TECHNICAL SUMMARY

CLIMATE CHANGE 2001: MITIGATION

A Report of Working Group III
of the Intergovernmental Panel on Climate Change

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Lead Authors:
Tariq Banuri (Pakistan), Terry Barker (UK), Igor Bashmakov (Russian Federation), Kornelis Blok (Netherlands), John Christensen (Denmark), Ogunlade Davidson (Sierra Leone), Michael Grubb (UK), Kirsten Halsnaes (Denmark), Catrinus Jepma (Netherlands), Eberhard Jochem (Germany), Pekka Kauppi (Finland), Olga Krankina (Russian Federation), Alan Krupnick (USA), Lambert Kuijpers (Netherlands), Snorre Kverndokk (Norway), Anil Markandya (UK), Bert Metz (Netherlands), William R. Moomaw (USA), Jose Roberto Moreira (Brazil), Tsuneyuki Morita (Japan), Jiahua Pan (China), Lynn Price (USA), Richard Richels (USA), John Robinson (Canada), Jayant Sathaye (USA), Rob Swart (Netherlands), Kanako Tanaka (Japan), Tomihiru Taniguchi (Japan), Ferenc Toth (Germany), Tim Taylor (UK), John Weyant (USA)

Review Editor:
Rajendra Pachauri (India)

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1 Scope of the Report

1.1 Background

In 1998, Working Group (WG) III of the Intergovernmental Panel on Climate Change (IPCC) was charged by the IPCC Plenary for the Panel's Third Assessment Report (TAR) to assess the scientific, technical, environmental, economic, and social aspects of the mitigation of climate change. Thus, the mandate of the Working Group was changed from a predominantly disciplinary assessment of the economic and social dimensions on climate change (including adaptation) in the Second Assessment Report (SAR), to an interdisciplinary assessment of the options to control the emissions of greenhouse gases (GHGs) and/or enhance their sinks.

After the publication of the SAR, continued research in the area of mitigation of climate change, which was partly influenced by political changes such as the adoption of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997, has been undertaken and is reported on here. The report also draws on a number of IPCC Special Reports[1] and IPCC co-sponsored meetings and Expert Meetings that were held in 1999 and 2000, particularly to support the development of the IPCC TAR. This summary follows the 10 chapters of the report.

1.2 Broadening the Context of Climate Change Mitigation

This chapter places climate change mitigation, mitigation policy, and the contents of the rest of the report in the broader context of development, equity, and sustainability. This context reflects the explicit conditions and principles laid down by the UNFCCC on the pursuit of the ultimate objective of stabilizing greenhouse gas concentrations. The UNFCCC imposes three conditions on the goal of stabilization: namely that it should take place 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" (Art. 2). It also specifies several principles to guide this process: equity, common but differentiated responsibilities, precaution, cost-effective measures, right to sustainable development, and support for an open international economic system (Art. 3).

Previous IPCC assessment reports sought to facilitate this pursuit by comprehensively describing, cataloguing, and comparing technologies and policy instruments that could be used to achieve mitigation of greenhouse gas emissions in a cost-effective and efficient manner. The present assessment advances this process by including recent analyses of climate change that place policy evaluations in the context of sustainable development. This expansion of scope is consistent both with the evolution of the literature on climate change and the importance accorded by the UNFCCC to sustainable development - including the recognition that "Parties have a right to, and should promote sustainable development" (Art. 3.4). It therefore goes some way towards filling the gaps in earlier assessments.

Climate change involves complex interactions between climatic, environmental, economic, political, institutional, social, and technological processes. It cannot be addressed or comprehended in isolation of broader societal goals (such as equity or sustainable development), or other existing or probable future sources of stress. In keeping with this complexity, a multiplicity of approaches have emerged to analyze climate change and related challenges. Many of these incorporate concerns about development, equity, and sustainability (DES) (albeit partially and gradually) into their framework and recommendations. Each approach emphasizes certain elements of the problem, and focuses on certain classes of responses, including for example, optimal policy design, building capacity for designing and implementing policies, strengthening synergies between climate change mitigation and/or adaptation and other societal goals, and policies to enhance societal learning. These approaches are therefore complementary rather than mutually exclusive.

This chapter brings together three broad classes of analysis, which differ not so much in terms of their ultimate goals as of their points of departure and preferred analytical tools. The three approaches start with concerns, respectively, about efficiency and cost-effectiveness, equity and sustainable development, and global sustainability and societal learning. The difference between the three approaches selected lies in their starting point not in their ultimate goals. Regardless of the starting point of the analysis, many studies try in their own way to incorporate other concerns. For example, many analyses that approach climate change mitigation from a cost-effectiveness perspective try to bring in considerations of equity and sustainability through their treatment of costs, benefits, and welfare. Similarly, the class of studies that are motivated strongly by considerations of inter-country equity tend to argue that equity is needed to ensure that developing countries can pursue their internal goals of sustainable development–a concept that includes the implicit components of sustainability and efficiency. Likewise, analysts focused on concerns of global sustainability have been compelled by their own logic to make a case for global efficiency–often modelled as the decoupling of production from material flows–and social equity. In other words, each of the three perspectives has led writers to search for ways to incorporate concerns that lie beyond their initial starting point. All three classes of analyses look at the relationship of climate change mitigation with all three goals–development, equity, and sustainability–albeit in different and often highly complementary ways. Nevertheless, they frame the issues dif-

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[1] Notably the Special Report on Aviation and the Global Atmosphere, the Special Report on Methodological and Technological Issues in Technology Transfer, the Special Report on Emissions Scenarios, and the Special Report on Land Use, Land-Use Change and Forestry.

ferently, focus on different sets of causal relationships, use different tools of analysis, and often come to somewhat different conclusions.

There is no presumption that any particular perspective for analysis is most appropriate at any level. Moreover, the three perspectives are viewed here as being highly synergistic. The important changes have been primarily in the types of questions being asked and the kinds of information being sought. In practice, the literature has expanded to add new issues and new tools, subsuming rather than discarding the analyses included in the other perspectives. The range and scope of climate policy analyses can be understood as a gradual broadening of the types and extent of uncertainties that analysts have been willing and able to address.

The first perspective on climate policy analysis is cost effectiveness. It represents the field of conventional climate policy analysis that is well represented in the First through Third Assessments. These analyses have generally been driven directly or indirectly by the question of what is the most cost-effective amount of mitigation for the global economy starting from a particular baseline GHG emissions projection, reflecting a specific set of socio-economic projections. Within this framework, important issues include measuring the performance of various technologies and the removal of barriers (such as existing subsidies) to the implementation of those candidate policies most likely to contribute to emissions reductions. In a sense, the focus of analysis here has been on identifying an efficient pathway through the interactions of mitigation policies and economic development, conditioned by considerations of equity and sustainability, but not primarily guided by them. At this level, policy analysis has almost always taken the existing institutions and tastes of individuals as given; assumptions that might be valid for a decade or two, but may become more questionable over many decades.

The impetus for the expansion in the scope of the climate policy analysis and discourse to include equity considerations was to address not simply the impacts of climate change and mitigation policies on global welfare as a whole, but also of the effects of climate change and mitigation policies on existing inequalities among and within nations. The literature on equity and climate change has advanced considerably over the last two decades, but there is no consensus on what constitutes fairness. Once equity issues were introduced into the assessment agenda, though, they became important components in defining the search for efficient emissions mitigation pathways. The considerable literature that indicated how environmental policies could be hampered or even blocked by those who considered them unfair became relevant. In light of these results, it became clear how and why any widespread perception that a mitigation strategy is unfair would likely engender opposition to that strategy, perhaps to the extent of rendering it non-optimal (or even infeasible, as could be the case if non-Annex I countries never participate). Some cost-effectiveness analyses had, in fact, laid the groundwork for applying this literature by demonstrating the sensitivity of some equity measures to policy design, national perspective, and regional context. Indeed, cost-effectiveness analyses had even highlighted similar sensitivities for other measures of development and sustainability. As mentioned, the analyses that start from equity concerns have by and large focused on the needs of developing countries, and in particular on the commitment expressed in Article 3.4 of the UNFCCC to the pursuit of sustainable development. Countries differ in ways that have dramatic implications for scenario baselines and the range of mitigation options that can be considered. The climate policies that are feasible, and/or desirable, in a particular country depend significantly on its available resources and institutions, and on its overall objectives including climate change as but one component. Recognizing this heterogeneity may, thus, lead to a different range of policy options than has been considered likely thus far and may reveal differences in the capacities of different sectors that may also enhance appreciation of what can be done by non-state actors to improve their ability to mitigate.

The third perspective is global sustainability and societal learning. While sustainability has been incorporated in the analyses in a number of ways, a class of studies takes the issue of global sustainability as their point of departure. These studies focus on alternative pathways to pursue global sustainability and address issues like decoupling growth from resource flows, for example through eco-intelligent production systems, resource light infrastructure and appropriate technologies, and decoupling wellbeing from production, for example through intermediate performance levels, regionalization of production systems, and changing lifestyles. One popular method for identifying constraints and opportunities within this perspective is to identify future sustainable states and then examine possible transition paths to those states for feasibility and desirability. In the case of developing countries this leads to a number of possible strategies that can depart significantly from those which the developed countries pursued in the past.

1.3 Integrating the Various Perspectives

Extending discussions of how nations might respond to the mitigation challenge so that they include issues of cost-effectiveness and efficiency, distribution narrowly defined, equity more broadly defined, and sustainability, adds enormous complexity to the problem of uncovering how best to respond to the threat of climate change. Indeed, recognizing that these multiple domains are relevant complicates the task assigned to policymakers and international negotiators by opening their deliberations to issues that lie beyond the boundaries of the climate change problem, *per se*. Their recognition thereby underlines the importance of integrating scientific thought across a wide range of new policy-relevant contexts, but not simply because of some abstract academic or narrow parochial interest advanced by a small set of researchers or nations. Cost-effectiveness, equity, and sustainability have all been identified as critical issues by the drafters of the UNFCCC, and they are an integral part of the charge given to the drafters of the TAR. Integration across the domains of cost-effectiveness, equity, and sustainability is therefore profoundly relevant to policy deliberations according to the letter as well as the spirit of the UNFCCC itself.

The literature being brought to bear on climate change mitigation increasingly shows that policies lying beyond simply reducing GHG emissions from a specified baseline to minimize costs can be extremely effective in abating the emission of GHGs. Therefore, a portfolio approach to policy and analysis would be more effective than exclusive reliance on a narrow set of policy instruments or analytical tools. Besides the flexibility that an expanded range of policy instruments and analytical tools can provide to policymakers for achieving climate objectives, the explicit inclusion of additional policy objectives also increases the likelihood of "buy-in" to climate policies by more participants. In particular, it will expand the range of no regrets[2] options. Finally, it could assist in tailoring policies to short-, medium-, and long-term goals.

In order to be effective, however, a portfolio approach requires weighing the costs and impacts of the broader set of policies according to a longer list of objectives. Climate deliberations need to consider the climate ramifications of policies designed primarily to address a wide range of issues including DES, as well as the likely impacts of climate policies on the achievement of these objectives. As part of this process the opportunity costs and impacts of each instrument are measured against the multiple criteria defined by these multiple objectives. Furthermore, the number of decision makers or stakeholders to be considered is increased beyond national policymakers and international negotiators to include state, local, community, and household agents, as well as non-government organizations (NGOs).

The term "ancillary benefits" is often used in the literature for the ancillary, or secondary, effects of climate change mitigation policies on problems other than GHG emissions, such as reductions in local and regional air pollution, associated with the reduction of fossil fuels, and indirect effects on issues such as transportation, agriculture, land use practices, biodiversity preservation, employment, and fuel security. Sometimes these are referred to as "ancillary impacts", to reflect the fact that in some cases the benefits may be negative[3]. The concept of "mitigative capacity" is also introduced as a possible way to integrate results derived from the application of the three perspectives in the future. The determinants of the capacity to mitigate climate change include the availability of technological and policy options, and access to resources to underwrite undertaking those options. These determinants are the focus of much of the TAR. The list of determinants is, however, longer than this. Mitigative capacity also depends upon nation-specific characteristics that facilitate the pursuit of sustainable development – e.g., the distribution of resources, the relative empowerment of various segments of the population, the credibility of empowered decision makers, the degree to which climate objectives complement other objectives, access to credible information and analyses, the will to act on that information, the ability to spread risk intra- and inter-generationally, and so on. Given that the determinants of mitigative capacity are essentially the same as those of the analogous concept of adaptive capacity introduced in the WGII Report, this approach may provide an integrated framework for assessing both sets of options.

2 Greenhouse Gas Emissions Scenarios

2.1 Scenarios

A long-term view of a multiplicity of future possibilities is required to consider the ultimate risks of climate change, assess critical interactions with other aspects of human and environmental systems, and guide policy responses. Scenarios offer a structured means of organizing information and gleaning insight on the possibilities.

Each mitigation scenario describes a particular future world, with particular economic, social, and environmental characteristics, and they therefore implicitly or explicitly contain information about DES. Since the difference between reference case scenarios and stabilization and mitigation scenarios is simply the addition of deliberate climate policy, it can be the case that the differences in emissions among different reference case scenarios are greater than those between any one such scenario and its stabilization or mitigation version.

This section presents an overview of three scenario literatures: general mitigation scenarios produced since the SAR, narrative-based scenarios found in the general futures literature, and mitigation scenarios based on the new reference scenarios developed in the IPCC SRES.

2.2 Greenhouse Gas Emissions Mitigation Scenarios

This report considers the results of 519 quantitative emissions scenarios from 188 sources, mainly produced after 1990. The review focuses on 126 mitigation scenarios that cover global emissions and have a time horizon encompassing the coming century. Technological improvement is a critical element in all the general mitigation scenarios.

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[2] In this report, as in the SAR, no regrets options are defined as those options whose benefits such as reduced energy costs and reduced emissions of local/regional pollutants equal or exceed their costs to society, excluding the benefits of avoided climate change. They are also known as negative cost options.

[3] In this report sometimes the term "co-benefits" is also used to indicate the additional benefits of policy options that are implemented for various reasons at the same time, acknowledging that most policies designed to address GHG mitigation also have other, often at least equally important, rationales, e.g., related to objectives of development, sustainability and equity. The benefits of avoided climate change are not covered in ancillary or co-benefits. See also Section 7.2.

Based on the type of mitigation, the scenarios fall into four categories: concentration stabilization scenarios, emission stabilization scenarios, safe emission corridor scenarios, and other mitigation scenarios. All the reviewed scenarios include energy-related carbon dioxide (CO_2) emissions; several also include CO_2 emissions from land-use changes and industrial processes, and other important GHGs.

Policy options used in the reviewed mitigation scenarios take into account energy systems, industrial processes, and land use, and depend on the underlying model structure. Most of the scenarios introduce simple carbon taxes or constraints on emissions or concentration levels. Regional targets are introduced in the models with regional disaggregation. Emission permit trading is introduced in more recent work. Some models employ policies of supply-side technology introduction, while others emphasize efficient demand-side technology.

Allocation of emission reduction among regions is a contentious issue. Only some studies, particularly recent ones, make explicit assumptions about such allocations in their scenarios. Some studies offer global emission trading as a mechanism to reduce mitigation costs.

Technological improvement is a critical element in all the general mitigation scenarios.

Detailed analysis of the characteristics of 31 scenarios for stabilization of CO_2 concentrations at 550ppmv[4] (and their baseline scenarios) yielded several insights:

- There is a wide range in baselines, reflecting a diversity of assumptions, mainly with respect to economic growth and low-carbon energy supply. High economic growth scenarios tend to assume high levels of progress in the efficiency of end-use technologies; however, carbon intensity reductions were found to be largely independent of economic growth assumptions. The range of future trends shows greater divergence in scenarios that focus on developing countries than in scenarios that look at developed nations. There is little consensus with respect to future directions in developing regions.

- The reviewed 550ppmv stabilization scenarios vary with respect to reduction time paths and the distribution of emission reductions among regions. Some scenarios suggested that emission trading may lower the overall mitigation cost, and could lead to more mitigation in the non-OECD countries. The range of assumed mitigation policies is very wide. In general, scenarios in which there is an assumed adoption of high-efficiency measures in the baseline show less scope for further introduction of efficiency measures in the mitigation scenarios. In part this results from model input assumptions, which do not assume major technological breakthroughs. Conversely, baseline scenarios with high carbon intensity reductions show larger carbon intensity reductions in their mitigation scenarios.

Only a small set of studies has reported on scenarios for mitigating non-CO_2 gases. This literature suggests that small reductions of GHG emissions can be accomplished at lower cost by including non-CO_2 gases; that both CO_2 and non-CO_2 emissions would have to be controlled in order to slow the increase of atmospheric temperature sufficiently to achieve climate targets assumed in the studies; and that methane (CH_4) mitigation can be carried out more rapidly, with a more immediate impact on the atmosphere, than CO_2 mitigation.

Generally, it is clear that mitigation scenarios and mitigation policies are strongly related to their baseline scenarios, but no systematic analysis has been published on the relationship between mitigation and baseline scenarios.

