarding the former, there are multiple equity principles (and all have adherents and opponents), and the debate between them has coloured the interpretation of the allocation issue. According to the IPCC, more than a dozen different equity rules are defined and extensively discussed in the literature (see IPCC, 2001, Vol. 3, Chapter 10). These range from egalitarian rules (where equal rights are assigned on a per capita basis), to sovereignty rules (where allocation is to governments), to ability to pay rules (varying according to national well-being), to polluter pays (where abatement costs are distributed in proportion to emissions levels), to utilitarian rules (where the goal is the greatest happiness for the greatest number), to procedural equity (related to how a decision is made).

Acceptability is linked to the relationship between each party's expectations from an agreement and what it would achieve without it, that is, the reference situation. If all parties to an agreement benefit, it is likely to go forward. Not all systems of allocation – even if they have a degree of distributive justice – would necessarily be considered acceptable by all parties; this is particularly the case in which, for one Party, the distribution entails losses. In cases where decisions (such as international agreements) are determined by consensus, it is unlikely that action will be taken where any Party feels disadvantaged, and where it has the capacity to block the agreement. It is only where a majority rule is adopted (as in most national frameworks) that redistributive measures might be imposed, despite the opposition of those who will incur losses (see, e.g., Godard, 2000).

OPTIONS FOR FUTURE AGREEMENTS

In the preceding chapters we have discussed several alternative approaches to addressing climate change – as well as some of the key criteria that any successful approach must consider. It is clear that until scientific uncertainties have been resolved, any agreement must aim for the lowest possible emission or concentration levels that are feasible – recognising that their achievement would be constrained by costs. Because national circumstances differ significantly, any agreement must reflect these differences between countries. And finally, a new agreement must engage all countries, because any agreement that omits a large share of global emissions will not succeed in addressing the problem. This chapter seeks to develop further possible ideas on instruments that meet these criteria.

UNCERTAINTIES ARE THE PROBLEM

While the issue of scientific uncertainties has been discussed in Chapter 1, the issue of uncertainties in the cost of mitigation is equally troubling for the policy-making community. If too much is spent on programmes to mitigate climate change, other, equally pressing programmes could go unfunded. Conversely, if not enough is spent, emissions will rise, and the consequences of global warming, which might have been avoided, are manifest.

Any solution would have to address these two issues. Setting an ambitious climate goal through emissions targets, but qualifying them with a cap on the price, is a potentially pragmatic mechanism that meets both concerns. Such a hybrid mechanism could help industrialised countries take on progressively heavier commitments by removing concerns about possible skyrocketing costs. Such a mechanism could have an even greater impact in developing countries, many of which may be willing to engage in specific and binding commitments if legitimate concerns about possible constraints on their economic development are removed. For this to work, two further sets of issues must be resolved: the form of the quantitative emissions limits, and issues pertaining to the price cap.

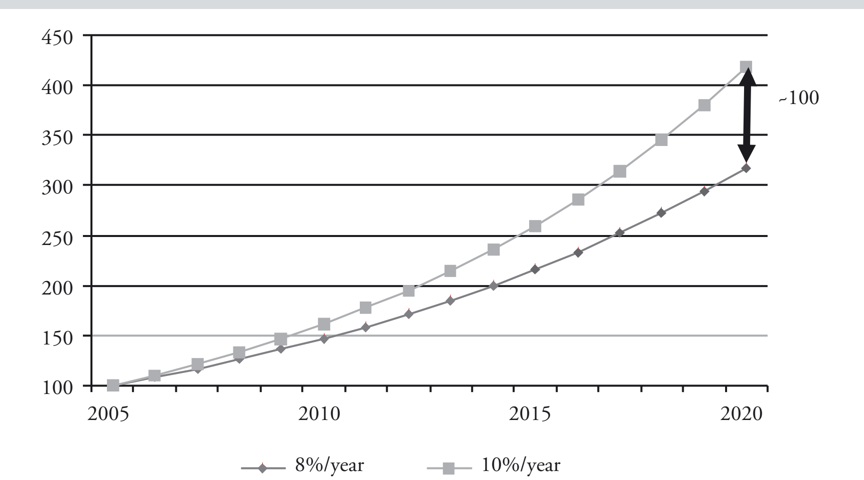
Box 11

Illustrating the effects of uncertainties

An illustration of the potential effects of the uncertainties on economic growth may be helpful. In practice, effects could be considerable if compounded, for example, over 15 years (the time lag between Kyoto and the end of the first commitment period for industrialised countries). Let us suppose that a particular developing country's objective is for its GDP to grow by 10 per cent each year. This aim would be difficult to contest, for even if it may not appear feasible, it is desirable, and other countries would be reluctant to challenge such an objective. Fixed assigned amounts would be derived from this projected economic growth, with some rate of reduction in carbon intensity, partly to take into account the autonomous progression of energy efficiency, as well as to fix an objective of relative reductions in emissions (i.e., an absolute increase in emissions, but a reduction relative to business as usual).

Figure 13

Effects of uncertainty on economic growth



Over a 15-year period, an annual growth rate of 8 per cent leads to a tripling of GDP, while a growth rate of 10 per cent per annum leads to its quadrupling ,. The difference is roughly equal to current GDP.

Now let us suppose that this country's average annual economic growth during this 15-year period is 8 per cent – which would be considered a good result. However, the difference in GDP amounts at the end of the period would be very large. With an 8 per cent rate of annual growth, GDP would be multiplied by 3.2 over 15 years, whereas with 10 per cent annual growth it would be multiplied by 4.2, as shown in Figure 13. If actual emissions were closely linked to GDP growth, then the amount of surplus allowances at the end of the commitment period would be roughly equal to the current emissions of that country.

Let us now suppose that, on the contrary, the target was set at an annual economic growth rate of 8 per cent and that the final growth rate was 10 per cent. The country would then have to achieve emission reductions close to its current amount. This is not only unrealistic, but also highly unfair from a developing country perspective... and makes this scenario less likely to happen.

Historically, developing countries have made it clear that they are neither politically nor economically prepared to take on reduction obligations. However, their rejection was largely due to the open-ended structure of the reduction target, which was presumably of the same nature and stringency as that adopted by Annex I Parties. Developing countries have argued that uncertainties in their economic growth – coupled with an expectation that any target would slow that growth – are sufficient justification for rejecting an agreement. However, it is clear that most developing countries could take on a quantitative target close to their business-as-usual emission trends. Under an emissions trading regime, such a target would give the international community access to cheap emission reduction potential through emissions trading, and on a much broader scale than is possible with the Clean Development Mechanism. Participating in the trading regime would give developing countries access to finance for further growth and development.

Industrialised countries often share the same concerns, although, unlike developing countries, where poverty renders action difficult and limits their willingness to pay, developed countries have already expressed a willingness to bear some of the financial costs. However, uncertainty about costs is still a significant problem, even though economic growth rates in developed countries have been more stable and predictable over the past few decades. This uncertainty is likely to lead developed countries to take on relatively less ambitious commitments than if abatement costs were known in advance. These costs depend mainly on business-as-usual emissions and economic growth scenarios that are, at least in part, uncertain. If the problems arising from cost uncertainties were addressed, countries would be in a better position to adopt a more stringent policy.

Three options are considered here that can apply to developed and/or developing countries and that seek to address the issue of uncertainty. The first two apply respectively to developed and developing countries, but are very similar in nature and provide a link between both groups: the price cap and non-binding target options. The third option – the dynamic targets option – could be applied to both developed and developing countries, while allowing full differentiation. These options also allow developing countries to participate in global emissions trading while addressing concerns about restricting economic growth.

THE PRICE CAP

Using hybrid systems associating a quantitative target and a "price cap" to deal with climate change has been suggested by Pizer (1997), in a domestic context by Kopp & al. (1999) and Morgenstern (2002), and at the international level by McKibbin & Wilcoxen (1997), Kopp & al. (2000), Victor (2001), Schlamadinger et al. (2001), Aldy et al. (2001) and Jacoby & Ellerman (2002). We will now consider the potential advantages of such an instrument, and some aspects of its implementation:

- How to get an agreement on the level of the price cap
- Where the money might go – if any
- How it could work in a global context

Hybrid instruments and price cap

Roberts and Spence suggested "hybrid instruments" as far back as 1976. Such hybrid instruments associate a quantitative target, a "floor" price and a "ceiling" price. If abatement costs in achieving the quantitative target remain below the floor price, a subsidy is paid to all agents, thus providing further abatement. If, on the contrary, abatement costs reach the ceiling price, additional permits are sold at this fixed price. This allows the emissions trading regime to spontaneously adapt the level of abatement to actual abatement costs – essentially acting in the same way as a tax.