2.3 Global Futures Scenarios

Global futures scenarios do not specifically or uniquely consider GHG emissions. Instead, they are more general “stories” of possible future worlds. They can complement the more quantitative emissions scenario assessments, because they consider dimensions that elude quantification, such as governance and social structures and institutions, but which are nonetheless important to the success of mitigation policies. Addressing these issues reflects the different perspectives presented in Section 1: cost-effectiveness and/or efficiency, equity, and sustainability.

A survey of this literature has yielded a number of insights that are relevant to GHG emissions scenarios and sustainable development. First, a wide range of future conditions has been identified by futurists, ranging from variants of sustainable development to collapse of social, economic, and environmental systems. Since future values of the underlying socio-economic drivers of emissions may vary widely, it is important that climate policies should be designed so that they are resilient against widely different future conditions.

Second, the global futures scenarios that show falling GHG emissions tend to show improved governance, increased equity and political participation, reduced conflict, and improved environmental quality. They also tend to show increased energy efficiency, shifts to non-fossil energy sources, and/or shifts to a post-industrial (service-based) economy; population tends to stabilize at relatively low levels, in many cases thanks to increased prosperity, expanded provision of family planning, and improved rights and opportunities for women. A key impli-

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[4] The reference to a particular concentration level does not imply an agreed-upon desirability of stabilization at this level. The selection of 550ppmv is based on the fact that the majority of studies in the literature analyze this level, and does not imply any endorsement of this level as a target for climate change mitigation policies.

cation is that sustainable development policies can make a significant contribution to emission reduction.

Third, different combinations of driving forces are consistent with low emissions scenarios, which agrees with the SRES findings. The implication of this seems to be that it is important to consider the linkage between climate policy and other policies and conditions associated with the choice of future paths in a general sense.

2.4 Special Report on Emissions Scenarios

Six new GHG emission reference scenario groups (not including specific climate policy initiatives), organized into 4 scenario "families", were developed by the IPCC and published as the Special Report on Emissions Scenarios (SRES). Scenario families A1 and A2 emphasize economic development but differ with respect to the degree of economic and social convergence; B1 and B2 emphasize sustainable development but also differ in terms of degree of convergence (see *Box TS.1*). In all, six models were used to generate the 40 scenarios that comprise the six scenario groups. Six of these scenarios, which should be considered equally sound, were chosen to illustrate the whole set of scenarios. These six scenarios include marker scenarios for each of the worlds as well as two scenarios, A1FI and A1T, which illustrate alternative energy technology developments in the A1 world (see *Figure TS.1*).

The SRES scenarios lead to the following findings:

- Alternative combinations of driving-force variables can lead to similar levels and structure of energy use, land-use patterns, and emissions.
- Important possibilities for further bifurcations in future development trends exist within each scenario family.
- Emissions profiles are dynamic across the range of SRES scenarios. They portray trend reversals and indicate possible emissions cross-over among different scenarios.
- Describing potential future developments involves inherent ambiguities and uncertainties. One and only one possible development path (as alluded to, for instance, in concepts such as "business-as-usual scenario") simply does not exist. The multi-model approach increases the value of the SRES scenario set, since uncertainties in the choice of model input assumptions can be more explicitly separated from the specific model behaviour and related modelling uncertainties.

Box TS.1. The Emissions Scenarios of the IPCC Special Report on Emissions Scenarios (SRES)

A1. The A1 storyline and scenario family describe a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

A2. The A2 storyline and scenario family describe a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in a continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than in other storylines.

B1. The B1 storyline and scenario family describe a convergent world with the same global population, which peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures towards a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describe a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than in A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1, and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

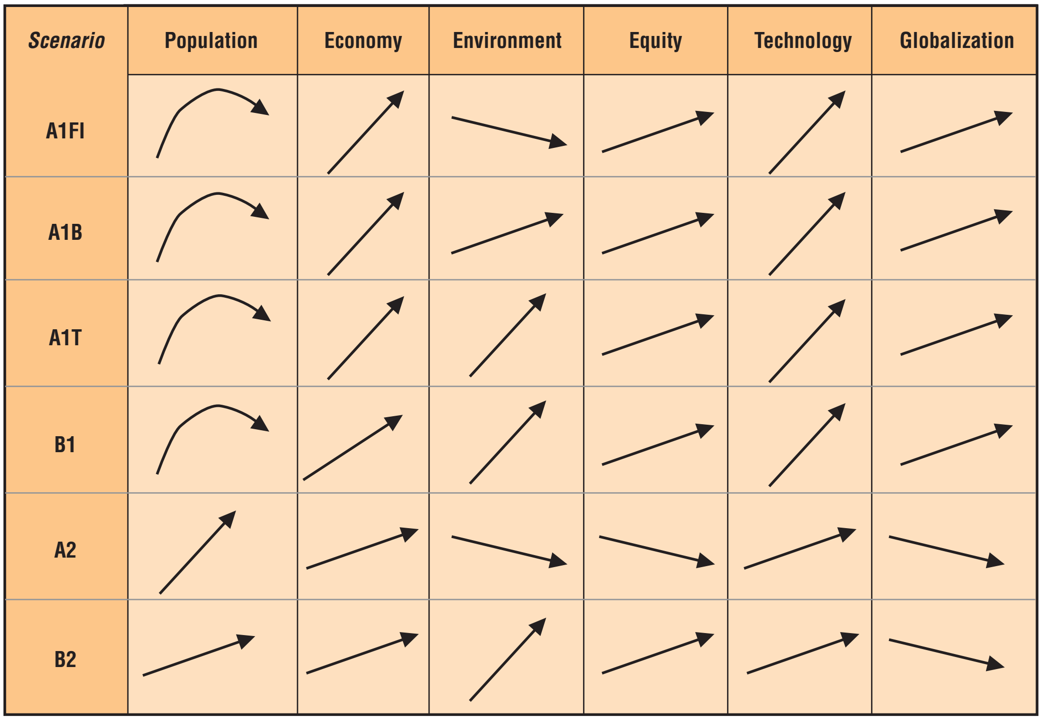

Figure TS.1: Qualitative directions of SRES scenarios for different indicators.

2.5 Review of Post-SRES Mitigation Scenarios

Recognizing the importance of multiple baselines in evaluating mitigation strategies, recent studies analyze and compare mitigation scenarios using as their baselines the new SRES scenarios. This allows for the assessment in this report of 76 "post-SRES mitigation scenarios" produced by nine modelling teams. These mitigation scenarios were quantified on the basis of storylines for each of the six SRES scenarios that describe the relationship between the kind of future world and the capacity for mitigation.

Quantifications differ with respect to the baseline scenario, including assumed storyline, the stabilization target, and the model that was used. The post-SRES scenarios cover a very wide range of emission trajectories, but the range is clearly below the SRES range. All scenarios show an increase in CO_2 reduction over time. Energy reduction shows a much wider range than CO_2 reduction, because in many scenarios a decoupling between energy use and carbon emissions takes place as a result of a shift in primary energy sources.

In general, the lower the stabilization target and the higher the level of baseline emissions, the larger the CO_2 divergence from the baseline that is needed, and the earlier that it must occur. The A1FI, A1B, and A2 worlds require a wider range of and more strongly implemented technology and/or policy measures than A1T, B1, and B2. The 450ppmv stabilization case requires more drastic emission reduction to occur earlier than under the 650ppmv case, with very rapid emission reduction over the next 20 to 30 years (see *Figure TS.2*).

A key policy question is what kind of emission reductions in the medium term (after the Kyoto Protocol commitment period) would be needed. Analysis of the post-SRES scenarios (most of which assume developing country emissions to be below baselines by 2020) suggests that stabilization at 450 ppmv will require emissions reductions in Annex I countries after 2012 that go significantly beyond their Kyoto Protocol commitments. It also suggests that it would not be necessary to go much beyond the Kyoto commitments for Annex I by 2020 to achieve stabilization at 550ppmv or higher. However, it should be recognized that several scenarios indicate the need for significant Annex I emission reductions by 2020 and that none of the scenarios introduces other constraints such as a limit to the rate of temperature change.

An important policy question already mentioned concerns the participation of developing countries in emission mitigation. A preliminary finding of the post-SRES scenario analysis is that, if it is assumed that the CO_2 emission reduction needed for stabilization occurs in Annex I countries only, Annex I per capita CO_2 emissions would fall below non-Annex I per capita emissions during the 21st century in nearly all of the stabilization scenarios, and before 2050 in two-thirds of the scenarios, if developing countries emissions follow the baseline scenarios. This suggests that the stabilization target and the baseline emission level are both important determinants of the

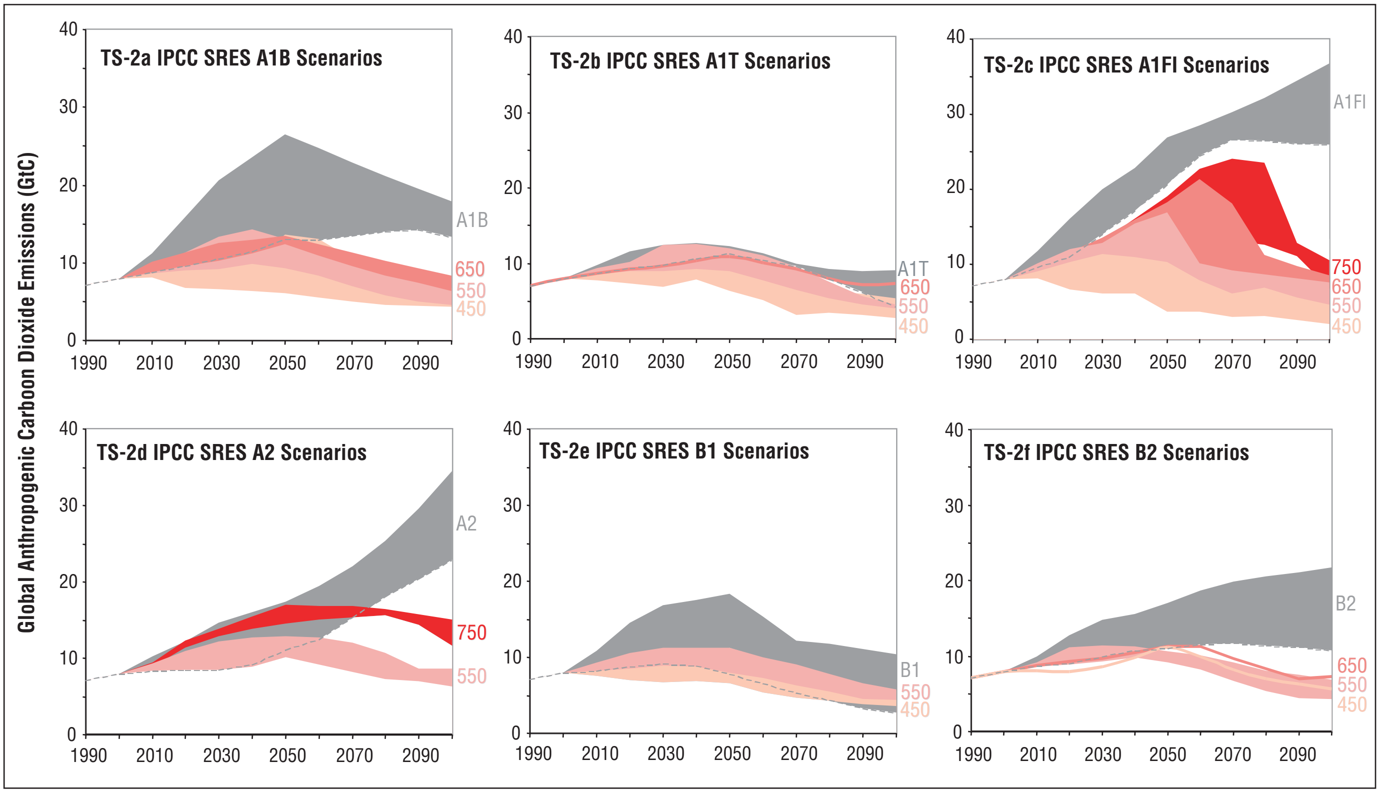

Figure TS.2: *Comparison of reference and stabilization scenarios. The figure is divided into six parts, one for each of the reference scenario groups from the Special Report on Emissions Scenarios (SRES). Each part of the figure shows the range of total global CO_2 emissions (gigatonnes of carbon (GtC)) from all anthropogenic sources for the SRES reference scenario group (shaded in grey) and the ranges for the various mitigation scenarios assessed in the TAR leading to stabilization of CO_2 concentrations at various levels (shaded in colour). Scenarios are presented for the A1 family subdivided into three groups (the balanced A1B group (Figure TS-2a), non-fossil fuel A1T (Figure TS-2b), and the fossil intensive A1FI (Figure TS-2c)) and stabilization of CO_2 concentrations at 450, 550, 650 and 750ppmv; for the A2 group with stabilization at 550 and 750ppmv in Figure TS-2d, the B1 group and stabilization at 450 and 550ppmv in Figure TS-2e, and the B2 group including stabilization at 450, 550, and 650ppmv in Figure TS-2f. The literature is not available to assess 1000ppmv stabilization scenarios. The figure illustrates that the lower the stabilization level and the higher the baseline emissions, the wider the gap. The difference between emissions in different scenario groups can be as large as the gap between reference and stabilization scenarios within one scenario group. The dotted lines depict the boundaries of the ranges where they overlap (see Box TS.1).*

timing when developing countries emissions might need to diverge from their baseline.

Climate policy would reduce per capita final energy use in the economy-emphasized worlds (A1FI, A1B, and A2), but not in the environment-emphasized worlds (B1 and B2). The reduction in energy use caused by climate policies would be larger in Annex I than in non-Annex I countries. However, the impact of climate policies on equity in per capita final energy use would be much smaller than that of the future development path.

There is no single path to a low emission future and countries and regions will have to choose their own path. Most model results indicate that known technological options[5] could achieve a broad range of atmospheric CO_2 stabilization levels, such as 550ppmv, 450ppmv or, below over the next 100 years or more, but implementation would require associated socio-economic and institutional changes..

Assumed mitigation options differ among scenarios and are strongly dependent on the model structure. However, common features of mitigation scenarios include large and continuous energy efficiency improvements and afforestation as well as low-carbon energy, especially biomass over the next 100 years and natural gas in the first half of the 21st century. Energy conservation and reforestation are reasonable first steps, but innovative supply-side technologies will eventually be required. Possible robust options include using natural gas and combined-cycle technology to bridge the transition to more

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[5] "Known technological options" refer to technologies that exist in operation or pilot plant stage today, as referenced in the mitigation scenarios discussed in this report. It does not include any new technologies that will require drastic technological breakthroughs. In this way it can be considered to be a conservative estimate, considering the length of the scenario period.

advanced fossil fuel and zero-carbon technologies, such as hydrogen fuel cells. Solar energy as well as either nuclear energy or carbon removal and storage would become increasingly important for a higher emission world or lower stabilization target.

Integration between global climate policies and domestic air pollution abatement policies could effectively reduce GHG emissions in developing regions for the next two or three decades. However, control of sulphur emissions could amplify possible climate change, and partial trade-offs are likely to persist for environmental policies in the medium term.

Policies governing agriculture, land use and energy systems could be linked for climate change mitigation. Supply of biomass energy as well as biological CO_2 sequestration would broaden the available options for carbon emission reductions, although the post-SRES scenarios show that they cannot provide the bulk of the emission reductions required. That has to come from other options.

3 Technological and Economic Potential of Mitigation Options

3.1 Key Developments in Knowledge about Technological Options to Mitigate GHG Emissions in the Period up to 2010-2020 since the Second Assessment Report

Technologies and practices to reduce GHG emissions are continuously being developed. Many of these technologies focus on improving the efficiency of fossil fuel energy or electricity use and the development of low carbon energy sources, since the majority of GHG emissions (in terms of CO_2 equivalents) are related to the use of energy. Energy intensity (energy consumed divided by gross domestic product (GDP)) and carbon intensity (CO_2 emitted from burning fossil fuels divided by the amount of energy produced) have been declining for more than 100 years in developed countries without explicit government policies for decarbonization, and have the potential to decline further. Much of this change is the result of a shift away from high carbon fuels such as coal towards oil and natural gas, through energy conversion efficiency improvements and the introduction of hydro and nuclear power. Other non-fossil fuel energy sources are also being developed and rapidly implemented and have a significant potential for reducing GHG emissions. Biological sequestration of CO_2 and CO_2 removal and storage can also play a role in reducing GHG emissions in the future (see also Section 4 below). Other technologies and measures focus on the non-energy sectors for reducing emissions of the remaining major GHGs: CH_4, nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).

Since the SAR several technologies have advanced more rapidly than was foreseen in the earlier analysis. Examples include the market introduction of efficient hybrid engine cars, rapid advancement of wind turbine design, demonstration of underground carbon dioxide storage, and the near elimination of N_2O emissions from adipic acid production. Greater energy efficiency opportunities for buildings, industry, transportation, and energy supply are available, often at a lower cost than was expected. By the year 2010 most of the opportunities to reduce emissions will still come from energy efficiency gains in the end-use sectors, by switching to natural gas in the electric power sector, and by reducing the release of process GHGs from industry, e.g., N_2O, perfluoromethane (CF_4), and HFCs. By the year 2020, when a proportion of the existing power plants will have been replaced in developed countries and countries with economies in transition (EITs), and when many new plants will become operational in developing countries, the use of renewable sources of energy can begin contributing to the reduction of CO_2 emissions. In the longer term, nuclear energy technologies – with inherent passive characteristics meeting stringent safety, proliferation, and waste storage goals – along with physical carbon removal and storage from fossil fuels and biomass, followed by sequestration, could potentially become available options.