Economic textbooks (see, e.g., Baumol & Oates, 1988) usually consider hybrid systems at least as efficient as pure permit or price instruments. Either of these pure instruments may be considered as a special case in a hybrid system: a floor price equal to the ceiling price would make it a price instrument (while the need for any subsidy disappears), a zero floor price and an infinite ceiling price would make it a permit instrument.

When quantity instruments are to be preferred over price instruments, setting ceiling and floor prices could help to avoid mistakes in choosing quantities in a context of cost uncertainty. One type of error could occur if costs were significantly underestimated (i.e., if targets were too stringent, and costs to meet them were substantially higher than willingness to pay). The second type of error would occur if costs were overestimated – that is, if the targets set were too lax (due to an erroneously perceived high cost) and too few benefits were attained as a result.

If price instruments are to be preferred over quantity instruments – as is the case with global climate change – hybrid instruments could help approximate more closely the expected marginal benefit curve – which a "fixed" price cannot do, unless the marginal benefit itself is constant (see Appendix for further elaboration).

As a result, whatever our beliefs about the slope of the marginal benefit curve of climate mitigation policies, hybrid instruments perform better (in terms of welfare maximisation) than either pure quantity or price instruments. In that sense, in the case of climate change, the argument that a price instrument should be preferred over a quantity instrument because the marginal benefit curve is fairly flat is not necessary in arguing in favour of a hybrid instrument, although it makes the case much stronger.

Moreover, the main advantage of hybrid instruments in the case of climate change may be their ability to associate some of the advantages of a price mechanism with those associated with a trading regime. Permit systems have already demonstrated important advantages in achieving an international agreement. They may also help in implementing the agreement on a domestic scale and offer incentives to extend it to a global scale.

This reasoning has led a number of authors to recommend hybrid instruments in climate change negotiations. Most of them have not considered the "floor price" component of a "textbook" hybrid instrument, perhaps on the grounds that at the international level (and in most domestic contexts) a "floor price" has little chance of ever being adopted and implemented[16]. Their proposals have concentrated on the "ceiling price" – or price cap – part of the argument.

However, it must be recognised that a hybrid instrument limited to a price cap would not perform as well as a complete hybrid instrument. If costs turn out to be much lower than expected, the abatement provided by fixed targets will remain far below what would have been optimal. The price cap only works in the opposite case – when costs turn out to be higher than expected.

The quantity allowed should be reduced to compensate for the absence of a subsidy and the resulting risk of too little abatement. Therefore, not only "could" countries adopt more stringent policies if they chose a better option than mere fixed quantity instruments, as suggested above, but in fact they "should" do so with an asymmetric hybrid instrument – in order to achieve optimality and maximise expected welfare.

A cap – but at what price?

As Aldy et al. (2001) stated:

"The safety valve is not intended to set an inefficiently low carbon price over time. Indeed, the safety valve may allow a higher price of carbon than would otherwise be the case, because it provides assurance that the costs will not exceed that level. (...) The cost insurance provided by the safety valve could thus have environmental benefits, once the political economy of the emission reduction effort is taken into account".

If the marginal benefits were known with certainty, or at least with a high degree of confidence, this would drive the level of the price cap. But this

16 However, Newell & Pizer mention the "dynamic efficiencies" usually associated with using direct subsidies to reduce pollution. Such subsidies may well reduce firms' emissions but risk increasing the emissions of the whole industry (see Baumol & Oates, 1988).

is not the case, at least at present. Still, the level should be set somewhere in the range of expected marginal climate benefits. Given this uncertainty, cost estimates would enter the discussion on the price, which is likely to follow or be closely associated to that of assigned amounts for future commitments.

To be effective as a price cap while keeping all the advantages associated with a trading regime, the price cap should be set somewhere in the upper-range of cost estimates resulting from quantitative targets on a global scale. Therefore, it is only in the case of significantly higher-than-expected costs that the price cap will relax the quantitative targets and provide the necessary flexibility. In the majority of situations, the price cap will not be activated.

It will be necessary to agree on a common "trigger price" – at least for relatively similar countries that want to have full emissions trading between themselves. As Pizer (1999) stated:

"There would be a need for either harmonisation of the trigger price across countries, or restrictions on the sale of permits from those countries with low trigger prices. Otherwise, there would be an incentive for countries with a low trigger price to simply print and export permits to countries with higher permit prices. This would not only effectively create low trigger prices everywhere; it would also create large international capital flows to the governments of countries with the low trigger prices."

Müller et al. (2002) argue that *"setting the price cap on an international level would be a political nightmare, especially under the consensus principle"*. While negotiating assigned amounts or "quantities" allows differentiation, this is not the case for negotiating a common "price". Willingness-to-pay is likely to differ from country to country. Moreover, there is a risk that negotiating both quantities and a common trigger price would complicate the negotiating process even further.

There are, however, a number of arguments that offer a different and more positive perspective. First, and most importantly, countries' willingness-to-pay is best expressed by concepts such as "level of effort" (total costs over GDP), rather than by marginal costs. While a price cap would cap the marginal cost of the global effort, if set as suggested above, countries' respective total costs and thus, levels of effort, will be more influenced by quantitative commitments – and these may be widely differentiated amongst countries.

Second, it seems that negotiators often associate expectations of high costs with beliefs of low benefits, or expectations of low costs with beliefs of high benefits[17]. This may facilitate an agreement on a common price. Countries willing to pay a lot but expecting low costs, and countries willing to pay less but expecting high costs could find a common cap price. The former would see it as unlikely to be attained, and the latter as an instrument that will actually cap compliance costs.

Finally, negotiating a trigger price could make the negotiating process more complex. However, its existence may facilitate successful negotiations on assigned amounts, since it alleviates the risk of the adverse economic outcomes they imply. On balance, it is not clear if negotiating a price cap would increase or reduce the overall difficulty of future negotiations.

Some guidance may be available on the price itself. At present, countries are engaged in quite different domestic levels of effort (with concomitant associated prices). For example, tax policies or backstop energy R&D policies have relatively low associated prices – often in the range of $5-50 a tonne CO_2. Few countries have explicitly priced the policies being taken in the energy or industry sector – although many countries' policies focus on those that have net benefits and show a real return on investment, and thus have extremely low costs. Further guidance is available from the market: emissions trading, as simulated in global markets (with the US out of the system), suggests prices in the range of $1-20 a tonne of CO_2, while the World Bank's Prototype Carbon Fund is contracting for units at a price of less than $5 per tonne of CO_2. On the low side, therefore, prices of $5–30 a tonne may be reasonable.

Conversely, Annex I countries expected to pay up to $100/tonne CO_2 to abate emissions under Kyoto (according to most econometric models and with all Annex I Parties adopting commitments, including the US). Such costs would be reduced through agreements on all gases (most models address only CO_2), and with sinks (excluded from models). However, at

17 Tomas Heller, presentation at the invitation of French Authorities, Paris, 27 March 2001.

\$100/tonne of CO_2, several countries are still unwilling to ratify – notably the United States. This price may then represent a maximum, although it is only in association with quantitative commitments that the level of effort can be assessed and accepted. A lower price, at least during the next period, may help ensure maximum participation in the agreement.

Where the money might go – if any

With a price cap, unlimited amounts of supplementary permits would be sold at a fixed price – but only if abatement costs reach this price. Where should the revenue go? What should the money finance? Who should sell these supplementary permits – the countries themselves, or some international body?

It has been suggested that the money should allow "full" restoration, that is, be used to buy enough additional emission reductions – presumably in developing countries – to cover the compliance gap and guarantee the environmental integrity of the Kyoto Protocol. However, by construction, full restoration is impossible, as there would be no cheaper reductions left untapped anywhere. If the money is used to buy more abatement, it would do so at progressively greater costs – and costs now higher than the value of the marginal environmental benefit they entail. Using the price cap money to reduce the gap between the short-term objective and what has been achieved might make the price cap approach more palatable. Kopp et al. (2000) have suggested a mechanism, based on a reverse auction, that would minimise bureaucracy and maximise reductions.

Schlamadinger et al. (2001) made an interesting proposal in the context of the Kyoto Protocol: using the price-cap money to mitigate emissions in some "sinks" projects in developing countries. Specifically, these projects would be among those not allowed through the Clean Development Mechanism. These could include, *inter alia*, projects that exceed the limits put on using sinks under the CDM in the Marrakech Accords. Thus, full restoration or even "over-restoration" could be possible – if not necessarily granted – as these presumably cheap options would not have been tapped through the CDM.