Running counter to the technological and economic potential for GHG emissions reduction are rapid economic development and accelerating change in some socio-economic and behavioural trends that are increasing total energy use, especially in developed countries and high-income groups in developing countries. Dwelling units and vehicles in many countries are growing in size, and the intensity of electrical appliance use is increasing. Use of electrical office equipment in commercial buildings is increasing. In developed countries, and especially the USA, sales of larger, heavier, and less efficient vehicles are also increasing. Continued reduction or stabilization in retail energy prices throughout large portions of the world reduces incentives for the efficient use of energy or the purchase of energy efficient technologies in all sectors. With a few important exceptions, countries have made little effort to revitalize policies or programmes to increase energy efficiency or promote renewable energy technologies. Also since the early 1990s, there has been a reduction in both public and private resources devoted to R&D (research and development) to develop and implement new technologies that will reduce GHG emissions.

In addition, and usually related to technological innovation options, there are important possibilities in the area of social innovation. In all regions, many options are available for lifestyle choices that may improve quality of life, while at the same time decreasing resource consumption and associated GHG emissions. Such choices are very much dependent on local and regional cultures and priorities. They are very closely related to technological changes, some of which can be associated with profound lifestyle changes, while others do not require such changes. While these options were hardly noted in the SAR, this report begins to address them.

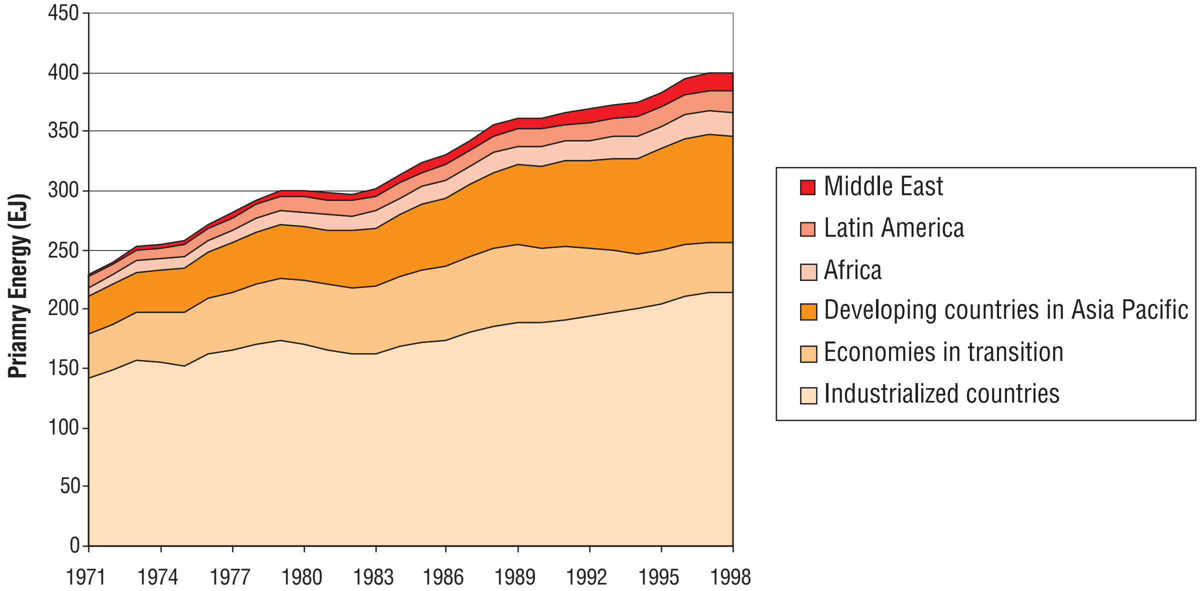

Figure TS.3: *World primary energy use by region from 1971 to 1998.*

Note: Primary energy calculated using the IEA's physical energy content method based on the primary energy sources used to produce heat and electricity.

3.2 Trends in Energy Use and Associated Greenhouse Gas Emissions

Global consumption of energy and associated emission of CO_2 continue an upward trend in the 1990s (*Figures TS.3* and *TS.4*). Fossil fuels remain the dominant form of energy utilized in the world, and energy use accounts for more than two thirds of the GHG emissions addressed by the Kyoto Protocol. In 1998, 143 exajoules (EJ) of oil, 82EJ of natural gas, and 100EJ of coal were consumed by the world's economies. Global primary energy consumption grew an average of 1.3% annually between 1990 and 1998. Average annual growth rates were 1.6% for developed countries and 2.3% to 5.5% for developing countries between 1990 and 1998. Primary energy use for the EITs declined at an annual rate of 4.7% between 1990 and 1998 owing to the loss of heavy industry, the decline in overall economic activity, and restructuring of the manufacturing sector.

Average global carbon dioxide emissions grew – approximately at the same rate as primary energy – at a rate of 1.4% per year between 1990 and 1998, which is much slower than the 2.1% per year growth seen in the 1970s and 1980s. This was in large measure because of the reductions from the EITs and structural changes in the industrial sector of the developed countries. Over the longer term, global growth in CO_2 emissions from energy use was 1.9% per year between 1971 and 1998. In 1998, developed countries were responsible for over 50% of energy-related CO_2 emissions, which grew at a rate of 1.6% annually from 1990. The EITs accounted for 13% of 1998 emissions, and their emissions have been declining at an annual rate of 4.6% per year since 1990. Developing countries in the Asia-Pacific region emitted 22% of the global total carbon dioxide, and have been the fastest growing with increases of 4.9% per year since 1990. The rest of the developing countries accounted for slightly more than 10% of total emissions, growing at an annual rate of 4.3% since 1990.

During the period of intense industrialization from 1860 to 1997, an estimated 13,000EJ of fossil fuel were burned, releasing 290GtC into the atmosphere, which along with land-use change has raised atmospheric concentrations of CO_2 by 30%. By comparison, estimated natural gas resources[6] are comparable to those for oil, being approximately 35,000EJ. The coal resource base is approximately four times as large. Methane clathrates (not counted in the resource base) are estimated to be approximately 780,000EJ. Estimated fossil fuel reserves contain 1,500GtC, being more than 5 times the carbon already released, and if estimated resources are added, there is a total of 5,000GtC remaining in the ground. The scenarios modelled

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[6] Reserves are those occurrences that are identified and measured as economically and technically recoverable with current technologies and prices. Resources are those occurrences with less certain geological and/or economic characteristics, but which are considered potentially recoverable with foreseeable technological and economic developments. The resource base includes both categories. On top of that there are additional quantities with unknown certainty of occurrence and/or with unknown or no economic significance in the foreseeable future, referred to as "additional occurrences" (SAR). Examples of unconventional fossil fuel resources are tar sands and shale oils, geopressured gas, and gas in aquifers.

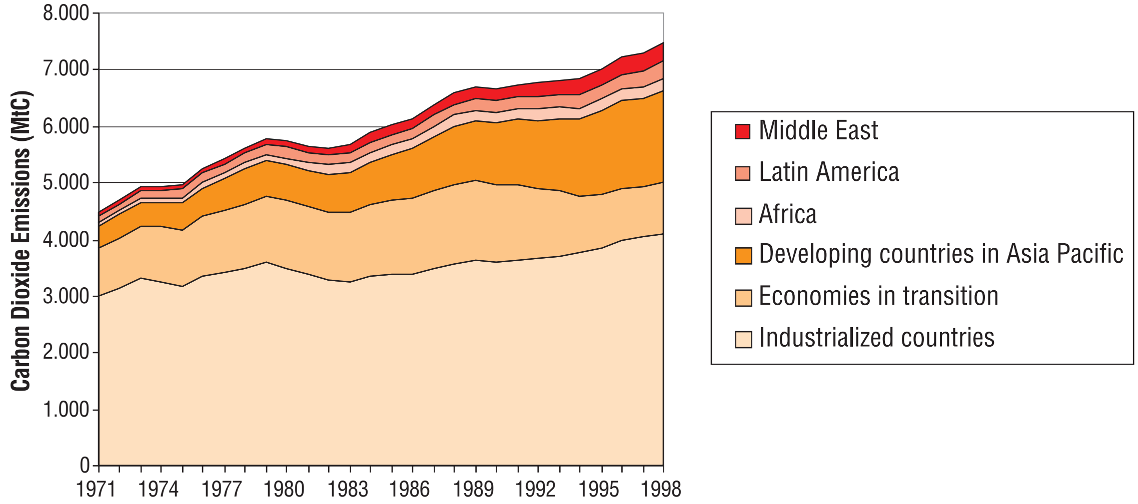

Figure TS.4: *World CO_2 emissions by region, 1971-1998.*

by the SRES without any specific GHG emission policies foresee cumulative release ranging from approximately 1,000 GtC to 2,100 GtC from fossil fuel consumption between 2,000 and 2,100. Cumulative carbon emissions for stabilization profiles of 450 to 750 ppmv over that same period are between 630 and 1,300GtC (see *Figure TS.5*). Fossil-fuel scarcity, at least at the global level, is therefore not a significant factor in considering climate change mitigation. On the contrary, different from the relatively large coal and unconventional oil and gas deposits, the carbon in conventional oil and gas reserves or in conventional oil resources is much less than the cumulative carbon emissions associated with stabilisation at 450 ppmv or higher (*Figure TS.5*). In addition, there is the potential to contribute large quantities of other GHGs as well. At the same time it is clear from *Figure TS.5* that the conventional oil and gas reserves are only a small fraction of the total fossil fuel resource base. These resource data may imply a change in the energy mix and the introduction of new sources of energy during the 21st century. The choice of energy mix and associated investment will determine whether, and if so at what level and cost, greenhouse concentrations can be stabilized. Currently most such investment is directed towards discovering and developing more conventional and unconventional fossil resources.

3.3 Sectoral Mitigation Technological Options[7]

The potential[8] for major GHG emission reductions is estimated for each sector for a range of costs (*Table TS.1*). In the industrial sector, costs for carbon emission abatement are estimated to range from negative (i.e., no regrets, where reductions can be made at a profit), to around US$300/tC[9]. In the buildings sector, aggressive implementation of energy-efficient technologies and measures can lead to a reduction in CO_2 emissions from residential buildings in 2010 by 325MtC/yr in developed and EIT countries at costs ranging from -US$250 to –US$150/tC and by 125MtC in developing countries at costs of –US$250 to US$50/tC. Similarly, CO_2 emissions from commercial buildings in 2010 can be reduced by 185MtC in developed and EIT countries at costs ranging from –US$400 to –US$250/tC avoided and by 80MtC in developing countries at costs ranging from -US$400 to US$0/tC. In the transport sector costs range from –US$200/tC to US$300/tC, and in the agricultural sector from –US$100/tC to US$300/tC. Materials management, including recycling and landfill gas recovery, can also produce savings at negative to modest costs under US$100/tC. In the energy supply sector a number of fuel switching and technological substitutions are possible at costs from –US$100 to more than US$200/tC. The realization of this potential will be determined by the market conditions as influenced by human and societal preferences and government interventions.

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[7] International Energy Statistics (IEA) report sectoral data for the industrial and transport sectors, but not for buildings and agriculture, which are reported as “other”. In this section, information on energy use and CO_2 emissions for these sectors has been estimated using an allocation scheme and based on a standard electricity conversion factor of 33%. In addition, values for the EIT countries are from a different source (British Petroleum statistics). Thus, the sectoral values can differ from the aggregate values presented in section 3.2, although general trends are the same. In general, there is uncertainty in the data for the EITs and for the commercial and residential sub-categories of the buildings sector in all regions.

[8] The potential differs in different studies assessed but the aggregate potential reported in Sections 3 and 4 refers to the socio-economic potential as indicated in *Figure TS.7*.

[9] All costs in US$.

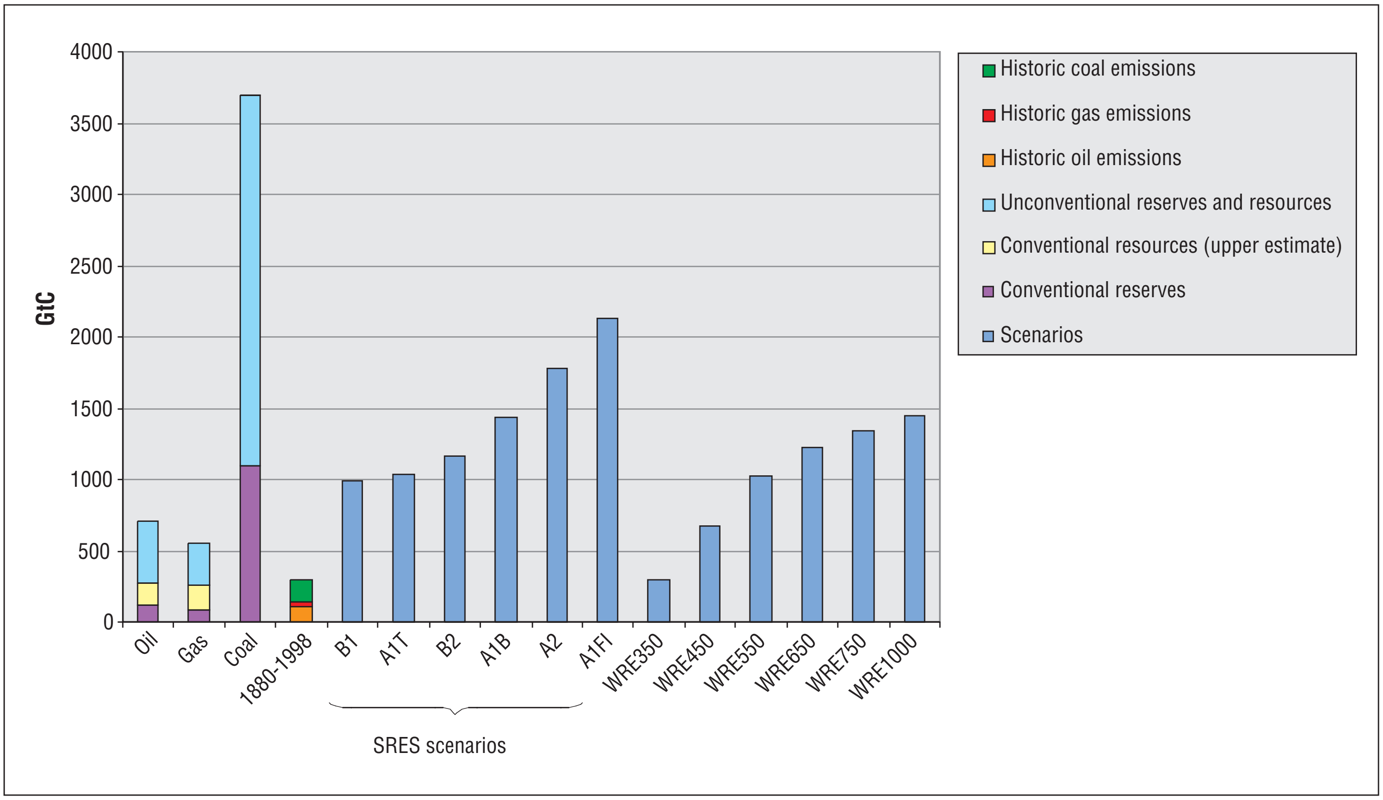


Figure TS.5: *Carbon in oil, gas and coal reserves and resources compared with historic fossil fuel carbon emissions 1860-1998, and with cumulative carbon emissions from a range of SRES scenarios and TAR stabilization scenarios up until 2100. Data for reserves and resources are shown in the left hand columns. Unconventional oil and gas includes tar sands, shale oil, other heavy oil, coal bed methane, deep geopressured gas, gas in acquifers, etc. Gas hydrates (clathrates) that amount to an estimated 12,000 GtC are not shown. The scenario columns show both SRES reference scenarios as well as scenarios which lead to stabilization of* CO_2 *concentrations at a range of levels. Note that if by 2100 cumulative emissions associated with SRES scenarios are equal to or smaller than those for stabilization scenarios, this does not imply that these scenarios equally lead to stabilization.*

Table TS.2 provides an overview and links with barriers and mitigation impacts. Sectoral mitigation options are discussed in more detail below.

3.3.1 The Main Mitigation Options in the Buildings Sector

The buildings sector contributed 31% of global energy-related CO_2 emissions in 1995, and these emissions have grown at an annual rate of 1.8% since 1971. Building technology has continued on an evolutionary trajectory with incremental gains during the past five years in the energy efficiency of windows, lighting, appliances, insulation, space heating, refrigeration, and air conditioning. There has also been continued development of building controls, passive solar design, integrated building design, and the application of photovoltaic systems in buildings. Fluorocarbon emissions from refrigeration and air conditioning applications have declined as chlorofluorocarbons (CFCs) have been phased out, primarily thanks to improved containment and recovery of the fluorocarbon refrigerant and, to a lesser extent, owing to the use of hydrocarbons and other non-fluorocarbon refrigerants. Fluorocarbon use and emission from insulating foams have declined as CFCs have been phased out, and are projected to decline further as HCFCs are phased out. R&D effort has led to increased efficiency of refrigerators and cooling and heating systems. In spite of the continued improvement in technology and the adoption of improved technology in many countries, energy use in buildings has grown more rapidly than total energy demand from 1971 through 1995, with commercial building energy registering the greatest annual percentage growth (3.0% compared to 2.2% in residential buildings). This is largely a result of the increased amenity that consumers demand – in terms of increased use of appliances, larger dwellings, and the modernization and expansion of the commercial sector – as economies grow. There presently exist significant cost-effective technological opportunities to slow this trend. The overall technical potential for reducing energy-related CO_2 emissions in the buildings sector using existing technologies combined with future technical advances is 715MtC/yr in 2010 for a base case with carbon emissions of 2,600MtC/yr (27%), 950MtC/yr in 2020 for a base case with carbon emissions of 3,000MtC/yr (31%), and 2,025MtC/yr in 2050 for a base case with carbon emissions of 3,900MtC/yr (52%). Expanded R&D can assure continued technology improvement in this sector.

Table TS.1: *Estimations of greenhouse gas emission reductions and cost per tonne of carbon equivalent avoided following the anticipated socio-economic potential uptake by 2010 and 2020 of selected energy efficiency and supply technologies, either globally or by region and with varying degrees of uncertainty*

	Region	**US$/tC avoided** –400 –200 0 +200	**2010**		**2020**		**References, comments, and relevant section in Chapter 3 of this report**
			Potential[a]	Probability[b]	**Potential**[a]	Probability[b]	
Buildings / appliances							
Residential sector	OECD/EIT		◆◆◆◆◆	◊◊◊◊◊	◆◆◆◆◆	◊◊◊◊◊	Acosta Moreno *et al*., 1996; Brown *et al*., 1998 Wang and Smith, 1999
	Dev. cos.		◆◆◆◆	◊◊◊	◆◆◆◆	◊◊◊◊◊	
Commercial sector	OECD/EIT		◆◆◆◆	◊◊◊◊	◆◆◆◆◆	◊◊◊◊◊	
	Dev. cos.		◆◆◆	◊◊◊	◆◆◆◆	◊◊◊◊◊	
Transport							
Automobile efficiency improvements	USA		◆◆◆◆◆	◊◊◊◊	◆◆◆◆◆	◊◊◊	Interlab. Working Group, 1997 Brown *et al*, 1998 US DOE/EIA, 1998 ECMT, 1997 (8 countries only) Kashiwagi *et al*, 1999 Denis and Koopman, 1998 Worrell *et al*., 1997b
	Europe		◆◆◆◆◆	◊◊	◆◆◆◆◆	◊◊	
	Japan		◆◆◆◆	◊◊	◆◆◆◆◆	◊◊	
	Dev. cos.		◆◆◆◆	◊◊	◆◆◆◆◆	◊◊	
Manufacturing							
CO_2 removal – fertilizer; refineries	Global		◆	◊◊◊◊	◆	◊◊◊◊	*Table 3.21*
Material efficiency improvement	Global		◆◆◆◆	◊◊◊	◆◆◆◆	◊◊◊	*Table 3.21*
Blended cements	Global		◆	◊◊◊	◆	◊◊◊	*Table 3.21*
N_2O reduction by chem. indus.	Global		◆	◊◊◊◊	◆	◊◊◊	*Table 3.21*
PFC reduction by Al industry	Global		◆	◊◊◊	◆	◊◊◊	*Table 3.21*
HFC-23 reduction by chem. industry	Global		◆◆	◊◊◊	◆◆	◊◊◊	*Table 3.21*
Energy efficient improvements	Global		◆◆◆◆◆	◊◊◊◊◊	◆◆◆◆◆	◊◊◊◊	*Table 3.19*

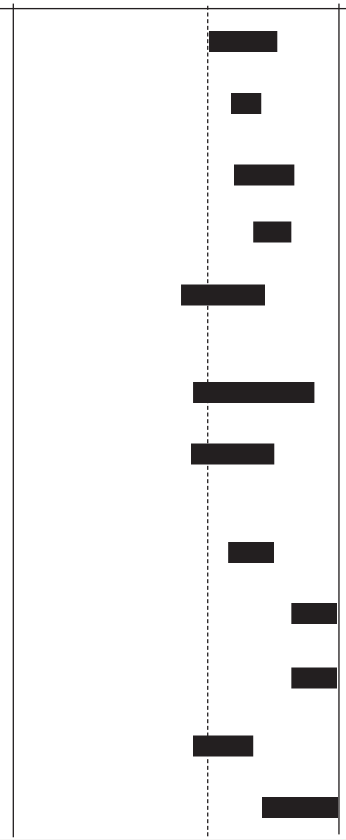
(continued)

Table TS.1: continued

	Region	US $/tC avoided –400 –200 0 +200	2010		2020		References, comments, and relevant section in Chapter 3 of this report
			Potential[a]	Probability[b]	**Potential[a]**	Probability[b]	
Agriculture							
Increased uptake of conservation tillage and cropland management	Dev. cos.		◆	◊◊	◆	◊◊	Zhou, 1998; *Table 3.27* Dick *et al.*, 1998
	Global		◆◆◆	◊◊	◆◆◆◆	◊◊◊	IPCC, 2000
Soil carbon sequestration	Global		◆◆◆	◊◊	◆◆◆◆	◊◊◊	Lal and Bruce, 1999 *Table 3.27*
Nitrogenous fertilizer management	OECD		◆	◊◊◊	◆	◊◊◊	Kroeze & Mosier, 1999 *Table 3.27*
	Global		◆	◊◊◊	◆◆◆	◊◊◊◊	OECD, 1999; IPCC, 2000
Enteric methane reduction	OECD		◆◆	◊◊	◆◆	◊◊◊	Kroeze & Mosier, 1999 *Table 3.27*
	USA		◆	◊◊	◆	◊◊◊	OECD, 1998 Reimer & Freund, 1999
	Dev. cos.		◆	◊	◆	◊◊	Chipato, 1999
Rice paddy irrigation and fertilizers	Global		◆◆◆	◊◊	◆◆◆◆	◊◊◊	Riemer & Freund, 1999 IPCC, 2000
Wastes							
Landfill methane capture	OECD		◆◆◆◆	◊◊◊	◆◆◆◆	◊◊◊◊	Landfill methane USEPA, 1999
Energy supply							
Nuclear for coal	Global		◆◆◆◆	◊◊	◆◆◆◆◆	◊◊◊◊	Totals[c] – See Section 3.8.6
	Annex I		◆◆	◊◊	◆◆◆◆	◊◊	*Table 3.35a*
	Non-Annex I		◆◆	◊◊◊	◆◆◆◆◆	◊◊◊	*Table 3.35b*
Nuclear for gas	Annex I		◆◆◆	◊	◆◆◆◆	◊	*Table 3.35c*
	Non-Annex I		◆	◊	◆◆◆	◊	*Table 3.35d*

(continued)

Table TS.1: continued

	Region	**US\$/tC avoided** –400 –200 0 +200	**2010**		**2020**		**References, comments, and relevant section in Chapter 3 of this report**
			Potential[a]	Probability[b]	**Potential**[a]	Probability[b]	
Gas for coal	Annex I		◆	◊◊◊	◆◆◆◆	◊◊◊◊	*Table 3.35a*
	Non-Annex I		◆	◊◊◊◊	◆◆◆◆	◊◊◊◊	*Tables 3.35b*
CO_2 capture from coal	Global		◆	◊◊	◆◆	◊◊	*Tables 3.35a + b*
CO_2 capture from gas	Global		◆	◊◊	◆◆	◊◊	*Tables 3.35c + d*
Biomass for coal	Global		◆	◊◊◊◊	◆◆◆	◊◊◊◊	*Tables 3.35a + b* Moore, 1998; Interlab w. gp. 1997
Biomass for gas	Global		◆	◊	◆	◊◊◊	*Tables 3.35c + d*
Wind for coal or gas	Global		◆◆◆	◊◊◊	◆◆◆◆◆	◊◊◊◊	*Tables 3.35a - d* BTM Cons 1999; Greenpeace, 1999
Co-fire coal with 10% biomass	USA		◆	◊◊◊	◆◆	◊◊◊	Sulilatu, 1998
Solar for coal	Annex I		◆	◊	◆	◊	*Table 3.35a*
	Non-Annex I		◆	◊	◆	◊	*Table 3.35b*
Hydro for coal	Global		◆◆	◊	◆◆◆	◊◊	*Tables 3.35a + b*
Hydro for gas	Global		◆	◊	◆◆	◊◊	*Tables 3.35c + d*

Notes:

[a] Potential in terms of tonnes of carbon equivalent avoided for the cost range of US\$/tC given.

◆ = <20 MtC/yr
◆◆ = 20-50 MtC/yr
◆◆◆ = 50-100MtC/yr
◆◆◆◆ = 100-200MtC/yr
◆◆◆◆◆ = >200 MtC/yr

[b] Probability of realizing this level of potential based on the costs as indicated from the literature.

◊ = Very unlikely
◊◊ = Unlikely
◊◊◊ = Possible
◊◊◊◊ = Probable
◊◊◊◊◊ = Highly probable

[c] Energy supply total mitigation options assumes that not all the potential will be realized for various reasons including competition between the individual technologies as listed below the totals.

Table TS.2: *Technological options, barriers, opportunities, and impacts on production in various sectors*

Technological options	Barriers and opportunities	Implications of mitigation policies on sectors
Buildings, households and services: Hundreds of technologies and measures exist that can improve the energy efficiency of appliances and equipment as well as building structures in all regions of the world. It is estimated that CO_2 emissions from residential buildings in 2010 can be reduced by 325MtC in developed countries and the EIT region at costs ranging from -US$250 to -US$150/tC and by 125MtC in developing countries at costs of -US$250 to US$50/tC. Similarly, CO_2 emissions from commercial buildings in 2010 can be reduced by 185MtC in industrialized countries and the EIT region at costs ranging from -US$400 to -US$250/tC and by 80MtC in developing countries at costs ranging from -US$400 to US$0/tC. These savings represent almost 30% of buildings, CO_2 emissions in 2010 and 2020 compared to a central scenario such as the SRES B2 Marker scenario.	Barriers: In developed countries a market structure not conducive to efficiency improvements, misplaced incentives, and lack of information; and in developing countries lack of financing and skills, lack of information, traditional customs, and administered pricing. Opportunities: Developing better marketing approaches and skills, information-based marketing, voluntary programmes and standards have been shown to overcome barriers in developed countries. Affordable credit skills, capacity building, information base and consumer awareness, standards, incentives for capacity building, and deregulation of the energy industry are ways to address the aforementioned barriers in the developing world.	Service industries: Many will gain output and employment depending on how mitigation policies are implemented, however in general the increases are expected to be small and diffused. Households and the informal sector: The impact of mitigation on households comes directly through changes in the technology and price of household's use of energy and indirectly through macroeconomic effects on income and employment. An important ancillary benefit is the improvement in indoor and outdoor air quality, particularly in developing countries and cities all over the world.
Transportation: Transportation technology for light-duty vehicles has advanced more rapidly than anticipated in the SAR, as a consequence of international R&D efforts. Hybrid-electric vehicles have already appeared in the market and introduction of fuel cell vehicles by 2003 has been announced by most major manufacturers. The GHG mitigation impacts of technological efficiency improvements will be diminished to some extent by the rebound effect, unless counteracted by policies that effectively increase the price of fuel or travel. In countries with high fuel prices, such as Europe, the rebound effect may be as large as 40%; in countries with low fuel prices, such as the USA, the rebound appears to be no larger than 20%. Taking into account rebound effects, technological measures can reduce GHG emissions by 5%-15% by 2010 and 15%-35% by 2020, in comparison to a baseline of continued growth.	Barriers: Risk to manufacturers of transportation equipment is an important barrier to more rapid adoption of energy efficient technologies in transport. Achieving significant energy efficiency improvements generally requires a "clean sheet" redesign of vehicles, along with multibillion dollar investments in new production facilities. On the other hand, the value of greater efficiency to customers is the difference between the present value of fuel savings and increased purchase price, which net can often be a small quantity. Although markets for transport vehicles are dominated by a very small number of companies in the technical sense, they are nonetheless highly competitive in the sense that strategic errors can be very costly. Finally, many of the benefits of increased energy efficiency accrue in the form of social rather than private benefits. For all these reasons, the risk to manufacturers of sweeping technological change to improve energy efficiency is generally perceived to outweigh the direct market benefits. Enormous public and private investments in transportation infrastructure and a built environment adapted to motor vehicle travel pose significant barriers to changing the modal structure of transportation in many countries.	Transportation: Growth in transportation demand is projected to remain, influenced by GHG mitigation policies only in a limited way. Only limited opportunities for replacing fossil carbon - based fuels exist in the short to medium term. The main effect of mitigation policies will be to improve energy efficiency in all modes of transportation.

(continued)

Table TS.2: *continued*

Technological options	Barriers and opportunities	Implications of mitigation policies on sectors
	Opportunities: Information technologies are creating new opportunities for pricing some of the external costs of transportation, from congestion to environmental pollution. Implementation of more efficient pricing can provide greater incentives for energy efficiency in both equipment and modal structure. The factors that hinder the adoption of fuel-efficient technologies in transport vehicle markets create conditions under which energy efficiency regulations, voluntary or mandatory, can be effective. Well-formulated regulations eliminate much of the risk of making sweeping technological changes, because all competitors face the same regulations. Study after study has demonstrated the existence of technologies capable of reducing vehicle carbon intensities by up to 50% or in the longer run 100%, approximately cost-effectively. Finally, intensive R&D efforts for light-duty road vehicles have achieved dramatic improvements in hybrid power-train and fuel cell technologies. Similar efforts could be directed at road freight, air, rail, and marine transport technologies, with potentially dramatic pay-offs.	
Industry. Energy efficiency improvement is the main emission reduction option in industry. Especially in industrialized countries much has been done already to improve energy efficiency, but options for further reductions remain. 300 - 500MtC/yr and 700 -1,100MtC/yr can be reduced by 2010 and 2020, respectively, as compared to a scenario like SRES B2. The larger part of these options has net negative costs. Non-CO_2 emissions in industry are generally relatively small and can be reduced by over 85%, most at moderate or sometimes even negative costs.	Barriers: lack of full-cost pricing, relatively low contribution of energy to production costs, lack of information on part of the consumer and producer, limited availability of capital and skilled personnel are the key barriers to the penetration of mitigation technology in the industrial sector in all, but most importantly in developing countries. Opportunities: legislation to address local environmental concerns; voluntary agreements, especially if complemented by government efforts; and direct subsidies and tax credits are approaches that have been successful in overcoming the above barriers. Legislation, including standards, and better marketing are particularly suitable approaches for light industries.	Industry: Mitigation is expected to lead to structural change in manufacturing in Annex I countries (partly caused by changing demands in private consumption), with those sectors supplying energy-saving equipment and low-carbon technologies benefitting and energy-intensive sectors having to switch fuels, adopt new technologies, or increase prices. However, rebound effects may lead to unexpected negative results

(continued)

Table TS.2: *continued*

Technological options	Barriers and opportunities	Implications of mitigation policies on sectors
Land-use change and forestry. There are three fundamental ways in which land use or management can mitigate atmospheric CO_2 increases: protection, sequestration, and substitution[a]. These options show different temporal patterns; consequently, the choice of options and their potential effectiveness depend on the target time frame as well as on site productivity and disturbance history. The SAR estimated that globally these measures could reduce atmospheric C by about 83 to 131GtC by 2050 (60 to 87GtC in forests and 23 to 44GtC in agricultural soils). Studies published since then have not substantially revised these estimates. The costs of terrestrial management practices are quite low compared to alternatives, and range from 0 ('win-win' opportunities) to US$12/tC.	Barriers: to mitigation in land-use change and forestry include lack of funding and of human and institutional capacity to monitor and verify, social constraints such as food supply, people living off the natural forest, incentives for land clearing, population pressure, and switch to pastures because of demand for meat. In tropical countries, forestry activities are often dominated by the state forest departments with a minimal role for local communities and the private sector. In some parts of the tropical world, particularly Africa, low crop productivity and competing demands on forests for crop production and fuelwood are likely to reduce mitigation opportunities. Opportunities: in land use and forestry, incentives and policies are required to realize the technical potential. There may be in the form of government regulations, taxes, and subsidies, or through economic incentives in the form of market payments for capturing and holding carbon as suggested in the Kyoto Protocol, depending on its implementation following decisions by CoP.	GHG mitigation policies can have a large effect on land use, especially through carbon sequestration and biofuel production. In tropical countries, large-scale adoption of mitigation activities could lead to biodiversity conservation, rural employment generation and watershed protection contributing to sustainable development. To achieve this, institutional changes to involve local communities and industry and necessary thereby leading to a reduced role for governments in managing forests.
Agriculture and waste management. Energy inputs are growing by <1% per year globally with the highest increases in non-OECD countries but they have reduced in the EITs. Several options already exist to decrease GHG emissions for investments of -US$50 to 150/tC. These include increasing carbon stock by cropland management (125MtC/yr by 2010); reducing CH_4 emissions from better livestock management (>30MtC/yr) and rice production (7MtC/yr); soil carbon sequestration (50-100MtC/yr) and reducing N_2O emissions from animal wastes and application of N measures are feasible in most regions given appropriate technology transfer and incentives for farmers to change their traditional methods. Energy cropping to displace fossil fuels has good prospects if the costs can be made more competitive and the crops are produced sustainably. Improved waste management can decrease GHG emissions by 200MtC$_{eq}$ in 2010 and 320MtC$_{eq}$ in 2020 as compared to 240MtC$_{eq}$ emissions in 1990.	Barriers: In agriculture and waste management, these include inadequate R&D funding, lack of intellectual property rights, lack of national human and institutional capacity and information in the developing countries, farm-level adoption constraints, lack of incentives and information for growers in developed countries to adopt new husbandry techniques, (need other benefits, not just greenhouse gas reduction). Opportunities: Expansion of credit schemes, shifts in research priorities, development of institutional linkages across countries, trading in soil carbon, and integration of food, fibre, and energy products are ways by which the barriers may be overcome. Measures should be linked with moves towards sustainable production methods. Energy cropping provides benefits of land use diversification where suitable land is currently under utilized for food and fibre production and water is readily available.	Energy: forest and land management can provide a variety of solid, liquid, or gaseous fuels that are renewable and that can substitute for fossil fuels. Materials: products from forest and other biological materials are used for construction, packaging, papers, and many other uses and are often less energy-intensive than are alternative materials that provide the same service. Agriculture/land use: commitment of large areas to carbon sequestration or carbon management may compliment or conflict with other demands for land, such as agriculture. GHG mitigation will have an impact on agriculture through increased demand for biofuel production in many regions. Increasing competition for arable land may increase prices of food and other agricultural products.