Such a proposal may face the same objections as the non-restricted use of any kind of "sinks" projects under the CDM – such as concerns about national sovereignty in the case of forest conservation. However, as Schlamadinger et al. point out, *"because the incentive would not be purely to maximise carbon sequestration, many of the problems associated with crediting land-use activities would be reduced or removed. It would then be far easier to strike a balance between carbon uptake and the many other objectives of land-use management, such as protecting and enhancing biodiversity, protecting watersheds, reducing soil erosion, or improving local livelihoods."*

Another possible use of this money could be to finance adaptation. One interpretation of the price cap is that it represents what we believe is the cost of the GHG externality. When adaptation is possible, its cost is usually considered as the best proxy for the cost of the externality itself. Thus, it is the level above which money is best used to finance adaptation rather than further emission reductions. It could therefore be argued that this money should be added to the "Adaptation Fund" created under the Bonn agreement.

It has also been suggested that the revenue from the price cap could support co-ordinated efforts to speed up the development and dissemination of backstop technologies. Again, this would not "restore" the environmental integrity of near-term targets, but would fulfil their most important objective in making available cost-effective technologies for deeper cuts in subsequent periods.

There is, however, a completely different way of implementing a hybrid instrument, namely, requesting each participating country to create supplementary permits at an internationally agreed price. For example, the price cap could take the form of (domestic) "non-compliance penalties". Indeed, the price cap concept does not necessitate that countries pay. Rather, it supposes that economic agents within all countries are faced with this price – but this could be paid to each government. The money could then be used, say, to finance mitigating technology research and development at the country level, or reduce diverse taxes, or for other purposes.

If implemented internationally, the price cap would allow countries to avoid being in non-compliance if they purchased additional permits at the fixed price; no legal stigma would be attached to such purchases. There may, however, be a reluctance to allow money to flow out of the country, as implied with full trading. If implemented domestically it would suppose that all emitters be regulated through an "upstream" trading regime, or that emitters not part of a trading scheme be tapped through a carbon tax at the same level. A domestic price cap may face some of the same political difficulties as internationally co-ordinated carbon taxes, and countries may be reluctant to submit to its "intrusive" character. There may be resistance to allowing the international community to closely monitor national compliance to ensure that permits are only sold once abatements have been reached, and no excess sales are undertaken.

ZERO PRICE CAP: THE NON-BINDING TARGET OPTION

Supporters of hybrid approaches seem to have devoted little effort so far to include developing countries in a global mitigating framework[18]. Although carbon taxes could bring a "double dividend" and thus be an option for developing countries too (Philibert & Pershing, 2001), it is unlikely that many developing countries would agree to adopt a "trigger price" that would represent the same marginal cost as applied to industrialised countries.

An emission trading global regime with two different price caps runs the risk that the lower price would be globally determinative. Economically, it would be advantageous to buy permits in the country with the lowest price (and for the emitter to pay that price if selling more permits resulted in it exceeding its assigned amount) than to realise any emission reductions at a higher cost – even if lower than the higher price cap.

However, as Pizer (1999) pointed out, there is an alternative to a fully harmonised trigger price: restrictions to emissions trading. In fact, such restrictions could even allow trading to occur between one zone with a positive price cap, and another with a zero price cap. The latter would be

18 McKibbin & Wilcoxen (2000) offer one alternative. They suggest a distinction between emission permits, valid for one year, and emission endowments, allowing emissions forever. Developing countries would be given endowments above current levels – but limited. Although incurring no immediate cost, economic agents would thus be given the long-term signals that would encourage them to act early. However, both the likelihood of a successful negotiation on such endowments, as well as the efficacy of any agreement along these lines, would seem to be low.

no more than a "non-binding" target, or "emission budget", without penalties if not attained, but could still allow emissions trading if the target was reached, as suggested by Philibert (2000).

Clearly, non-binding targets could hardly be an option for all countries. If we want to preserve the advantage of establishing a global trading regime, we need potential buyers, and they would necessarily be Annex I countries with binding commitments[19]. The need for trading restrictions is even more obvious in the case of the non-binding cap. If a country could sell part of its emission budget while its actual emissions exceeded this budget (diminished by selling), the "value" of permits would become meaningless. In fact, in an extreme case, a country could even sell its entire budget and thus flood the market while keeping its emission level unchanged! As targets under this scenario are by definition non-binding, countries taking this path would not be "out of compliance".

There are several different options for avoiding these pitfalls (Philibert & Pershing, 2001). One possibility is that as soon as a country with an emission budget starts to sell allowances it automatically assumes a limit on its emissions. It thus becomes a binding commitment, but only at the time it sells emissions (i.e., during the commitment period, when uncertainties are reduced, and not years in advance). Another possibility is to allow countries with emission budgets to trade only at the end of the commitment period, that is, when an actual surplus of allowances has been determined. This does not, however, allow for the provision of immediate up-front financing for emission reductions.

A third possibility is to require countries to buy back the allowances sold if the budget is exceeded. If a country has an emission budget of 100 million tonnes and sells 10 million tonnes, and if its emissions then exceed 90 million tonnes, the country should buy back the surplus of up to 10 million tonnes – but not beyond the amount it has sold. Such an option preserves the non-binding character of the targets, while allowing emissions trading to occur on a sound basis. A commitment period

19 David Bradford (2001) proposed a *No Cap but Trade* system in which all countries would have non-binding targets set on their estimated baseline emission scenarios. A world agency, financed by proportionate contributions by countries, would buy a certain amount of emission reductions. The trouble with such a scheme is that it requires more public funding and the establishment of a new (and potentially unwelcome) institution.

reserve, as adopted in the Bonn and Marrakech Accords, may help in establishing desirable levels of liquidity and safety to prevent overselling (IEA, 2001a).

How to set non-binding targets

As is the case with the price cap described above, a non-binding target allows developing countries to accept more ambitious objectives. The rationale is clear: if developing countries were to accept fixed and binding targets, these would have to be safe from both an energy and an economic perspective – and not put development at risk. Assigned amounts would thus be above any expected reasonable level of business-as-usual. Conversely, if targets for developing countries are non-binding, the situation is quite different: the discussion is simply about a potential advantage, not about a potential disadvantage. It becomes easier to negotiate reasonable baselines, since the only risk is of being unable to participate in emissions trading. There is no risk of being forced to buy emission reductions elsewhere, to finance more costly emission reductions domestically or to slow economic growth to fulfil the commitment.

There are multiple interests in this process that could help promote a more environmentally sound outcome. While developing countries have an interest in having the largest assigned amounts possible, if their "hot air" floods the market, permit prices will decline, and revenues decrease. For other countries, a balance will also have to be struck between the risk of creating large amounts of hot air with a weak target, against that of leaving the country out of the trading regime if the target is too strict.

In setting the level for developing country targets, it would make sense to follow (as closely as possible) a "business-as-usual" emission scenario – albeit after taking into account the "win-win" or "no-cost" potential. There is no reason for industrialised countries to pay developing countries to achieve such win-win emission reductions (such as those provided by subsidy removal). Setting the target in this manner would open the door for full – and profitable – emissions trading, reinforcing the incentive to achieve the non-binding target.

Determining the "correct" business-as-usual emission scenario is by no means easy; it is precisely its uncertain character that justifies this option!

A number of models are available to develop and assess such a policy. On the development side, most countries project economic welfare (either through national treasuries or other such institutions); such projections are standard in formulating tax and revenue policy and setting government expenditures. Using these projections could help make the programmes consistent with those already implemented – and the fact that any emissions sales are likely to be only a minute share of government expenditure could contribute to keeping projections relatively unbiased. In addition, many developing countries already submit information on their economic projections to international institutions in order to qualify for loans or grants. Again, consistency with such reporting would help to ensure accuracy. Finally, a process would need to be set up in the UNFCCC to assess such reports. As noted above, those countries already in the trading regime – and who have purchased permits at a given price – would be reluctant to see the price decrease as a result of "hot air" granted to newcomers to the system. Thus, a review in which existing permit holders were engaged could help to ensure a rigorous process, and maintain stringency in setting new targets.