(continued)

Table TS.2: *continued*

Technological options	Barriers and opportunities	Implications of mitigation policies on sectors
Waste management: Utilization of methane from landfills and from coal beds. The use of landfill gas for heat and electric power is also growing. In several industrial countries and especially in Europe and Japan, waste-to-energy facilities have become more efficient with lower air pollution emissions, paper and fibre recycling, or by utilizing waste paper as a biofuel in waste to energy facilities.	Barriers: Little is being done to manage landfill gas or to reduce waste in rapidly growing markets in much of the developing world. Opportunities: countries like the US and Germany have specific policies to either reduce methane producing waste, and/or requirements to utulize methane from landfills as an energy source. Costs of recovery are negative for half of landfill methane.	
Energy sector: In the energy sector, options are available both to increase conversion efficiency and to increase the use of primary energy with less GHGs per unit of energy produced, by sequestering carbon, and reducing GHG leakages. Win-win options such as coal bed methane recovery and improved energy efficiency in coal and gas fired power generation as well as co-production of heat and electricity can help to reduce emissions. With economic development continuing, efficiency increases alone will be insufficient to control GHG emissions from the energy sector. Options to decrease emissions per unit energy produced include new renewable forms of energy, which are showing strong growth but still account for less than 1% of energy produced worldwide. Technologies for CO2 capture and disposal to achieve "clean fossil" energy have been proposed and could contribute significantly at costs competitive with renewable energy although considerable research is still needed on the feasibility and possible environmental impacts of such methods to determine their application and usage. Nuclear power and, in some areas, larger scale hydropower could make a substantially increased contribution but face problems of costs and acceptability. Emerging fuel cells are expected to open opportunities for increasing the average energy conversion efficiency in the decades to come.	Barriers: key barriers are human and institutional capacity, imperfect capital markets that discourage investment in small decentralized systems, more uncertain rates of return on investment, high trade tariffs, lack of information, and lack of intellectual property rights for mitigation technologies. For renewable energy, high first costs, lack of access to capital, and subsidies for fossil fuels and key barriers. Opportunities for developing countries include promotion of leapfrogs in energy supply and demand technology, facilitating technology transfer through creating an enabling environment, capacity building, and appropriate mechanisms for transfer of clean and efficient energy technologies. Full cost pricing and information systems provide opportunities in developed countries. Ancillary benefits associated with improved technology, and with reduced production and use of fossil fuels, can be substantial.	Coal: Coal production, use, and employment are likely to fall as a result of greenhouse gas mitigation policies, compared with projections of energy supply without additional climate policies. However, the costs of adjustment will be much lower if policies for new coal production also encourage clean coal technology. Oil: Global mitigation policies are likely to lead to reductions in oil production and trade, with energy exporters likely to face reductions in real incomes as compared to a situation without such policies. The effect on the global oil price of achieving the Kyoto targets, however, may be less severe than many of the models predict, because of the options to include non-CO2 gases and the flexible mechanisms in achieving the target, which are often not included in the models. Gas: Over the next 20 years mitigation may influence the use of natural gas may positively or negatively, depending on regional and local conditions. In the Annex I countries any switch that takes place from coal or oil would be towards natural gas and renewable sources for power generation. In the case of the non-Annex 1 countries, the potential for switching to natural gas is much higher, however energy security and the availability of domestic resources are considerations, particularly for countries such as China and India with large coal reserves.

(continued)

Table TS.2: *continued*

Technological options	Barriers and opportunities	Implications of mitigation policies on sectors
		Renewables: Renewable sources are very diverse and the mitigation impact would depend on technological development. It would vary from region to region depending on resource endowment. However, mitigation is very likely to lead to larger markets for the renewables industry. In that situation, R&D for cost reduction and enhanced performance and increased flow of funds to renewables could increase their application leading to cost reduction. Nuclear: There is substantial technical potential for nuclear power development to reduce greenhouse gas emissions; whether this is realized will depend on relative costs, political factors, and public acceptance.
Halocarbons: Emissions of HFCs are growing as HFCs are being used to replace some of the ozone-depleting substances being phased out. Compared to SRES projections for HFCs in 2010, it is estimated that emissions could be lower by as much as $100MtC_{eq}$ at costs below $US\$200/tC_{eq}$. About half of the estimated reduction is an artifact caused by the SRES baseline values being higher than the study baseline for this report. The remainder could be accomplished by reducing emissions through containment, recovering and recycling refrigerants, and through use of alternative fluids and technologies.	Barriers: uncertainty with respect to the future of HFC policy in relation to global warming and ozone depletion. Opportunities: capturing new technological developments	
Geo-engineering: Regarding mitigation opportunities in marine ecosystems and geo-engineering[b], human understanding of biophysical systems, as well as many ethical, legal, and equity assessments are still rudimentary.	Barriers: In geo-engineering, the risks for unanticipated consequences are large and it may not even be possible to engineer the regional distribution of temperature and precipitation. Opportunities: Some basic inquiry appears appropriate.	Sector not yet in existence: not applicable.

[a] 'Protection' refers to active measures that maintain and preserve existing C reserves, including those in vegetation, soil organic matter, and products exported from the ecosystem (e.g., preventing the conversion of tropical forests for agricultural purposes and avoiding drainage of wetlands). 'Sequestration' refers to measures, deliberately undertaken, that increase C stocks above those already present (e.g., afforestation, revised forest management, enhanced C storage in wood products, and altered cropping systems, including more forage crops, reduced tillage). “Substitution” refers to practices that substitute renewable biological products for fossil fuels or energy-intensive products, thereby avoiding the emission of CO_2 from combustion of fossil fuels.

[b] Geo-engineering involves efforts to stabilize the climate system by directly managing the energy balance of the earth, thereby overcoming the enhanced greenhouse effect.

3.3.2 The Main Mitigation Options in the Transport Sector

In 1995, the transport sector contributed 22% of global energy-related carbon dioxide emissions; globally, emissions from this sector are growing at a rapid rate of approximately 2.5% annually. Since 1990, principal growth has been in the developing countries (7.3% per year in the Asia–Pacific region) and is actually declining at a rate of 5.0% per year for the EITs. Hybrid gasoline-electric vehicles have been introduced on a commercial basis with fuel economies 50%-100% better than those of comparably sized four-passenger vehicles. Biofuels produced from wood, energy crops, and waste may also play an increasingly important role in the transportation sector as enzymatic hydrolysis of cellulosic material to ethanol becomes more cost effective. Meanwhile, biodiesel, supported by tax exemptions, is gaining market share in Europe. Incremental improvements in engine design have, however, largely been used to enhance performance rather than to improve fuel economy, which has not increased since the SAR. Fuel cell powered vehicles are developing rapidly, and are scheduled to be introduced to the market in 2003. Significant improvements in the fuel economy of aircraft appear to be both technically and economically possible for the next generation fleet. Nevertheless, most evaluations of the technological efficiency improvements (*Table TS.3*) show that because of growth in demand for transportation, efficiency improvement alone is not enough to avoid GHG emission growth. Also, there is evidence that, other things being equal, efforts to improve fuel efficiency have only partial effects in emission reduction because of resulting increases in driving distances caused by lower specific operational costs.

3.3.3 The Main Mitigation Options in the Industry Sector

Industrial emissions account for 43% of carbon released in 1995. Industrial sector carbon emissions grew at a rate of 1.5% per year between 1971 and 1995, slowing to 0.4% per year since 1990. Industries continue to find more energy efficient processes and reductions of process-related GHGs. This is the only sector that has shown an annual decrease in carbon emissions in OECD economies (-0.8%/yr between 1990 and 1995). The CO_2 from EITs declined most strongly (-6.4% per year between 1990 and 1995 when total industrial production dropped).

Differences in the energy efficiency of industrial processes between different developed countries, and between developed and developing countries remain large, which means that there are substantial differences in relative emission reduction potentials between countries.

Improvement of the energy efficiency of industrial processes is the most significant option for lowering GHG emissions. This potential is made up of hundreds of sector-specific technologies. The worldwide potential for energy efficiency improvement – compared to a baseline development – for the year 2010 is estimated to be 300-500MtC and for the year 2020 700-900MtC. In the latter case continued technological development is necessary to realize the potential. The majority of energy efficiency improvement options can be realized at net negative costs.

Another important option is material efficiency improvement (including recycling, more efficient product design, and material substitution); this may represent a potential of 600MtC in the year 2020. Additional opportunities for CO_2 emissions reduction exist through fuel switching, CO_2 removal and storage, and the application of blended cements.

A number of specific processes not only emit CO_2, but also non-CO_2 GHGs. The adipic acid manufacturers have strongly reduced their N_2O emissions, and the aluminium industry has made major gains in reducing the release of PFCs (CF_4, C_2F_6). Further reduction of non-CO_2 GHGs from manufacturing industry to low levels is often possible at relatively low costs per tonne of C-equivalent (tC_{eq}) mitigated.

Sufficient technological options are known today to reduce GHG emissions from industry in absolute terms in most developed countries by 2010, and to limit growth of emissions in this sector in developing countries significantly.

Table TS.3: *Projected energy intensities for transportation from 5-Laboratory Study in the USA*[a]

Determinants	**1997**	**2010**		
		BAU	**Energy efficiency**	**HE/LC**
New passenger car l/100km	8.6	8.5	6.3	5.5
New light truck l/100km	11.5	11.4	8.7	7.6
Light-duty fleet l/100km[b]	12.0	12.1	10.9	10.1
Aircraft efficiency (seat-l/100km)	4.5	4.0	3.8	3.6
Freight truck fleet l/100km	42.0	39.2	34.6	33.6
Rail efficiency (tonne-km/MJ)	4.2	4.6	5.5	6.2

[a] BAU, Business as usual; HE/LC, high- energy/low-carbon.

[b] Includes existing passenger cars and light trucks.

3.3.4 The Main Mitigation Options in the Agricultural Sector

Agriculture contributes only about 4% of global carbon emissions from energy use, but over 20% of anthropogenic GHG emissions (in terms of MtC_{eq}/yr) mainly from CH_4 and N_2O as well as carbon from land clearing. There have been modest gains in energy efficiency for the agricultural sector since the SAR, and biotechnology developments related to plant and animal production could result in additional gains, provided concerns about adverse environmental effects can be adequately addressed. A shift from meat towards plant production for human food purposes, where feasible, could increase energy efficiency and decrease GHG emissions (especially N_2O and CH_4 from the agricultural sector). Significant abatement of GHG emissions can be achieved by 2010 through changes in agricultural practices, such as:

- soil carbon uptake enhanced by conservation tillage and reduction of land use intensity;
- CH_4 reduction by rice paddy irrigation management, improved fertilizer use, and lower enteric CH_4 emissions from ruminant animals;
- avoiding anthropogenic agricultural N_2O emissions (which for agriculture exceeds carbon emission from fossil fuel use) through the use of slow release fertilizers, organic manure, nitrification inhibitors, and potentially genetically-engineered leguminous plants. N_2O emissions are greatest in China and the USA, mainly from fertilizer use on rice paddy soils and other agricultural soils. More significant contributions can be made by 2020 when more options to control N_2O emissions from fertilized soils are expected to become available.

Uncertainties on the intensity of use of these technologies by farmers are high, since they may have additional costs involved in their uptake. Economic and other barriers may have to be removed through targetted policies.

3.3.5 The Main Mitigation Options in the Waste Management Sector

There has been increased utilization of CH_4 from landfills and from coal beds. The use of landfill gas for heat and electric power is also growing because of policy mandates in countries like Germany, Switzerland, the EU, and USA. Recovery costs are negative for half of landfill CH_4. Requiring product life management in Germany has been extended from packaging to vehicles and electronics goods. If everyone in the USA increased per capita recycling rates from the national average to the per capita recycling rate achieved in Seattle, Washington, the result would be a reduction of 4% of total US GHG emissions. Debate is taking place over whether the greater reduction in lifecycle GHG emissions occurs through paper and fibre recycling or by utilizing waste paper as a biofuel in waste-to-energy facilities. Both options are better than landfilling in terms of GHG emissions. In several developed countries, and especially in Europe and Japan, waste-to-energy facilities have become more efficient with lower air pollution emissions.

3.3.6 The Main Mitigation Options in the Energy Supply Sector

Fossil fuels continue to dominate heat and electric power production. Electricity generation accounts for 2,100MtC/yr or 37.5% of global carbon emissions[10]. Baseline scenarios without carbon emission policies anticipate emissions of 3,500 and 4,000MtC_{eq} for 2010 and 2020, respectively. In the power sector, low-cost combined cycle gas turbines (CCGTs) with conversion efficiencies approaching 60% for the latest model have become the dominant option for new electric power plants wherever adequate natural gas supply and infrastructure are available. Advanced coal technologies based on integrated gasification combined cycle or supercritical (IGCCS) designs potentially have the capability of reducing emissions at modest cost through higher efficiencies. Deregulation of the electric power sector is currently a major driver of technological choice. Utilization of distributed industrial and commercial combined heat and power (CHP) systems to meet space heating and manufacturing needs could achieve substantial emission reductions. The further implications of the restructuring of the electric utility industry in many developed and developing countries for CO_2 emissions are uncertain at this time, although there is a growing interest in distributed power supply systems based on renewable energy sources and also using fuel cells, micro-turbines and Stirling engines.

The nuclear power industry has managed to increase significantly the capacity factor at existing facilities, which improved their economics sufficiently that extension of facility life has become cost effective. But other than in Asia, relatively few new plants are being proposed or built. Efforts to develop intrinsically safe and less expensive nuclear reactors are proceeding with the goal of lowering socio-economic barriers and reducing public concern about safety, nuclear waste storage, and proliferation. Except for a few large projects in India and China, construction of new hydropower projects has also slowed because of few available major sites, sometimes-high costs, and local environmental and social concerns. Another development is the rapid growth of wind turbines, whose annual growth rate has exceeded 25% per year, and by 2000 exceeded 13GW of installed capacity. Other renewables, including solar and biomass, continue to grow as costs decline, but total contributions from non-hydro renewable sources remain below 2% globally. Fuel cells have the potential to provide highly efficient combined sources of electricity and heat as power densities increase and costs continue to drop. By 2010, co-firing of coal with biomass, gasification of fuel wood, more effi-

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[10] Note that the section percentages do not add up to 100% as these emissions have been allocated to the four sectors in the paragraphs above.

cient photovoltaics, off-shore wind farms, and ethanol-based biofuels are some of the technologies that are capable of penetrating the market. Their market share is expected to increase by 2020 as the learning curve reduces costs and capital stock of existing generation plants is replaced.

Physical removal and storage of CO_2 is potentially a more viable option than at the time of the SAR. The use of coal or biomass as a source of hydrogen with storage of the waste CO_2 represents a possible step to the hydrogen economy. CO_2 has been stored in an aquifer, and the integrity of storage is being monitored. However, long-term storage is still in the process of being demonstrated for that particular reservoir. Research is also needed to determine any adverse and/or beneficial environmental impacts and public health risks of uncontrolled release of the various storage options. Pilot CO_2 capture and storage facilities are expected to be operational by 2010, and may be capable of making major contributions to mitigation by 2020. Along with biological sequestration, physical removal and storage might complement current efforts at improving efficiency, fuel switching, and the development of renewables, but must be able to compete economically with them.

The report considers the potential for mitigation technologies in this sector to reduce CO_2 emissions to 2020 from new power plants. CCGTs are expected to be the largest provider of new capacity between now and 2020 worldwide, and will be a strong competitor to displace new coal-fired power stations where additional gas supplies can be made available. Nuclear power has the potential to reduce emissions if it becomes politically acceptable, as it can replace both coal and gas for electricity production. Biomass, based mainly on wastes and agricultural and forestry by-products, and wind power are also potentially capable of making major contributions by 2020. Hydropower is an established technology and further opportunities exist beyond those anticipated to contribute to reducing CO_2 equivalent emissions. Finally, while costs of solar power are expected to decline substantially, it is likely to remain an expensive option by 2020 for central power generation, but it is likely to make increased contributions in niche markets and off-grid generation. The best mitigation option is likely to be dependent on local circumstances, and a combination of these technologies has the potential to reduce CO_2 emissions by 350-700MtC by 2020 compared to projected emissions of around 4,00MtC from this sector.

3.3.7 The Main Mitigation Options for Hydrofluorocarbons and Perfluorocarbons

HFC and, to a lesser extent, PFC use has grown as these chemicals replaced about 8% of the projected use of CFCs by weight in 1997; in the developed countries the production of CFCs and other ozone depleting substances (ODSs) was halted in 1996 to comply with the Montreal Protocol to protect the stratospheric ozone layer. HCFCs have replaced an additional 12% of CFCs. The remaining 80% have been eliminated through controlling emissions, specific use reductions, or alternative technologies and fluids including ammonia, hydrocarbons, carbon dioxide and water, and not-in-kind technologies. The alternative chosen to replace CFCs and other ODSs varies widely among the applications, which include refrigeration, mobile and stationary air-conditioning, heat pumps, medical and other aerosol delivery systems, fire suppression, and solvents. Simultaneously considering energy efficiency with ozone layer protection is important, especially in the context of developing countries, where markets have just begun to develop and are expected to grow at a fast rate.

Based on current trends and assuming no new uses outside the ODS substitution area, HFC production is projected to be 370 kt or $170MtC_{eq}$/yr by 2010, while PFC production is expected to be less than $12MtC_{eq}$/yr. For the year 2010, annual emissions are more difficult to estimate. The largest emissions are likely to be associated with mobile air conditioning followed by commercial refrigeration and stationary air conditioning. HFC use in foam blowing is currently low, but if HFCs replaces a substantial part of the HCFCs used here, their use is projected to reach $30MtC_{eq}$/yr by 2010, with emissions in the order of 5-$10MtC_{eq}$/yr.

3.4 The Technological and Economic Potential of Greenhouse Gas Mitigation: Synthesis

Global emissions of GHGs grew on average by 1.4% per year during the period 1990 to 1998. In many areas, technical progress relevant to GHG emission reduction since the SAR has been significant and faster than anticipated. The total potential for worldwide GHG emissions reductions resulting from technological developments and their adoption amount to 1,900 to 2,600MtC/yr by 2010, and 3,600 to 5,050MtC/yr by 2020. The evidence on which this conclusion is based is extensive, but has several limitations. No comprehensive worldwide study of technological potential has yet been done, and the existing regional and national studies generally have varying scopes and make different assumptions about key parameters. Therefore, the estimates as presented in *Table TS.1* should be considered to be indicative only. Nevertheless, the main conclusion in the paragraph above can be drawn with high confidence.

Costs of options vary by technology and show regional differences. Half of the potential emissions reductions may be achieved by 2020 with direct benefits (energy saved) exceeding direct costs (net capital, operating, and maintenance costs), and the other half at a net direct cost of up to US$100/$tC_{eq}$ (at 1998 prices). These cost estimates are derived using discount rates in the range of 5% to 12%, consistent with public sector discount rates. Private internal rates of return vary greatly, and are often significantly higher, which affects the rate of adoption of these technologies by private entities. Depending on the emissions scenario this could allow global emissions to be reduced below 2000 levels in 2010-2020 at these net direct costs. Realizing these reductions will involve additional implementation costs, which in some cases may be substantial, and will possibly need supporting policies (such as those described in Section 6), increased research and development, effective technology transfer, and other barriers to be overcome (Section 5 for details).

Hundreds of technologies and practices exist to reduce GHG emissions from the buildings, transport, and industry sectors. These energy efficiency options are responsible for more than half of the total emission reduction potential of these sectors. Efficiency improvements in material use (including recycling) will also become more important in the longer term. The energy supply and conversion sector will remain dominated by cheap and abundant fossil fuels. However, there is significant emission reduction potential thanks to a shift from coal to natural gas, conversion efficiency improvement of power plants, the expansion of distributed co-generation plants in industry, commercial buildings and institutions, and CO_2 recovery and sequestration. The continued use of nuclear power plants (including their lifetime extension), and the application of renewable energy sources could avoid some additional emissions from fossil fuel use. Biomass from by-products and wastes such as landfill gas are potentially important energy sources that can be supplemented by energy crop production where suitable land and water are available. Wind energy and hydropower will also contribute, more so than solar energy because of its relatively high costs. N_2O and fluorinated GHG reductions have already been achieved through major technological advances. Process changes, improved containment and recovery, and the use of alternative compounds and technologies have been implemented. Potential for future reductions exists, including process-related emissions from insulated foam and semiconductor production and by-product emissions from aluminium and HCFC-22. The potential for energy efficiency improvements connected to the use of fluorinated gases is of a similar magnitude to reductions of direct emissions. Soil carbon sequestration, enteric CH_4 control, and conservation tillage can all contribute to mitigating GHG emissions from agriculture.

Appropriate policies are required to realize these potentials. Furthermore, on-going research and development is expected to significantly widen the portfolio of technologies that provide emission reduction options. Maintaining these R&D activities together with technology transfer actions will be necessary if the longer term potential as outlined in *Table TS.1* is to be realized. Balancing mitigation activities in the various sectors with other goals, such as those related to DES, is key to ensuring they are effective.

4 Technological and Economic Potential of Options to Enhance, Maintain and Manage Biological Carbon Reservoirs and Geo-engineering

4.1 Mitigation through Terrestrial Ecosystem and Land Management

Forests, agricultural lands, and other terrestrial ecosystems offer significant, if often temporary, mitigation potential. Conservation and sequestration allow time for other options to be further developed and implemented. The IPCC SAR estimated that about 60 to 87GtC could be conserved or sequestered in forests by the year 2050 and another 23 to 44GtC could be sequestered in agricultural soils. The current assessment of the potential of biological mitigation options is in the order of 100GtC (cumulative) by 2050, equivalent to about 10% to 20% of projected fossil fuel emissions during that period. In this section, biological mitigation measures in terrestrial ecosystems are assessed, focusing on the mitigation potential, ecological and environmental constraints, economics, and social considerations. Also, briefly, the so-called geo-engineering options are discussed.

Increased carbon pools through the management of terrestrial ecosystems can only partially offset fossil fuel emissions. Moreover, larger C stocks may pose a risk for higher CO_2 emissions in the future, if the C-conserving practices are discontinued. For example, abandoning fire control in forests, or reverting to intensive tillage in agriculture may result in a rapid loss of at least part of the C accumulated during previous years. However, using biomass as a fuel or wood to displace more energy-intensive materials can provide permanent carbon mitigation benefits. It is useful to evaluate terrestrial sequestration opportunities alongside emission reduction strategies, as both approaches will likely be required to control atmospheric CO_2 levels.

Carbon reservoirs in most ecosystems eventually approach some maximum level. The total amount of carbon stored and/or carbon emission avoided by a forest management project at any given time is dependent on the specific management practices (see *Figure TS.6*). Thus, an ecosystem depleted of carbon by past events may have a high potential rate of carbon accumulation, while one with a large carbon pool tends to have a low rate of carbon sequestration. As ecosystems eventually approach their maximum carbon pool, the sink (i.e., the rate of change of the pool) will diminish. Although both the sequestration rate and pool of carbon may be relatively high at some stages, they cannot be maximized simultaneously. Thus, management strategies for an ecosystem may depend on whether the goal is to enhance short-term accumulation or to maintain the carbon reservoirs through time. The ecologically achievable balance between the two goals is constrained by disturbance history, site productivity, and target time frame. For example, options to maximize sequestration by 2010 may not maximize sequestration by 2020 or 2050; in some cases, maximizing sequestration by 2010 may lead to lower carbon storage over time.

The effectiveness of C mitigation strategies, and the security of expanded C pools, will be affected by future global changes, but the impacts of these changes will vary by geographical region, ecosystem type, and local abilities to adapt. For example, increases in atmospheric CO_2, changes in climate, modified nutrient cycles, and altered (either natural or human induced disturbance) regimes can each have negative or positive effects on C pools in terrestrial ecosystems.

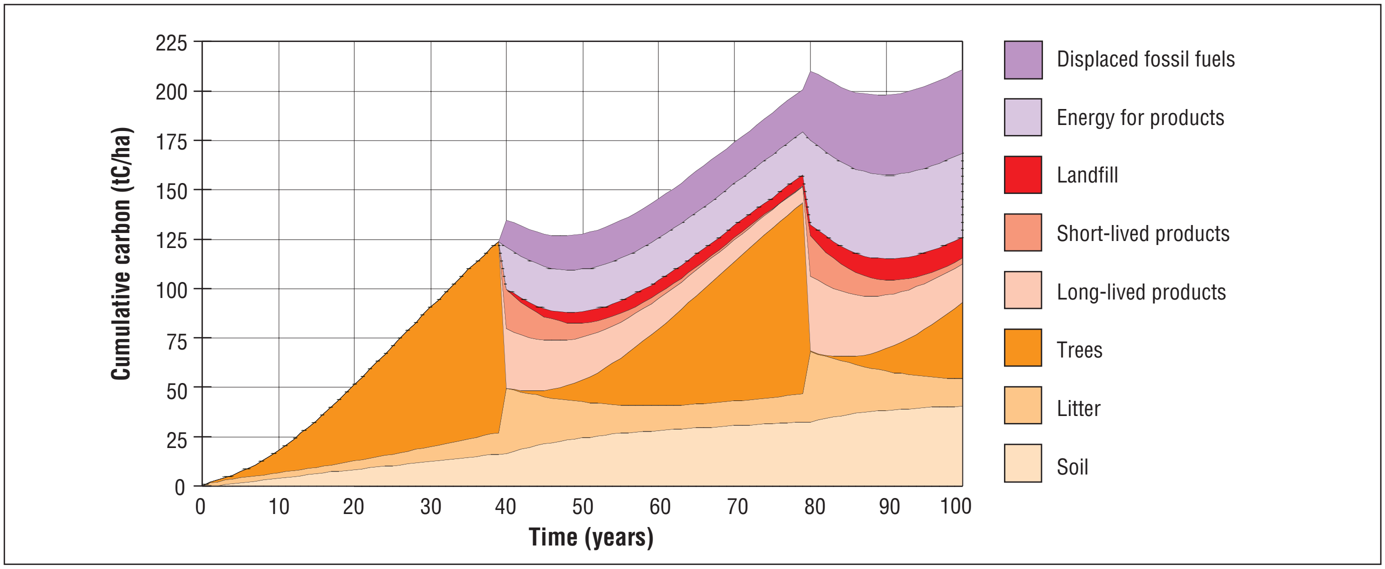

Figure TS.6: *Carbon balance from a hypothetical forest management project.*

Note: The figure shows cumulative carbon-stock changes for a scenario involving afforestation and harvest for a mix of traditional forest products with some of the harvest being used as a fuel. Values are illustrative of what might be observed in the southeastern USA or Central Europe. Regrowth restores carbon to the forest and the (hypothetical) forest stand is harvested every 40 years, with some litter left on the ground to decay, and products accumulate or are disposed of in landfills. These are net changes in that, for example, the diagram shows savings in fossil fuel emissions with respect to an alternative scenario that uses fossil fuels and alternative, more energy-intensive products to provide the same services.

In the past, land management has often resulted in reduced C pools, but in many regions like Western Europe, C pools have now stabilized and are recovering. In most countries in temperate and boreal regions forests are expanding, although current C pools are still smaller than those in pre-industrial or prehistoric times. While complete recovery of pre-historic C pools is unlikely, there is potential for substantial increases in carbon stocks. The Food and Agriculture Organization (FAO) and the UN Economic Commission for Europe (ECE)'s statistics suggest that the average net annual increment exceeded timber fellings in managed boreal and temperate forests in the early 1990s. For example, C stocks in live tree biomass have increased by 0.17GtC/yr in the USA and 0.11GtC/yr in Western Europe, absorbing about 10% of global fossil CO_2 emissions for that time period. Though these estimates do not include changes in litter and soils, they illustrate that land surfaces play a significant and changing role in the atmospheric carbon budget. Enhancing these carbon pools provides potentially powerful opportunities for climate mitigation.

In some tropical countries, however, the average net loss of forest carbon stocks continues, though rates of deforestation may have declined slightly in the past decade. In agricultural lands, options are now available to recover partially the C lost during the conversion from forest or grasslands.

4.2 Social and Economic Considerations

Land is a precious and limited resource used for many purposes in every country. The relationship of climate mitigation strategies with other land uses may be competitive, neutral, or symbiotic. An analysis of the literature suggests that C mitigation strategies can be pursued as one element of more comprehensive strategies aimed at sustainable development, where increasing C stocks is but one of many objectives. Often, measures can be adopted within forestry, agriculture, and other land uses to provide C mitigation and, at the same time, also advance other social, economic, and environmental goals. Carbon mitigation can provide additional value and income to land management and rural development. Local solutions and targets can be adapted to priorities of sustainable development at national, regional, and global levels.

A key to making C mitigation activities effective and sustainable is to balance it with other ecological and/or environmental, economic, and social goals of land use. Many biological mitigation strategies may be neutral or favourable for all three goals and become accepted as "no regrets" or "win-win" solutions. In other cases, compromises may be needed. Important potential environmental impacts include effects on biodiversity, effects on amount and quality of water resources (particularly where they are already scarce), and long-term impacts on ecosystem productivity. Cumulative environmental, economic, and social impacts could be assessed in individual projects and also from broader, national and international perspectives. An important issue is "leakage" – an expanded or conserved C pool in one area leading to increased emissions elsewhere. Social acceptance at the local, national, and global levels may also influence how effectively mitigation policies are implemented.

4.3 Mitigation Options

In tropical regions there are large opportunities for C mitigation, though they cannot be considered in isolation of broader policies in forestry, agriculture, and other sectors. Additionally, options vary by social and economic conditions: in some regions slowing or halting deforestation is the major mitigation opportunity; in other regions, where deforestation rates have declined to marginal levels, improved natural forest management practices, afforestation, and reforestation of degraded forests and wastelands are the most attractive opportunities. However, the current mitigative capacity[11] is often weak and sufficient land and water is not always available.

Non-tropical countries also have opportunities to preserve existing C pools, enhance C pools, or use biomass to offset fossil fuel use. Examples of strategies include fire or insect control, forest conservation, establishing fast-growing stands, changing silvicultural practices, planting trees in urban areas, ameliorating waste management practices, managing agricultural lands to store more C in soils, improving management of grazing lands, and re-planting grasses or trees on cultivated lands.

Wood and other biological products play several important roles in carbon mitigation: they act as a carbon reservoir; they can replace construction materials that require more fossil fuel input; and they can be burned in place of fossil fuels for renewable energy. Wood products already contribute somewhat to climate mitigation, but if infrastructures and incentives can be developed, wood and agricultural products may become a vital element of a sustainable economy: they are among the few renewable resources available on a large scale.

4.4 Criteria for Biological Carbon Mitigation Options

To develop strategies that mitigate atmospheric CO_2 and advance other, equally important objectives, the following criteria merit consideration:

- potential contributions to C pools over time;
- sustainability, security, resilience, permanence, and robustness of the C pool maintained or created;
- compatibility with other land-use objectives;
- leakage and additionality issues;
- economic costs;
- environmental impacts other than climate mitigation;
- social, cultural, and cross-cutting issues, as well as issues of equity; and
- the system-wide effects on C flows in the energy and materials sector.

Activities undertaken for other reasons may enhance mitigation. An obvious example is reduced rates of tropical deforestation. Furthermore, because wealthy countries generally have a stable forest estate, it could be argued that economic development is associated with activities that build up forest carbon reservoirs.

4.5 Economic Costs

Most studies suggest that the economic costs of some biological carbon mitigation options, particularly forestry options, are quite modest through a range. Cost estimates of biological mitigation reported to date vary significantly from US\$0.1/tC to about US\$20/tC in several tropical countries and from US\$20 to US\$100/tC in non-tropical countries. Moreover the cost calculations do not cover, in many instances, *inter alia*, costs for infrastructure, appropriate discounting, monitoring, data collection and interpretation, and opportunity costs of land and maintenance, or other recurring costs, which are often excluded or overlooked. The lower end of the ranges are biased downwards, but understanding and treatment of costs is improving over time. Furthermore, in many cases biological mitigation activities may have other positive impacts, such as protecting tropical forests or creating new forests with positive external environmental effects. However, costs rise as more biological mitigation options are exercised and as the opportunity costs of the land increases. Biological mitigation costs appear to be lowest in developing countries and higher in developed countries. If biological mitigation activities are modest, leakage is likely to be small. However, the amount of leakage could rise if biological mitigation activities became large and widespread.

4.6 Marine Ecosystem and Geo-engineering

Marine ecosystems may also offer possibilities for removing CO_2 from the atmosphere. The standing stock of C in the marine biosphere is very small, however, and efforts could focus, not on increasing biological C stocks, but on using biospheric processes to remove C from the atmosphere and transport it to the deep ocean. Some initial experiments have been performed, but fundamental questions remain about the permanence and stability of C removals, and about unintended consequences of the large-scale manipulations required to have a significant impact on the atmosphere. In addition, the economics of such approaches have not yet been determined.