Once established, non-binding targets would be similar to a structure in which policy actions would be accepted under the Clean Development Mechanism (i.e., unilaterally funded, country-wide policies would be accepted for credit as long as they were below "business as usual"). In fact, it would be almost possible to implement non-binding targets using the CDM mechanism of the Kyoto Protocol. However, there would be a number of differences. First, at present, unilaterally funded policy actions have not yet been made explicitly creditable under the CDM regime. Partly because of this, in CDM projects, investors from industrialised countries are allowed to take the full rent accruing from the difference in their country's abatement costs and that of the host country. With emissions trading or unilaterally funded projects, certified emission reductions would be sold according to the international permit price. This price will be somewhere in between these two marginal costs (and, if markets are efficient, equal to the marginal cost of global abatement). However, perhaps the key difference lies in how the baseline is determined: the baselines for CDM projects must be agreed by the

Executive Board or its operating entity. Assigned amounts may be a matter of negotiating non-binding targets, which would undergo a different review process – and which, presumably, could change as economies matured.

From non-binding targets to price caps

The trigger price for developing countries need not – and probably should not – be zero. A low, but non-zero trigger price in developing countries may be justified under a "no-harm" rule, as emissions trading with industrialised countries is likely to be beneficial for developing countries, and some of these benefits may be used to mitigate climate change. However, given the refusal of many developing countries to discuss binding targets, it is clear that non-binding targets offer greater potential for political agreement. In fact, many countries, including China and India, may not (yet) be prepared to consider anything else.

Some other developing countries may be in a different position. Argentina and Kazakhstan have suggested a willingness to take on targets of the "dynamic" type (see below). Korea and Mexico, which are developing countries under the UN Climate Convention, have since joined the OECD and are also expressing a willingness to consider taking on commitments. As already mentioned in Chapter 5, according to per capita emissions or per capita GDP criteria, a number of developing countries are close to, or even better placed (for GDP) or worse placed (for emissions) than some industrialised countries.

Just as a non-binding option might facilitate the integration of developing countries into global emissions trading, a price cap might facilitate a country's graduation from one group to another, albeit with continued, differentiated quantitative commitments. In fact, in addition to a zero price cap or non-binding targets for most developing countries, or a binding commitment and a single price cap for most industrialised countries, there is a possible third alternative: to take an intermediate group of countries and explore a binding agreement with a lower price cap. As long as simultaneous trading restrictions were put into place (i.e., to ensure that cheaper or free supplementary permits do not invade zones with costlier obligations), such a regime might be worth considering. This may make the agreement more complex. However, cost effectiveness or leakage prevention would not be restricted by multiple ceiling prices, except if some countries stopped trading after having exceeded their assigned amounts. Emission reductions at a cost fixed between two cap prices will remain an attractive option if abatement costs are more expensive in countries with the highest cap price. Restrictions will prevent countries from reselling supplementary permits if they do not achieve their commitments (domestically or in buying reductions from other countries) but would not prevent more expensive abatement than the lower cap price to be undertaken.

A final remark on non-binding targets: the Marrakech Accords cautiously state that "*the Kyoto Protocol has not created or bestowed any right, title or entitlement to emissions of any kind on Parties included in Annex I*". This reflects the fears of developing countries that the allocation of assigned amounts to developed countries (mirroring their emission reduction commitments) could create a precedent. The concern also reflects a developing country fear that the non-allocation of assigned amounts may preclude them from holding rights in the future. However, non-binding targets for developing countries would establish a clear distinction between entitlements and transferable property rights. While the latter are strictly defined by the assigned amounts and for a limited period of time, the former would remain unlimited.

THE DYNAMIC TARGET OPTION

In this option, emissions would not be capped in absolute terms. Assigned amounts would be defined *ex ante* on the basis of some shared expectation about economic growth (though other variables could enter the picture, such as population, exports, etc.). These assigned amounts would then be adjusted *ex post* according to actual economic growth.

Dynamic targets have been suggested or endorsed as an efficient means to integrate developing countries by Frankel (1997), Hargrave (1998; 2001), Baumert et al. (1999), and Lutter (2002). Moreover, in 1998 Argentina suggested that it could adopt a dynamic target provided that the Kyoto framework evolved to allow countries with such targets to take part in global emissions trading. The idea of using dynamic targets for developed countries too is more recent, and has been supported by Philibert & Pershing (2001) and Lisowski (2002), but challenged by Müller et al. (2002) and Moor et al. (2002) – particularly in the light of its adoption by the new US administration. To date, the bulk of the dynamic target literature has only considered the cases of "carbon intensity" or "greenhouse gas intensity" targets; these constitute only a few of the possible forms that dynamic targets could take.

Indexing assigned amounts

Dynamic targets allow for differentiation between countries. Differentiation might affect the levels of assigned amounts or the formulae for indexation. Carbon intensity targets represent one extreme: as the target would be expressed by a fixed ratio, that of greenhouse gas emissions over GDP, an evolution of the denominator (the GDP) *vis-à-vis* expectations would allow a similar evolution of the numerator (the assigned amount). If GDP during the commitment period is 10 per cent more than expected, the assigned amount will be augmented by 10 per cent. If GDP is 10 per cent less than expected, the assigned amount will be reduced by 10 per cent. However, it could just as well be decided that in the case of a 10 per cent gap between expected and actual GDP, assigned amounts be reduced or augmented by 8 per cent, or 5 per cent, or 2 per cent. As we will see, there are many reasons to prefer a "less-than-proportionate" indexation of assigned amounts. This reasoning should not be followed to its extreme – which would bring the targets back to their "fixed" form. In sum, dynamic targets allow all variations between carbon intensity targets and fixed ones[20].

Other indices have been proposed – with considerably different levels of complexity. For example, the Argentinian proposal in 1998 was not a carbon intensity target, but much more complex: it was based on

20 Lisowski (2002) defends the straight "carbon intensity target" concept. He believes that such targets could be based on best practice levels – and his examples are of interest for industrialised as well as developing countries, or economies in transition. Botswana and South Africa have comparable per capita GDP and geography, as do Greece and Portugal, and Estonia and Lithuania. However, Botswana emits 70 per cent more carbon dioxide per million dollars of GDP than South Africa, Greece 73 per cent more than Portugal, Estonia 185 per cent more than Lithuania. Thus, Bostwana, Greece and Estonia might accept carbon intensity targets similar to the actual carbon intensities of South Africa, Portugal and Lithuania, respectively. However, as the differences reflect different economic structures, a full convergence would be unreasonable. Reasonable best practice targets could be calculated by normalising for economic structure.

emissions/square root of GDP index, implying a positive relationship not only between allowed emissions and GDP, but also between the level of effort and GDP. This criterion was chosen to take account of the large agriculture and livestock sector – from which emissions are relatively independent of the growth rate of the general economy.

It has also been noted (e.g., Müller et al., 2002) that emissions of greenhouse gases other than CO_2 are not as well correlated to economic output. For example, (and as in the case of Argentina), gases like methane are often correlated with agricultural activity – which, while it may lead to significant emissions, represents only a relatively small share of the economy.

There is no need for the rules to be the same for all countries. Each country has specific features (e.g., national circumstances or political constraints) that cannot be addressed in a single formula or framework. However, an agreement on some basic principles could guide the negotiation of individual dynamic targets. Naturally, and even if intermediate cases might be suggested, the polar cases of industrialised and developing countries must be considered separately. It is unlikely, however, that a single, simple rule will yield dynamic targets suitable for all countries. More complex rules such as the triptych or multi-stage approaches mentioned in the previous chapter are likely to be needed.

The setting of future targets will most probably have to take into account current carbon intensity performances (or more generally greenhouse gas intensities). However, other equally important aspects, such as per capita emission levels, will also have to be an intrinsic part of these negotiations. One drawback to using carbon intensity as the sole criterion is the implicit notion that countries should aim at converging on one carbon intensity target. The concept would limit the potential scope of the dynamic target debate, and may also be a form of unacceptable burden sharing. The distinction between "dynamic targets" and "carbon intensity targets" should thus be retained.

Dynamic targets and developing countries

The basic definition of assigned amounts for developing countries under dynamic targets could use a process similar to that described above in the setting of non-binding targets. It could also derive from the "no-harm" concept and allow targets to be set for most of the poor developing countries based on a business-as-usual emission scenario, once "win-win" emission reductions have been taken into account. Comparing carbon intensity and per capita emission levels between roughly similar countries would be useful in such a discussion.

It may make sense, as a general principle, to aim to index targets in a "less-than-proportional" fashion than strict carbon intensity targets would allow. If economic growth is higher than expected, more no-cost options arise as capital stock rotation accelerates, in particular in the energy sector. For "advanced" developing countries (and for industrialised countries as discussed below), the level of effort could increase along with economic growth. This would be reflected in an increase of the assigned amount that would be less than proportionate to the increase of GDP over expectations[21].