Geo-engineering involves efforts to stabilize the climate system by directly managing the energy balance of the earth, thereby overcoming the enhanced greenhouse effect. Although there appear to be possibilities for engineering the terrestrial energy balance, human understanding of the system is still rudimentary. The prospects of unanticipated consequences are large, and it may not even be possible to engineer the regional distribution of temperature, precipitation, etc. Geo-engineering raises scientific and technical questions as well as many ethical, legal, and equity issues. And yet, some basic inquiry does seem appropriate.

In practice, by the year 2010 mitigation in land use, land-use change, and forestry activities can lead to significant mitigation of CO_2 emissions. Many of these activities are compatible with, or complement, other objectives in managing land. The

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[11] Mitigative capacity: the social, political, and economic structures and conditions that are required for effective mitigation.

overall effects of altering marine ecosystems to act as carbon sinks or of applying geo-engineering technology in climate change mitigation remain unresolved and are not, therefore, ready for near-term application.

5 Barriers, Opportunities, and Market Potential of Technologies and Practices

5.1 Introduction

The transfer of technologies and practices that have the potential to reduce GHG emissions is often hampered by barriers[12] that slow their penetration. The opportunity[13] to mitigate GHG concentrations by removing or modifying barriers to or otherwise accelerating the spread of technology may be viewed within a framework of different potentials for GHG mitigation (*Figure TS.7*). Starting at the bottom, one can imagine addressing barriers (often referred to as market failures) that relate to markets, public policies, and other institutions that inhibit the diffusion of technologies that are (or are projected to be) cost-effective for users without reference to any GHG benefits they may generate. Amelioration of this class of "market and institutional imperfections" would increase GHG mitigation towards the level that is labelled as the "economic potential". The economic potential represents the level of GHG mitigation that could be achieved if all technologies that are cost-effective from the consumers' point of view were implemented. Because economic potential is evaluated from the consumer's point of view, we would evaluate cost-effectiveness using market prices and the private rate of time discounting, and also take into account consumers' preferences regarding the acceptability of the technologies' performance characteristics.

Of course, elimination of all these market and institutional barriers would not produce technology diffusion at the level of the "technical potential". The remaining barriers, which define the gap between economic potential and technical potential, are usefully placed in two groups separated by a socio-economic potential. The first group consists of barriers derived from people's preferences and other social and cultural barriers to the diffusion of new technology. That is, even if market and institutional barriers are removed, some GHG-mitigating technologies may not be widely used simply because people do not like them, are too poor to afford them, or because existing social and cultural forces operate against their acceptance. If, in addition to overcoming market and institutional barriers, this second group of barriers could be overcome, what is labelled as the "socio-economic potential" would be achieved. Thus, the socio-economic potential represents the level of GHG mitigation that would be approached by overcoming social and cultural obstacles to the use of technologies that are cost-effective.

Finally, even if all market, institutional, social, and cultural barriers were removed, some technologies might not be widely used simply because they are too expensive. Elimination of this requirement would therefore take us up to the level of "technological potential", the maximum technologically feasible extent of GHG mitigation through technology diffusion.

An issue arises as to how to treat the relative environmental costs of different technologies within this framework. Because the purpose of the exercise is ultimately to identify opportunities for global climate change policies, the technology potentials are defined without regard to GHG impacts. Costs and benefits associated with other environmental impacts would be part of the cost-effectiveness calculation underlying economic potential only insofar as existing environmental regulations or policies internalize these effects and thereby impose them on consumers. Broader impacts might be ignored by consumers, and hence not enter into the determination of economic potential, but they would be incorporated into a social cost-effectiveness calculation. Thus, to the extent that other environmental benefits make certain technologies socially cost-effective, even if they are not cost-effective from a consumer's point of view, the GHG benefits of diffusion of such technologies would be incorporated in the socio-economic potential.

5.2 Sources of Barriers and Opportunities

Technological and social innovation is a complex process of research, experimentation, learning, and development that can contribute to GHG mitigation. Several theories and models have been developed to understand its features, drivers, and implications. New knowledge and human capital may result from R&D spending, through learning by doing, and/or in an evolutionary process. Most innovations require some social or behavioural change on the part of users. Rapidly changing economies, as well as social and institutional structures offer opportunities for locking in to GHG-mitigative technologies that may lead countries on to sustainable development pathways. The pathways will be influenced by the particular socio-economic context that reflects prices, financing, international trade, market structure, institutions, the provision of information, and social, cultural, and behavioural factors; key elements of these are described below.

Unstable macroeconomic conditions increase risk to private investment and finance. Unsound government borrowing and fiscal policy lead to chronic public deficits and low liquidity in the private sector. Governments may also create perverse microeconomic incentives that the encourage rent-seeking and corruption, rather than the efficient use of resources. Trade barriers that favour inefficient technologies, or prevent access to

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[12] A barrier is any obstacle to reaching a potential that can be overcome by a policy, programme, or measure.

[13] An opportunity is a situation or circumstance to decrease the gap between the market potential of a technology or practice and the economic, socio-economic, or technological potential.

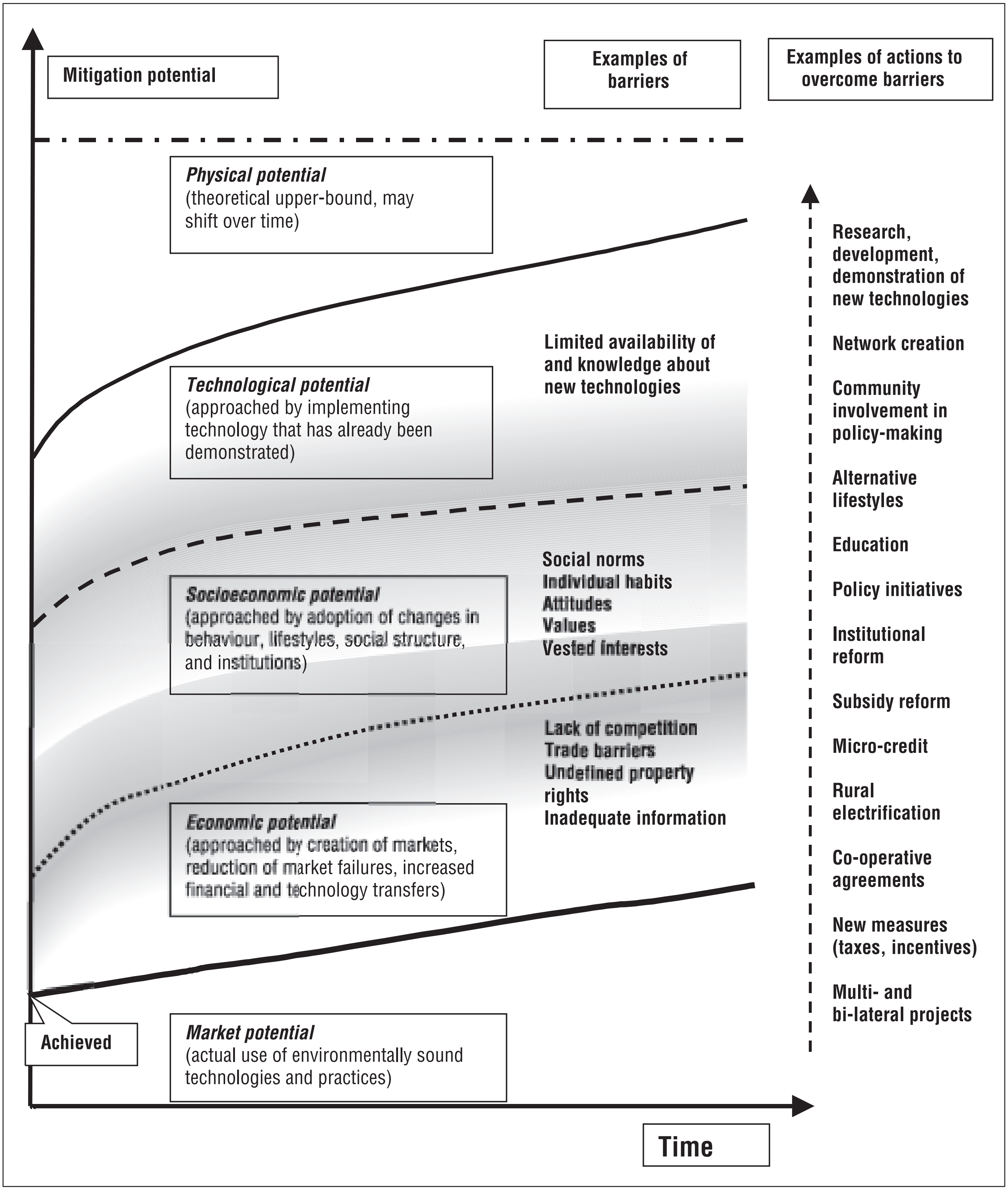

Figure TS.7: *Penetration of environmentally sound technologies: a conceptual framework.*

foreign technology, slow technology diffusion. Tied aid still dominates in official development assistance. It distorts the efficiency of technology choice, and may crowd-out viable business models.

Commercial financing institutions face high risks with developing "green" financial products. Environmentally sound technologies with relatively small project sizes and long repayment periods deter banks with their high transaction costs. Small collateral value makes it difficult to use financing instruments, such as project finance. Innovative approaches in the private sector to address these issues include leasing, environmental and ethical banks, micro-credits or small grants facilities targetted at low income households, environmental funds, energy service companies (ESCOs), and green venture capital. The insurance industry has already begun to react to risks of climate change. New green financial institutions, such as forestry investment funds, have tapped market opportunities by working towards capturing values of standing forests.

Distorted or incomplete prices are also important barriers. The absence of a market price for certain impacts(externalities), such as environmental harm, constitutes a barrier to the diffusion of environmentally beneficial technologies. Distortion of prices because of taxes, subsidies, or other policy interventions that make resource consumption more or less expensive to consumers also impedes the diffusion of resource-conserving technologies.

Network externalities can generate barriers. Some technologies operate in such a way that a given user's equipment interacts with the equipment of other users so as to create "network externalities". For example, the attractiveness of vehicles using alternative fuels depends on the availability of convenient refuelling sites. On the other hand, the development of a fuel distribution infrastructure depends on there being a demand for alternative fuel vehicles.

Misplaced incentives result between landlords and tenants when the tenant is responsible for the monthly cost of fuel and/or electricity, and the landlord is prone to provide the cheapest-first-cost equipment without regard to its monthly energy use. Similar problems are encountered when vehicles are purchased by companies for the use of their employees.

Vested interests: A major barrier to the diffusion of technical progress lies in the vested interests who specialize in conventional technologies and who may, therefore, be tempted to collude and exert political pressure on governments to impose administrative procedures, taxes, trade barriers, and regulations in order to delay or even prevent the arrival of new innovations that might destroy their rents.

Lack of effective regulatory agencies impedes the introduction of environmentally sound technologies. Many countries have excellent constitutional and legal provisions for environmental protection but the latter are not enforced. However, "informal regulation" under community pressure from, for example, non-governmental organizations (NGOs), trade unions, neighbourhood organizations, etc. may substitute for formal regulatory pressure.

Information is often considered *as a public good*. Generic information regarding the availability of different kinds of technologies and their performance characteristics may have the attributes of a "public good" and hence may be underprovided by the private market. This problem is exacerbated by the fact that even after a technology is in place and being used, it is often difficult to quantify the energy savings that resulted from its installation owing to measurement errors and the difficulty with baseline problems. Knowing that this uncertainty will prevail can itself inhibit technology diffusion.

Current lifestyles, behaviours, and consumption patterns have developed within current and historical socio-cultural contexts. Changes in behaviour and lifestyles may result from a number of intertwined processes, such as:

- scientific, technological, and economic developments;
- developments in dominant world views and public discourse;
- changes in the relationships among institutions, political alliances, or actor networks;
- changes in social structures or relationships within firms and households; and
- changes in psychological motivation (e.g., convenience, social prestige, career, etc.).

Barriers take various forms in association with each of the above processes.

In some situations policy development is based on a model of human psychology that has been widely criticized. People are assumed to be rational welfare-maximizers and to have a fixed set of values. Such a model does not explain processes, such as learning, habituation, value formation, or the bounded rationality, observed in human choice. Social structures can affect consumption, for example, through the association of objects with status and class. Individuals' adoption of more sustainable consumption patterns depends not only on the match between those patterns and their perceived needs, but also on the extent to which they understand their consumption options, and are able to make choices.

Uncertainty

Another important barrier is uncertainty. A consumer may be uncertain about future energy prices and, therefore, future energy savings. Also, there may be uncertainty about the next generation of equipment – will next year bring a cheaper or better model? In practical decision making, a barrier is often associated with the issue of sunk cost and long lifetimes of infrastructure, and the associated irreversibilities of investments of the non-fungible infrastructure capita.

5.3 Sector- and Technology-specific Barriers and Opportunities

The following sections describe barriers and opportunities particular to each mitigation sector (see also *Table TS.2*).

Buildings: The poor in every country are affected far more by barriers in this sector than the rich, because of inadequate access to financing, low literacy rates, adherence to traditional customs, and the need to devote a higher fraction of their income to satisfy basic needs, including fuel purchases. Other barriers in this sector are lack of skills and social barriers, misplaced incentives, market structure, slow stock turnover, administratively set prices, and imperfect information. Integrated building design for residential construction could lead to energy saving by 40%-60%, which in turn could reduce the cost of living (Section 3.3.4).

Policies, programmes, and measures to remove barriers and reduce energy costs, energy use, and carbon emissions in residential and commercial buildings fall into ten general categories: voluntary programmes, building efficiency standards, equipment efficiency standards, state market transformation programmes, financing, government procurement, tax credits, energy planning (production, distribution, and end-use), and accelerated R&D. Affordable credit financing is widely recognized in Africa as one of the critical measures to remove the high first-cost barrier. Poor macroeconomic management captured by unstable economic conditions often leads to financial repression and higher barriers. As many of several obstacles can be observed simultaneously in the innovation chain of an energy-efficient investment or organizational measure, policy measures usually have to be applied as a bundle to realize the economic potential of a particular technology.

Transport: The car has come to be widely perceived in modern societies as a means of freedom, mobility and safety, a symbol of personal status and identity, and as one of the most important products in the industrial economy. Several studies have found that people living in denser and more compact cities rely less on cars, but it is not easy, even taking congestion problems into account, to motivate the shift away from suburban sprawl to compact cities as advocated in some literature. An integrated approach to town and transport planning and the use of incentives are key to energy efficiency and saving in the transport sector. This is an area, where lock-in effects are very important: when land-use patterns have been chosen there is hardly a way back. This represents an opportunity in particular for the developing world.

Transport fuel taxes are commonly used, but have proved very unpopular in some countries, especially where they are seen as revenue-raising measures. Charges on road users have been accepted where they are earmarked to cover the costs of transport provision. Although trucks and cars may be subject to different barriers and opportunities because of differences in their purpose of use and travel distance, a tax policy that assesses the full cost of GHG emissions would result in a similar impact on CO_2 reductions in road transport. Several studies have explored the potential for adjusting the way existing road taxes, licence fees, and insurance premiums are levied and have found potential emissions reductions of around 10% in OECD countries. Inadequate development and provision of convenient and efficient mass transport systems encourage the use of more energy consuming private vehicles. It is the combination of policies protecting road transport interest, however, that poses the greatest barrier to change, rather than any single type of instrument.

New and used vehicles and/or their technologies mostly flow from the developed to developing countries. Hence, a global approach to reducing emissions that targets technology in developed countries would have a significant impact on future emissions from developing countries.

Industry: In industry, barriers may take many forms, and are determined by the characteristics of the firm (size and structure) and the business environment. Cost-effective energy efficiency measures are often not undertaken as a result of lack of information and high transaction costs for obtaining reliable information. Capital is used for competing investment priorities, and is subject to high hurdle rates for energy efficiency investments. Lack of skilled personnel, especially for small and medium-sized enterprises (SMEs), leads to difficulties installing new energy-efficient equipment compared to the simplicity of buying energy. Other barriers are the difficulty of quantifying energy savings and slow diffusion of innovative technology into markets, while at the same time firms typically underinvest in R&D, despite the high rates of return on investment.

A wide array of policies to reduce barriers, or the perception of barriers, has been used and tested in the industrial sector in developed countries, with varying success rates. Information programmes are designed to assist energy consumers in understanding and employing technologies and practices to use energy more efficiently. Forms of environmental legislation have been a driving force in the adoption of new technologies. New approaches to industrial energy efficiency improvement in developed countries include voluntary agreements (VAs).

In the energy supply sector virtually all the generic barriers cited in Section 5.2 restrict the introduction of environmentally sound technologies and practices. The increasing deregulation of energy supply, while making it more efficient, has raised particular concerns. Volatile spot and contract prices, short-term outlook of private investors, and the perceived risks of nuclear and hydropower plants have shifted fuel and technology choice towards natural gas and oil plants, and away from renewable energy, including – to a lesser extent – hydropower, in many countries.