If economic growth is lower than expected, the basic energy needs of the population will not diminish, whereas those related to market activities will, and this might be reflected in a decrease of the assigned amount that would be less than proportionate to the GDP decrease over expectations. In other words, the country would be allowed a relative increase of energy intensity in comparison with a strict carbon intensity target. This might be particularly necessary for countries at an early stage of industrialisation. It would thus be possible to offset the risk pointed out by Müller et al. (2002) that dynamic targets could become a "double pain" in the case of recession, no doubt a real fear in the case of carbon intensity targets for countries "at the bottom end of the wealth ladder".[22]

Randall Lutter (2000) has further analysed this scenario, by modelling the risk that developing countries would face in accepting binding targets. He also computed coefficients for indexing developing countries' assigned amounts

21 There are also arguments in favour of a "less-than-proportionate" indexation that seek to ameliorate the effects of possibly unexpectedly-high economic growth: increased wealth justifies increased levels of effort while accelerated capital stock turnover multiplies opportunities for cheap emission reductions. The case of unexpectedly-low economic growth might be slightly different: for Moor et al. (2002) the risk of carbon intensity targets is not so much that of a "double pain" but that of non-compliance. This is also likely to depend on the stringency of the targets and the level of effort they represent as expressed as a percentage of GDP.

22 Müller et al. (2002) illustrate the risk of "double pain" associated with carbon intensity targets in a case of economic recession using the example of the economic collapse of Russia. However, Lisowski (2002) notes that while Russia's intensity increase between 1990 and 1999 has been 18 per cent, the economies in transition improved their collective carbon efficiency by 12 per cent over the same period: *"Given Russia all but completely lacks a climate change programme and has numerous, inexpensive emissions reductions opportunities, an emissions intensity target may not have proven overly burdensome".*

Box 12

Sectoral targets for developing countries

Sectoral targets could be a pragmatic first step towards more comprehensive action. Sectoral targets could be preferable for various (although possibly somewhat contradictory) reasons. A developing country, for example, might wish to complement the Clean Development Mechanism by targets in sectors not readily addressed with project activities, such as household and transport. Alternatively, sectoral targets might be adopted for industry sector(s) while leaving emissions more directly linked to consumption unregulated for various reasons (from lack of monitoring to perception of unfairness). Sectoral targets might be fixed or dynamic, binding or non-binding.

One key issue that has been raised as an objection to sectoral targets is that of leakage. Concerns have been expressed both with respect to inter-country leakage (where competitors in different countries would see different policy constraints), as well as competitive consequence between sectors.

The implications of the extent of the leakage are governed by the relative stringency of the targets in the particular countries, as well as the forms of the targets. Thus, if a developed country undertakes a binding target, and a developing country adopts only a single-sector target, the extent of the leakage in that sector will be reduced by the level of the stringency of the sectoral target.

Unlike country-level dynamic targets, sectoral dynamic targets for industries offer little protection against leakage. The protection provided by country-level dynamic targets is essentially based on the fact that leakage would take place for energy-intensive industries that have a higher carbon intensity than the country's economy as a whole. The increase of economic output of these industries would presumably not be sufficient to make the country-level target ineffective. This may not be true with a sectoral dynamic target, where the pertinent criteria may be the carbon intensity of the sector, not that of the whole country.

based on recent statistics, and assessed the risk of economic losses for developing countries that had taken on fixed or dynamic targets. This analysis suggests that if a developing country agrees at this point in time to a fixed national emissions cap equal to the emissions expected between 2008 and 2012 under business-as-usual policies, there would be a 60 per cent chance of a net economic gain. It is unlikely, however, that developing countries would take the corresponding risk (with a probability of 0.4) of a net economic loss.

In addition to measuring the risk of economic loss, the international community will need to give serious consideration to potential environmental damage: allowing developing countries to sell excess permits on the market may increase global emissions if they do not reflect corresponding real emissions reductions. To control such risks, Lutter (2000) suggests that international negotiators should index the emissions limits of developing countries to variables that predict business-as-usual emissions. Another possibility is that adjustment should continue throughout the commitment period itself. This indexation could have the added benefit of lowering the likelihood of net losses for developing countries accepting emissions limits — according to Lutter, by about 5 per cent – from 40 to 35 per cent[23]. Although Argentina furnished an example of a developing country willing to accept a dynamic target provided it was allowed to enter global emissions trading, Lutter's analysis suggests that binding dynamic targets might still be perceived as entailing too large a risk of economic loss from a developing country perspective.

Overall, analyses suggest that the economic risk to a developing country of accepting a target is negatively correlated with the depth of commitments taken by industrialised countries, but positively correlated with the number and size of developing countries entering global trading.

Dynamic targets and industrialised countries

In the case of industrialised countries, the prevailing concern is the inherent uncertainty about the environmental effectiveness of dynamic targets, as measured by reduced emissions of greenhouse gases in the atmosphere (Moor et al., 2002).

23 While these estimates are based on the assumption of an international price of permits of 23$/tonne of carbon, they would be lower if the permit price were higher, down to roughly 20 per cent and 10 per cent for an international permit price around 80 $/t.

Müller et al. (2002) point out that emission levels in the commitment period cannot be guaranteed with intensity targets. They suggest that intensity targets would only be able to deliver substantial emission reductions if the required reduction of intensity is greater than the output growth, and that such tough targets would lose their comparative attractiveness compared with Kyoto-type (fixed cap) targets. However, this suggests that dynamic targets would only be economically attractive if they lead to lower abatement, i.e., higher emission levels than fixed targets. This misses the starting point of the analysis: the existence of an *ex ante* uncertainty about abatement costs, partly driven by uncertainty about economic growth projections.

Of course, if the economic projection on which a target is based materialises, the assigned amount will not be adjusted and the costs supported will be the same under fixed and dynamic target regimes. The differences rest, though, in the expected costs before uncertainties are resolved. While they provide more abatement if costs are lower than expected, dynamic targets have lower costs when abatement prices are higher. This allows countries to adopt more stringent commitments for the same expected costs and this would have environmental benefits. The value of eliminating the risk of paying "too much" is clearly articulated by Lisowski (2002): "*The risks associated with a 1°C temperature increase over the next couple of decades might be unacceptable if world economic growth were to stop, but perfectly acceptable if world economic output were to quadruple. Economic growth can facilitate climate change adaptation while alleviating poverty and improving health care and education.*"

Dynamic targets and emissions trading

Critics have also suggested that the uncertainty about actual assigned amounts under a dynamic target approach could make trading difficult (Moor et al., 2002). Countries with dynamic targets would not be sure of their assigned amounts, and this could complicate passing on these targets to domestic entities – unless these are given equally dynamic objectives. This is already the case in the UK trading regime, though an absolute, fixed target binds the country itself[24].

24 The UK system may also provide an analogue for trading between countries adopting fixed targets and those adopting dynamic targets.

However, assuming that the calculated link between economic growth and emissions holds, this may not be a problem; the uncertainties about both will essentially compensate for one another. In fact, the uncertainty regarding the available or required units of assigned amounts at the end of the period, i.e., the difference between the assigned amount and actual emissions, is likely to be reduced, not increased, by dynamic targets in comparison to fixed targets. Here again, a commitment period reserve such as that instituted by the Marrakech Accords might help in fine-tuning the balance between liquidity and the prevention of possible mistakes and the risk of overselling.

Data issues

Dynamic targets need a higher amount of indisputable information than straight fixed targets. GDP measurement is relatively inaccurate in many developing countries. Official Chinese and OECD estimates of Chinese economic growth have substantially differed in the recent past – in some years, by as much as 10 per cent. Such inaccuracies need to be substantially reduced for dynamic targets to work satisfactorily.

Another important issue might be the choice of the measurement unit for GDP. For example, using different means to compare GDP between countries – such as exchange rates or purchase power parities – would also lead to a different assessment of the GDP evolution over time of any single country (see Müller et al., 2002). Using a constant local currency would avoid this sensitivity problem, although at the cost of abandoning the capacity for international comparisons of absolute intensity levels (Baumert et al., 1999).

Comparing or combining the options

The key difference between a price cap and a dynamic target is fairly obvious: a price cap protects the international community against errors in fixing the global target by shaving marginal costs when international permit prices reach the cap price. Dynamic targets protect individual countries against mistakes in fixing countries' assigned amounts on the basis of expected economic growth.

All options considered here would allow differentiation amongst countries. With dynamic targets, differentiated assigned amounts and indexation formulas could be considered so as to take into account levels of development and national circumstances. With the price cap, a single price is preferable for unrestricted trading. However, presuming the price cap would be set in the upper range of cost expectations, levels of effort could differ from one country to another, thanks to differentiated assigned amounts.

The introduction of a ceiling price over a structure of fixed targets would better deal with cost uncertainty. A price cap need not be difficult to implement or institutionally complex. It would add some complexity to the negotiations, but might also facilitate them in helping countries adopt more stringent commitments. Provided the ceiling price is set in the upper range of cost estimates, advocates of stringent policies should be satisfied as they usually assume that abatement costs will be low. If they are right, the ceiling price will never be used in practice. Countries with a strong aversion to taxes may also feel better with such a "high" ceiling price, since it would probably maintain the "tradable permit" structure of the agreement. Clearly, the level of the ceiling price will be fixed by negotiation – between those favouring rapid reductions and arguing for a high price, and those in favour of limiting economic shocks, and supporting low prices. As the ceiling cost (like target levels themselves) can be changed over time, starting lower and building with time may be a practical solution.

Capping the price is not comparable to withdrawing from the Convention or the Protocol. Withdrawing from these treaties puts countries in the position of acting unilaterally – with the higher costs and reduced advantages such action entails. Conversely, the price cap ensures that any action below an agreed cost is taken – and a country does not need to withdraw from the agreement when the price exceeds that cost. Inasmuch as the initial agreement under which the cap was negotiated incorporates elements of fairness and cost-effectiveness, they are kept with the price cap – in a way that is certainly not retained when a Party withdraws. Naturally, the existence of the price cap does not offer a full guarantee against withdrawal. However, it makes it less likely.

The price cap option would presumably only apply to industrialised countries. However, the non-binding option for developing country commitments would be similar to the adoption of a price cap – where the cap price is set at zero. A global emissions trading regime involving a price cap at two different levels is thus conceivable, but would require some restrictions on trading.

Dynamic targets do not entirely remove cost uncertainties. Over time, however, as we learn more about abatement techniques and related costs, cost uncertainty will be more and more dependent on economic growth uncertainty – precisely the issue that dynamic targets can offset or reduce. Dynamic targets have the added advantage of being able to remove the hot air that would result from unexpectedly low economic growth – something that a price cap would not do (except insofar as it may promote more stringent commitments from the outset).

By allowing differentiation on both assigned amounts and index formulas, dynamic targets remain a valid option for engaging developing countries in an effective and acceptable manner – but only if the difficulties surrounding the measurement of the appropriate variables can be resolved. The extent to which dynamic targets would alleviate cost concerns is also questionable. If dynamic targets do not offer sufficient guarantees to developing countries for accepting a commitment, they might prefer non-binding targets to binding ones. However, dynamic non-binding targets may prove more effective than fixed ones, as they would increase the chance that a country enter global emissions trading.

As far as developing countries are concerned, the two options of "dynamic" and "non-binding" targets could be merged in a single concept of "non-binding dynamic targets". Such hybrids may offer attractive options for developing countries to proceed beyond the CDM. While developed countries could also consider architectures for future commitments encompassing both dynamic targets and price caps, it is not clear if the advantages would outweigh the added complexity: economic growth uncertainty is usually less important in mature economies than in developing ones, with the notable exception of economies in transition.

Both dynamic target and price cap options are likely to increase the complexity of negotiations over fixed targets. Both would need an agreement on two elements: assigned amounts and index formulas, on a country-by-country basis, for dynamic targets; and assigned amounts and common price caps for the price cap option. This added complexity – probably greater in the case of dynamic targets – might be the price for achieving the dual objectives in question: powering the global economy while stabilising greenhouse gas atmospheric concentrations at acceptable levels.

CONCLUSION

While some uncertainties remain in the science and economics of climate change, the international community already knows enough to be certain that action will be needed. We also know that energy is the prime culprit in the climate change problem – although it is also intimately linked to our aspirations for economic and social development. However, knowing this is not the same as being able to commit to a precise long-term objective – we do not know at what levels concentrations of greenhouse gases in the atmosphere will become dangerous. The critical question thus remains: how to develop appropriate near- and long-term solutions given our current levels of uncertainty.

The type of near-term targets adopted at Kyoto may not be the most appropriate if the principal concerns relate to uncertainties in damage or abatement costs. The approach adopted in Kyoto inherently entails the risk of spending too much at the margin for too small an incremental environmental benefit. Climate change is a "stock" pollutant: the precise level of today's emissions matters less than the accumulation of past emissions – even if, in the end, reductions are needed to avoid unprecedented changes in the earth's climate.

Economic uncertainty is also one of the elements that prevent developing countries from taking on targets – and concurrently participating in emissions trading, although their potential for relatively cheap emission reductions suggest that they could benefit from such participation. The global community would also benefit from their inclusion, even if they adopt relatively modest targets (e.g., close to their baseline emission levels). The same uncertainty may also prevent developed countries from adopting emission goals stringent enough to achieve climate stabilisation – today or in the future.

Some different solutions have been suggested – and are explored in this volume. For example, according to economic theory, GHG taxes provide a reliable alternative to the "cap-and-trade" model of Kyoto. However, such taxes would impose a direct cost on developing countries, unacceptable at this stage. The North-South transfers required to offset this burden would mean a considerable departure from the approach taken by countries so far to address their global problems.

Recognising the contribution that energy makes to greenhouse gas emissions, it is clear that energy-related policy choices will be critical to emissions reductions. It is also evident that continuing on a business-as-usual course, and burning the entirety of the world's fossil fuel resources will lead to an untenable future. Emission reduction strategies can be divided into three categories: using less (i.e., promoting efficiency), switching fuels (i.e., changing the fuels used – from fossil to nuclear or renewable energy), and capturing and storing emissions (i.e., through extraction and permanent storage of greenhouse gases). Actions in all sectors are clearly possible: buildings, power generation, transport, residential and commercial use and industrial activities all offer scope for reducing emissions. Individual government policies may promote action along one or more of the three alternative paths. However, it is ultimately likely that a combination of all three categories will be needed to meet the reductions demanded for stabilising atmospheric concentrations at a "safe" level.

The literature is also clear that a long-term solution is possible only if technology development proceeds along climate-friendly lines. Thus, an essential component of any successful near-term target is that it provides a strong impetus to technical change through a price signal, rather than exclusively a sizeable and/or immediate effect on greenhouse gas emissions. Specific technology agreements thus may offer an alternative to a tax or cap-and-trade policy. But the number of such agreements, the difficult negotiations among countries with radically different cultures, geography and resources, and the high cost of command-and-control measures when compared with economic instruments may render this option difficult to adopt in a global regime, although the approach could yield significant benefits.

Another alternative that is often suggested is that efforts be made to link climate change with development issues. History has clearly indicated that as countries develop, their focus on the local (and global) environment increases. However, while this might help, it will not necessarily produce the desired results: the richest countries today are responsible for the largest part of global emissions – and the richest – the USA – for the highest share. Following a trend of economic growth clearly does not by itself lead to emissions reductions. Furthermore, while increasing affluence does allow cost savings and energy efficiency technologies to be adopted, this route is very slow: it is hardly likely to drive the changes in energy production and use that are necessary to limit climate change to acceptable levels.

It has also been suggested that global international agreements may be politically impossible, as national and regional differences are too great to allow them to be adopted. If this is true, regional agreements (or other agreements between limited sets of countries) could be an alternative. However, they also pose problems – for example, they are likely to be less economically efficient (they would not allow global trading and the equalisation of global marginal abatement costs).

Recognising the pros and cons of possible alternatives, the current negotiated framework has much merit – including the experience of ten years of international negotiations and agreements. A world that was reluctant at the outset has become accustomed to the view that market mechanisms can help protect the environment, and help reconcile an acceptable global allocation of reduction efforts with a cost-effective distribution of emission reductions. The Kyoto Protocol's combination of a cap on emissions and tradable permits allows an acceptable allocation of effort without losing economic efficiency – something that a global carbon tax could not have achieved without significant financial transfers.

This framework could be even more acceptable for a broader set of countries if the nature of the targets is changed. Dynamic targets and the price cap option – including the non-binding target option for developing countries – could help deal with cost concerns. The international community could use them to undertake the necessary profound changes in energy production and use, to keep open the option of stabilising greenhouse gas atmospheric concentrations at relatively low levels. The achievement of targets would be conditional on actual costs. In addition, such a modification of the current international climate change regime may be easier to negotiate than many other alternatives – as it could build on the decade of past agreement under the UNFCCC.

The international community is sending mixed signals on climate change policy. While the EU, Japan and others have ratified the Kyoto Protocol, it is already clear that at least several major countries will not. Furthermore, even if all remaining countries ratified the agreement, it would yield little in the way of changes in the trend of atmospheric concentrations of greenhouse gases. The agreement currently places binding obligations for emissions limits or reductions on only about one-third of global emissions – and some parties to the agreement have stated that they will be unable to take additional actions unless all countries – both developed and developing – are engaged.

Thus, it is necessary to find ways of bringing all countries back to the negotiating table. Due consideration must be taken of the basic issues of equity, responsibility and capability to act. Economic principles that guide effective and efficient action clearly provide tools to help guide robust policy choices.

Countries are clearly taking action at the local and national levels – and many industries are seeking cost-effective and appropriate solutions. The issue confronting us now is how to move forward at a rate sufficient to limit the expected damage caused by climate change, while ensuring humanity the social and economic advances – and the energy resources – needed for future development.

This book has sought to put forward options that respond to all of the concerns voiced by different parties. However, no option can be a substitute for political will. While concerns about uncertain costs are legitimate – and can be dealt with – all countries must engage if the world is to stop climate change from rising beyond acceptable levels.

APPENDIX: CERTAINTY VERSUS STRINGENCY

Economic theory provides important insights into choosing between two types of economic instruments to deal with pollution problems – price instruments such as taxes, and quantity instruments such as tradable permit schemes.

In search of the optimum level of abatement

Economists use graphs like the one shown in Figure 14 to define the "optimal level" of pollution or – an equivalent, but perhaps more acceptable definition – the optimal level of de-pollution. They usually consider that the marginal benefit of abatement decreases with the level of abatement, because it is common that when pollution increases, its marginal environmental cost increases too. Marginal benefits here represent the present value of all future benefits arising from mitigating emissions over an infinite horizon[25].

Conversely, the marginal cost of abatement increases with the level of abatement. The first tonne of a pollutant is easier to eliminate than the last. Of course, over time things may change. But graphs like Figure 14 do not represent how costs and benefits may evolve over time – but how they relate to the level of effort undertaken at some point in time, or in some short period.

Finally, the optimal abatement quantity should be fixed at the point where the increasing marginal cost of abatement curve crosses the decreasing marginal benefit curve, according to the best estimate. Beyond that point, abatement costs are too high for too little additional environmental benefit.

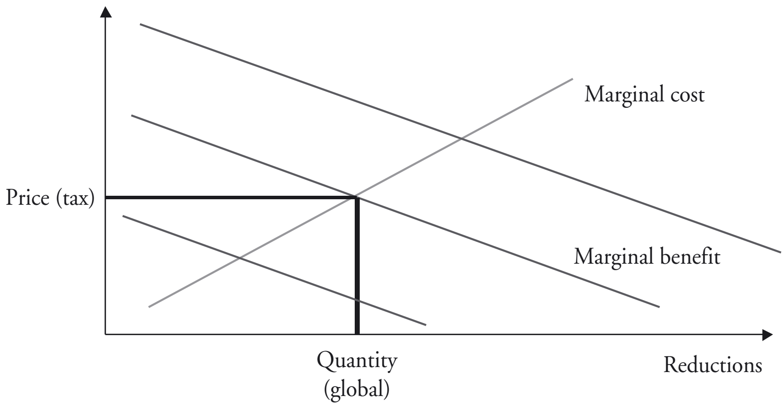
The salient point here is that if abatement costs are known with certainty, fixing a quantity fixes a price. Conversely, fixing a price would define a quantity. Thus, price and quantity instruments (say, taxes or tradable

25 We are looking here at marginal costs and benefits, not total costs and benefits. If each additional tonne of pollution is worse for the environment than the previous one, the marginal cost of pollution increases. But in this case, when one looks at the marginal benefits of abatement, the opposite happens: the marginal benefit of abatement decreases when its volume increases – while of course, the total benefits of abatement continue to increase.

quotas) are equivalent from an economic standpoint. This remains true even if the benefits are uncertain.

Figure 14

Price and quantity instruments are equivalent when costs are known



In order to reflect benefit uncertainty, three alternative marginal benefit curves are shown as a function of emission reductions produced during a given period (with the total level of reductions increasing from left to right).

Prices and quantities when abatement costs are uncertain

If abatement costs are not known with certainty, price and quantity instruments are no longer equivalent. As Martin Weitzman showed in 1974, it is the relative slopes of the benefit and cost curves that are important in this case. If the marginal damage cost ("benefit") curve is steep, the damage rapidly increases with the level of pollution. In this case it is worth determining the level of pollution rather than risk suffering too much environmental damage. If, on the contrary, the marginal benefit curve is flat, it means that the damage increases slowly with the level of pollution. It is then preferable to get certainty on the marginal cost of abatement, rather than risk paying too high a price for too small an incremental environmental benefit. A steeper benefit curve calls for quantity instruments, a steeper cost curve calls for price instruments. This is what Figure 3, in Chapter 1, illustrates. A more formal demonstration of these results can be found in Box 13.

Box 13

A formalisation of Weitzman's result

This rests on the important notion of *expectations*. Expected costs (or benefits) take into account all possible outcomes regarding uncertain costs (or benefits) and weigh them according to their probability of occurrence. Although they do not express the actual costs that will be incurred, they are useful instruments for making decisions in the context of uncertainty.

Weitzman showed that the value of the expected *costs* of choosing a price policy over a quantity is always negative: with a price instrument, the expected costs are always lower than with the equivalent (under a best guess) quantity instrument.

Let us denote:

c = marginal cost curve slope
b = marginal benefit curve slope
s^2 = variance of the cost curve function

The value of expected costs (E[C]) from choosing a price policy over a quantity policy writes:

$$E[C_{price} - C_{quantity}] = -\frac{\sigma^2}{2c}$$

The solution is intuitively obvious: the price instrument drives more reductions if costs are lower than expected, or less reductions if costs are higher than expected; however, the volume of supplementary costs incurred in the first case is less significant than the volume of costs saved in the second case. The marginal cost of abatement increases with its magnitude.

The value of expected *benefits* (ignoring the costs) of choosing a price policy over a quantity policy is also always negative. This is because the volume of supplementary benefits gained if the marginal cost is lower than expected is less significant than the volume of benefits lost if the marginal cost is higher than expected. The marginal benefit of abatement decreases with its magnitude (reflecting the increasing marginal damage when emissions increase). As a result, expected benefits are always lower with a price instrument than with the equivalent (under a best guess) quantity instrument.

The value of expected benefits (E[B]) from choosing a price policy over a quantity policy is:

$$E[B_{price} - B_{quantity}] = -\frac{\sigma^2}{2c^2}$$

These results help explain why people primarily concerned with environmental protection often show a preference for quantity instruments.

Let us now consider the difference between *net* expected benefits with a price instrument and *net* expected benefits with a quantity instrument – taking into account both costs and benefits. This difference is positive if the slope of the marginal cost curve is steeper than that of the marginal benefit curve, i.e., if costs grow faster than benefits[26]. In other words, saved costs are larger than lost expected benefits with the price instrument. The latter should be preferred over a quantity instrument. If, on the contrary, benefits grow faster than costs (because the marginal cost of pollution increases with its amount), a quantity instrument should be preferred. If a price were chosen instead, lost expected benefits would be more significant than saved expected costs.

The difference (benefit minus costs, or net benefits) is shown as:

$$\Delta = \frac{\sigma^2}{2c^2} \; c - b$$

As a result, the preference for price or quantity instruments only depends on the relative slopes of the marginal cost and benefit curves.

Hybrid instruments always perform better

In 1976, Roberts & Spence showed that a hybrid instrument, consisting of a quantity target, a price cap and a price floor as shown on Figure 15, would perform better than either a pure quantity or price instrument.

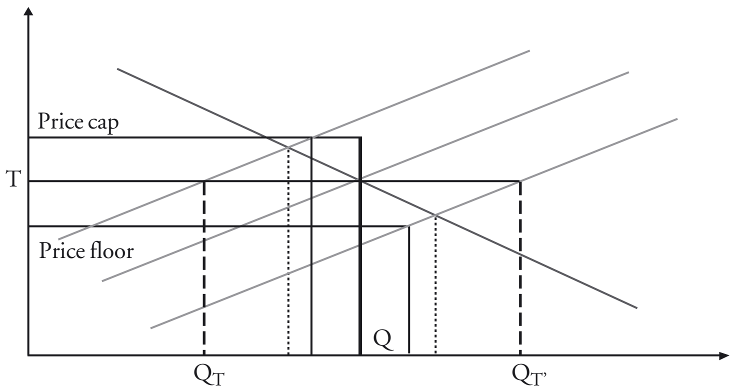
If abatement costs reach the price cap, less abatement is undertaken; emissions beyond the quantitative target are taxed at the price cap level. If abatement costs remain below the floor price, a subsidy finances additional abatement. The quantities actually achieved (solid vertical

26 Again, not over time, but with the quantity of abatement undertaken.

lines) are closer to the optima (dotted lines) than a fixed quantity (bold line). They are also closer to the optima than the quantities (Q_T or Q_T') that a pure tax would achieve (broken lines). This is due to the slope of the marginal benefit curve.

Figure 15

A hybrid instrument helps approximate the marginal benefit curve



In other words, a hybrid instrument allows for a fairly good approximation of the marginal benefit curve (near optimality) when abatement costs are uncertain. It would perform better than either a pure price or a quantity instrument, unless the benefit curve is perfectly horizontal (when a tax would prevail) or perfectly vertical (in which case a pure quantity would prevail).

The case of climate change

Climate change is a "stock" externality. GHG concentrations drive the climate. Given the importance of the "stock" (740 Pg of C in atmospheric CO_2) compared to annual emissions (8 PgC), the concentration evolves only slowly. This is what makes the marginal benefit curve rather flat or horizontal (reflecting a fairly constant marginal climate change damage cost: each additional tonne adds roughly the same stress as the one before).

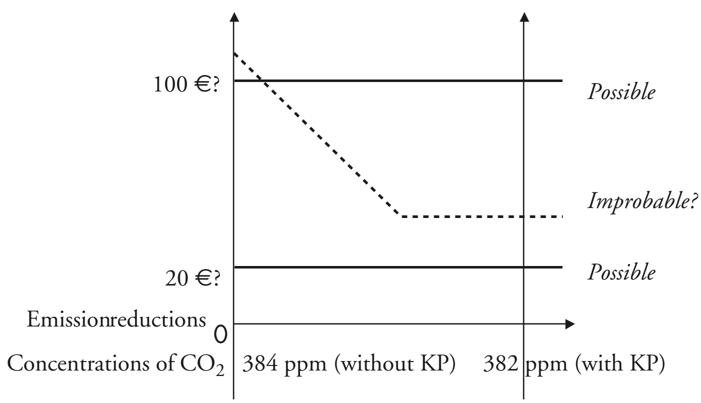
For example, consider the Kyoto Protocol in Figure 16. Its full implementation would reduce CO_2 concentrations in 2010 to 382 ppm, as opposed to 383 - 383.5 ppm under a business-as-usual scenario (Bolin, 1998). We don't know how the marginal climate change should be valued, but it is unlikely that it would be much different around 382 ppm than it would be around 384 ppm.

It should be noted that although the two "possible" benefit curves indicated here may seem to be parallel, in fact, they are not - they have a common origin, likely to be close to zero at pre-industrial concentration levels. Extremely high valuations of this damage could thus make these curves steeper.

Another limitation is that we cannot exclude a non-linear climate change that would introduce a turning point. But as we don't know at what concentration level this may happen, it hardly affects the expected damage function – particularly not within such a narrow range of emission levels.

Figure 16

Climate change cost curves

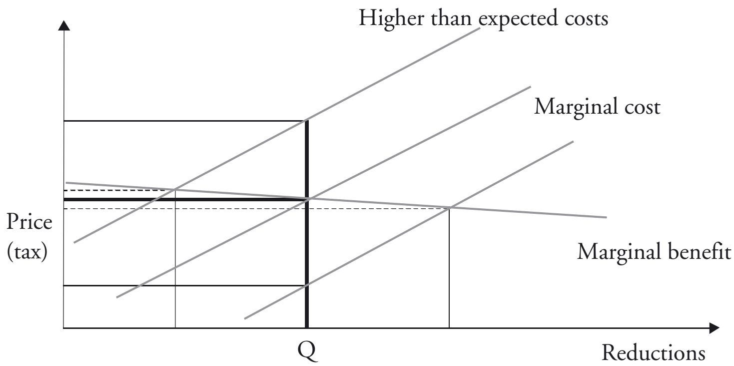


A consequence of the "flatness" of the marginal benefit curve is that price instruments should be preferred over quantity instruments to combat climate change. As shown in Figure 17, a fixed quantitative objective might be far from the optimum quantity once uncertainty on abatement costs is resolved, whereas a tax would always be close to the optimum price.

Newell and Pizer (2000) have adapted Martin Weitzman's analytical framework to deal with stock externalities, such as climate change. These adaptations take into account the persistence over time of expected benefit losses when price instruments are preferred over quantity instruments. If a price instrument leads to less mitigation in one period, this has long-lasting effects on subsequent periods. Thus, these adjustments tend to favour – in relative terms – quantity instruments.

Figure 17

A price instrument would be better in the case of climate change



However, these may not suffice to reverse policy preferences. A general conclusion is that the performance of price instruments is always increased by the size of the externality stock – given that benefits are relative to concentration level changes while costs are linked to short-term emission reductions.

In the case of climate change, this suggests a strong preference for price instruments. The adaptation made to the original framework cannot reverse the dominance of the stock nature of the externality. The parameters of Newell and Pizer's model may be questioned on a number of grounds. However, to reverse the policy conclusions, it would be necessary to give the marginal benefit – or climate change cost – a value more than 1,000 times higher – or a very rapid, non-linear increase of these costs.

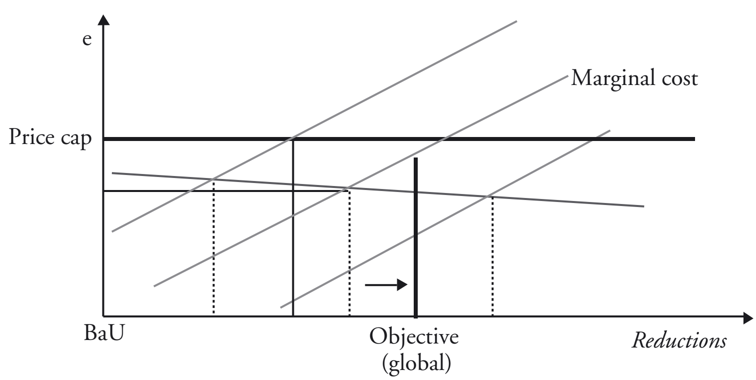
If this were the case, not only would the policy preference for price instruments be reversed; but the quantitative objective should also aim at reducing global emissions in the short term – from 40 to 100 per cent! This would be equivalent to stabilising CO_2 concentration at current levels. In other words, quantity targets are inconsistent with targets leading to reduce near-term global emission levels by 10, 20 or even 30 per cent.

However, quantitative instruments have a number of advantages. They help deal with sovereignty concerns; governments' fine-tuning between free allocations and auctioning in order to deal with vested interests; and, moreover, they help integrate countries with uneven levels of development into one single framework. This makes hybrid instruments even more appealing.

If a floor price appears impossible (or not desirable), it is necessary to set a more stringent quantitative objective than under a "best guess" on costs and benefits, as shown on Figure 18. This compensates for the risk of underinvestment in abatement policies in the absence of a floor price (Cournède & Gastaldo, 2002). The quantity of abatement undertaken is known, unless costs are higher than expected. In this case, the actual abatement will be less than the objective but still more than the optimum (dotted line on the left-hand side).

Figure 18

The price cap



LIST OF ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
AIJ	Activities Implemented Jointly
BaU	Business-as-usual
CDM	Clean Development Mechanism
Ceq	Carbon equivalent (weight of another GHG multiplied by its GWP – see those words)
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COP	Conference of the Parties
CFCs	Cholofluorocarbons
EITs	Economies in Transition
ET	Emissions Trading
FAIR	Framework to Assess International Regimes Differentiation of future commitments
FDI	Foreign Direct Investment
FSU	Former Soviet Union
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse gases
GtC	Gigatonnes (billion tonnes) of Carbone (or PgC)
GWPs	Global warming potentials
HC	Hydrocarbons
IBRD	International Bank for Reconstruction and Development
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
MtC	Million tonnes of Carbon
N_2O	Nitrous oxide
NO_x	Nitrogen oxides
ODA	Official Development Assistance
O_3	Ozone
PFCs	Perfluorocarbons

PgC	Petagramme of Carbon
ppm	parts per million
PV	Photovoltaic
SF_6	Sulfur hexafluoride
SRES	IPCC Special Report on Emission Scenarios
TAR	Third Assessment Report of the IPCC
UNFCCC	United Nations Framework Convention on Climate Change
WRE	Wigley, Richels and Edmonds
Wm^{-2}	Watts per square metre

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