Co-generation or combined production of power and heat (CHP) is much more efficient than the production of energy for each of these uses alone. The implementation of CHP is closely linked to the availability and density of industrial heat loads, district heating, and cooling networks. Yet, its implementation is hampered by lack of information, the decentralized character of the technology, the attitude of grid operators, the terms of grid connection, and a lack of policies that foster long-term planning. Firm public policy and regulatory authority is necessary to install and safeguard harmonized conditions, transparency, and unbundling of the main power supply functions.

Agriculture and Forestry: Lack of adequate capacity for research and provision of extension services will hamper the spread of technologies that suit local conditions, and the declining Consultative Group on International Agricultural Research (CGIAR) system has exacerbated this problem in the developing world. Adoption of new technology is also limited by small farm size, credit constraints, risk aversion, lack of access to information and human capital, inadequate rural infrastructure and tenurial arrangements, and unreliable supply of complementary inputs. Subsidies for critical inputs to agriculture, such as fertilizers, water supply, and electricity and fuels, and to outputs in order to maintain stable agricultural systems and an equitable distribution of wealth distort markets for these products.

Measures to address the above barriers include:

- The expansion of credit and savings schemes;
- Shifts in international research funding towards water-use efficiency, irrigation design, irrigation management, adaptation to salinity, and the effect of increased CO_2 levels on tropical crops;
- The improvement of food security and disaster early warning systems;
- The development of institutional linkages between countries; and
- The rationalization of input and output prices of agricultural commodities, taking DES issues into consideration.

The forestry sector faces land-use regulation and other macroeconomic policies that usually favour conversion to other land uses such as agriculture, cattle ranching, and urban industry. Insecure land tenure regimes and tenure rights and subsidies favouring agriculture or livestock are among the most important barriers for ensuring sustainable management of forests as well as sustainability of carbon abatement. In relation to climate change mitigation, other issues, such as lack of technical capability, lack of credibility about the setting of project baselines, and monitoring of carbon stocks, poses difficult challenges.

Waste Management: Solid waste and wastewater disposal and treatment represent about 20% of human-induced methane emissions. The principal barriers to technology transfer in this sector include limited financing and institutional capability, jurisdictional complexity, and the need for community involvement. Climate change mitigation projects face further barriers resulting from unfamiliarity with CH_4 capture and potential electricity generation, unwillingness to commit additional human capacity for climate mitigation, and the additional institutional complexity required not only by waste treatment but also byenergy generation and supply. The lack of clear regulatory and investment frameworks can pose significant challenges for project development.

To overcome the barriers and to avail the opportunities in waste management, it is necessary to have a multi-project approach, the components of which include the following :

- Building databases on availability of wastes, their characteristics, distribution, accessibility, current practices of utilization and/or disposal technologies, and economic viability;
- Institutional mechanism for technology transfer though a co-ordinated programme involving the R&D institutions, financing agencies, and industry; and
- Defining the role of stakeholders including local authorities, individual householders, industries, R&D institutions, and the government.

Regional Considerations: Changing global patterns provide an opportunity for introducing GHG mitigation technologies and practices that are consistent with DES goals. A culture of energy subsidies, institutional inertia, fragmented capital markets, vested interests, etc., however, presents major barriers to their implementation, and may be particular issues in developing and EIT countries. Situations in these two groups of countries call for a more careful analysis of trade, institutional, financial, and income barriers and opportunities, distorted prices, and information gaps. In the developed countries, other barriers such as the current carbon-intensive lifestyle and consumption patterns, social structures, network externalities, and misplaced incentives offer opportunities for intervention to control the growth of GHG emissions. Lastly, new and used technologies mostly flow from the developed to developing and transitioning countries. A global approach to reducing emissions that targets technology that is transferred from developed to developing countries could have a significant impact on future emissions.

6 Policies, Measures, and Instruments

6.1 Policy Instruments and Possible Criteria for their Assessment

The purpose of this section is to examine the major types of policies and measures that can be used to implement options to mitigate net concentrations of GHGs in the atmosphere. In keeping within the defined scope of this Report, policies and measures that can be used to implement or reduce the costs of adaptation to climate change are not examined. Alternative policy instruments are discussed and assessed in terms of specific criteria, all on the basis of the most recent literature. There is naturally some emphasis on the instruments mentioned in the Kyoto Protocol (the Kyoto mechanisms), because they are new and focus on achieving GHG emissions limits, and the extent of their envisaged international application is unprecedented. In addition to economic dimensions, political economy, legal, and institutional elements are discussed insofar as they are relevant to these policies and measures.

Any individual country can choose from a large set of possible policies, measures, and instruments, including (in arbitrary order): emissions, carbon, or energy taxes, tradable permits, subsidies, deposit-refund systems, voluntary agreements, non-tradable permits, technology and performance standards, product bans, and direct government spending, including R&D investment. Likewise, a group of countries that wants to limit its collective GHG emissions could agree to implement one, or a mix, of the following instruments (in arbitrary order): tradable quotas, joint implementation, clean development mechanism, harmonized emissions or carbon or energy taxes, an international emissions, carbon, or energy tax, non-tradable quotas, international technology and product standards, voluntary agreements, and direct international transfers of financial resources and technology.

Possible criteria for the assessment of policy instruments include: environmental effectiveness; cost effectiveness; distributional considerations including competitiveness concerns; administrative and political feasibility; government revenues; wider economic effects including implications for international trade rules; wider environmental effects including carbon leakage; and effects on changes in attitudes, awareness, learning, innovation, technical progress, and dissemination of technology. Each government may apply different weights to various criteria when evaluating GHG mitigation policy options depending on national and sector level circumstances. Moreover, a government may apply different sets of weights to the criteria when evaluating national (domestic) versus international policy instruments. Co-ordinated actions could help address competitiveness concerns, potential conflicts with international trade rules, and carbon leakage.

The economics literature on the choice of policies adopted has emphasized the importance of interest group pressures, focusing on the demand for regulation. But it has tended to neglect the “supply side” of the political equation, emphasized in the political science literature: the legislators and government and party officials who design and implement regulatory policy, and who ultimately decide which instruments or mix of instruments will be used. However, the point of compliance of alternative policy instruments, whether they are applied to fossil fuel users or manufacturers, for example, is likely to be politically crucial to the choice of policy instrument. And a key insight is that some forms of regulation actually can benefit the regulated industry, for example, by limiting entry into the industry or imposing higher costs on new entrants. A policy that imposes costs on industry as a whole might still be supported by firms who would fare better than their competitors. Regulated firms, of course, are not the only group with a stake in regulation: opposing interest groups will fight for their own interests.

6.2 National Policies, Measures, and Instruments

In the case of countries in the process of structural reform, it is important to understand the new policy context to develop reasonable assessments of the feasibility of implementing GHG mitigation policies. Recent measures taken to liberalize energy markets have been inspired for the most part by desires to increase competition in energy and power markets, but they also can have significant emission implications, through their impact on the production and technology pattern of energy or power supply. In the long run, the consumption pattern change might be more important than the sole implementation of climate change mitigation measures.

Market-based instruments – principally domestic taxes and domestic tradable permit systems – will be attractive to governments in many cases because they are efficient. They will frequently be introduced in concert with conventional regulatory measures. When implementing a domestic emissions tax, policymakers must consider the collection point, the tax base, the variation among sectors, the association with trade, employment, revenue, and the exact form of the mechanism. Each of these can influence the appropriate design of a domestic emissions tax, and political or other concerns are likely to play a role as well. For example, a tax levied on the energy content of fuels could be much more costly than a carbon tax for equivalent emissions reduction, because an energy tax raises the price of all forms of energy, regardless of their contribution to CO_2 emissions. Yet, many nations may choose to use energy taxes for reasons other than cost effectiveness, and much of the analysis in this section applies to energy taxes, as well as carbon taxes.

A country committed to a limit on its GHG emissions also can meet this limit by implementing a tradable permit system that directly or indirectly limits emissions of domestic sources. Like a tax, a tradable permit system poses a number of design issues, including type of permit, ways to allocate permits, sources included, point of compliance, and use of banking. To be able to cover all sources with a single domestic permit regime is unlikely. The certainty provided by a tradable permit system of achieving a given emissions level for participating sources comes at the cost of the uncertainty of permit prices (and hence compliance costs). To address this concern, a hybrid policy that caps compliance costs could be adopted, but the level of emissions would no longer be guaranteed.

For a variety of reasons, in most countries the management of GHG emissions will not be addressed with a single policy instrument, but with a portfolio of instruments. In addition to one or more market-based policies, a portfolio might include standards and other regulations, voluntary agreements, and information programmes:

- Energy efficiency standards have been effective in reducing energy use in a growing number of countries. They may be especially effective in many countries where the capacity to administer market instruments is relatively limited, thereby helping to develop this administrative infrastructure. They need updating to remain effective. The main disadvantage of standards is that they can be inefficient, but efficiency can be improved if the standard focuses on the desired results and leaves as much flexibility as possible in the choice of how to achieve the results.

- Voluntary agreements (VAs) may take a variety of forms. Proponents of VAs point to low transaction costs and consensus elements, while sceptics emphasize the risk of “free riding”, and the risk that the private sector will not pursue real emissions reduction in the absence of monitoring and enforcement. Voluntary agreements sometimes precede the introduction of more stringent measures.

- Imperfect information is widely recognized as a key market failure that can have significant effects on improved energy efficiency, and hence emissions. Information instruments include environmental labelling, energy audits, and industrial reporting requirements, and information campaigns are marketing elements in many energy-efficiency programmes.

A growing literature has demonstrated theoretically, and with numerical simulation models, that the economics of addressing GHG reduction targets with domestic policy instruments depend strongly on the choice of those instruments. Price-based policies tend to lead to positive marginal and positive total mitigation costs. In each case, the interaction of these abatement costs with the existing tax structure and, more generally, with existing factor prices is important. Price-based policies that generate revenues can be coupled with measures to improve market efficiency. However, the role of non-price policies, which affect the sign of the change in the unit price of energy services, often remains decisive.

6.3 International Policies and Measures

Turning to international policies and measures, the Kyoto Protocol defines three international policy instruments, the so-called Kyoto mechanisms: international emissions trading (IET), joint implementation (JI), and the Clean Development Mechanism (CDM). Each of these international policy instruments provides opportunities for Annex I Parties to fulfil their commitments cost-effectively. IET essentially would allow Annex I Parties to exchange part of their assigned national emission allowances (targets). IET implies that countries with high marginal abatement costs (MACs) may acquire emission reductions from countries with low MACs. Similarly, JI would allow Annex I Parties to exchange emission reduction units among themselves on a project-by-project basis. Under the CDM, Annex I Parties would receive credit – on a project-by-project basis – for reductions accomplished in non-Annex I countries.

Economic analyses indicate that the Kyoto mechanisms could reduce significantly the overall cost of meeting the Kyoto emissions limitation commitments. However, achievement of the potential cost savings requires the adoption of domestic policies that allow individual entities to use the mechanisms to meet their national emissions limitation obligations. If domestic policies limit the use of the Kyoto mechanisms, or international rules governing the mechanisms limit their use, the cost savings may be reduced.

In the case of JI, host governments have incentives to ensure that emission reduction units (ERUs) are issued only for real emission reductions, assuming that they face strong penalties for non-compliance with national emissions limitation commitments. In the case of CDM, a process for independent certification of emission reductions is crucial, because host governments do not have emissions limitation commitments and hence may have less incentive to ensure that certified emission reductions (CERs) are issued only for real emission reductions. The main difficulty in implementing project-based mechanisms, both JI and CDM, is determining the net additional emission reduction (or sink enhancement) achieved; baseline definition may be extremely complex. Various other aspects of these Kyoto mechanisms are awaiting further decision making, including: monitoring and verification procedures, financial additionality (assurance that CDM projects will not displace traditional development assistance flows), and possible means of standardizing methodologies for project baselines.

The extent to which developing country (non-Annex I) Parties will effectively implement their commitments under the UNFCCC may depend, among other factors, on the transfer of environmentally sound technologies (ESTs).

6.4 Implementation of National and International Policy Instruments

Any international or domestic policy instrument can be effective only if accompanied by adequate systems of monitoring and enforcement. There is a linkage between compliance enforcement and the amount of international co-operation that will actually be sustained. Many multilateral environmental agreements address the need to co-ordinate restrictions on conduct taken in compliance with obligations they impose and the expanding legal regime under the WTO and/or GATT umbrella. Neither the UNFCCC nor the Kyoto Protocol now provides for specific trade measures in response to non-compliance. But several domestic policies and measures that might be developed and implemented in conjunction with the Kyoto Protocol could conflict with WTO provisions. International differences in environmental regulation may have trade implications.

One of the main concerns in environmental agreements (including the UNFCCC and the Kyoto Protocol) has been with reaching wider participation. The literature on international environmental agreements predicts that participation will be incomplete, and incentives may be needed to increase participation (see also Section 10).

7 Costing Methodologies

7.1 Conceptual Basis

Using resources to mitigate greenhouse gases (GHGs) generates opportunity costs that should be considered to help guide reasonable policy decisions. Actions taken to abate GHG emissions or to increase carbon sinks divert resources from other alternative uses. Assessing the costs of these actions should ideally consider the total value that society attaches to the goods and services forgone because of the diversion of resources to climate protection. In some cases, the sum of benefits and costs will be negative, meaning that society gains from undertaking the mitigation action.

This section addresses the methodological issues that arise in the estimation of the monetary costs of climate change. The focus is on the correct assessment of the costs of mitigation measures to reduce the emissions of GHGs. The assessment of costs and benefits should be based on a systematic analytical framework to ensure comparability and transparency of estimates. One well-developed framework assesses costs as changes in social welfare based on individual values. These individual values are reflected by the willingness to pay (WTP) for environmental improvements or the willingness to accept (WTA) compensation. From these value measures can be derived measures such as the social surpluses gained or lost from a policy, the total resource costs, and opportunity costs.

While the underlying measures of welfare have limits and using monetary values remains controversial, the view is taken that the methods to "convert" non-market inputs into monetary terms provide useful information for policymakers. These methods should be pursued when and where appropriate. It is also considered useful to supplement this welfare-based cost methodology with a broader assessment that includes equity and sustainability dimensions of climate change mitigation policies. In practice, the challenge is to develop a consistent and comprehensive definition of the key impacts to be measured.

A frequent criticism of this costing method is that it is inequitable, as it gives greater weight to the "well off". This is because, typically, a well-off person has a greater WTP or WTA than a less well-off person and hence the choices made reflect more the preferences of the better off. This criticism is valid, but there is no coherent and consistent method of valuation that can replace the existing one in its entirety. Concerns about, for example, equity can be addressed along with the basic cost estimation. The estimated costs are one piece of information in the decision-making process for climate change that can be supplemented with other information on other social objectives, for example impacts on key stakeholders and the meeting of poverty objectives.

In this section the costing methodology is overviewed, and issues involved in using these methods addressed.

7.2 Analytical Approaches

Cost assessment is an input into one or more rules for decision-making, including cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), and multi-attribute analysis. The analytical approaches differ primarily by how the objectives of the decision-making framework are selected, specified, and valued. Some objectives in mitigation policies can be specified in economic units (e.g., costs and benefits measured in monetary units), and some in physical units (e.g., the amount of pollutants dispersed in tonnes of CO_2). In practice, however, the challenge is in developing a consistent and comprehensive definition of every important impact to be measured.

7.2.1 Co-Benefits and Costs and Ancillary Benefits and Costs

The literature uses a number of terms to depict the associated benefits and costs that arise in conjunction with GHG mitigation policies. These include co-benefits, ancillary benefits, side benefits, secondary benefits, collateral benefits, and associated benefits. In the current discussion, the term "co-benefits" refers to the non-climate benefits of GHG mitigation policies that are explicitly incorporated into the initial creation of mitigation policies. Thus, the term co-benefits reflects that most policies designed to address GHG mitigation also have other, often at least equally important, rationales involved at the inception of these policies (e.g., related to objectives of development, sustainability, and equity). In contrast, the term ancillary benefits connotes those secondary or side effects of climate change mitigation policies on problems that arise subsequent to any proposed GHG mitigation policies.

Policies aimed at mitigating GHGs, as stated earlier, can yield other social benefits and costs (here called ancillary or co- benefits and costs), and a number of empirical studies have made a preliminary attempt to assess these impacts. It is apparent that the actual magnitude of the ancillary benefits or co-benefits assessed critically depends on the scenario structure of the analysis, in particular on the assumptions about policy management in the baseline case. This implies that whether a particular impact is included or not depends on the primary objective of the programme. Moreover, something that is seen as a GHG reduction programme from an international perspective may be seen, from a national perspective, as one in which local pollutants and GHGs are equally important.

7.2.2 Implementation Costs

All climate change policies necessitate some costs of implementation, that is costs of changes to existing rules and regulations, making sure that the necessary infrastructure is available, training and educating those who are to implement the policy as well those affected by the measures, etc. Unfortunately, such costs are not fully covered in conventional cost analyses. Implementation costs in this context are meant to reflect the more permanent institutional aspects of putting a programme into place and are different to those costs conventionally considered as transaction costs. The latter, by definition, are temporary costs. Considerable work needs to be done to quantify the institutional and other costs of programmes, so that the reported figures are a better representation of the true costs that will be incurred if programmes are actually implemented.

7.2.3 Discounting

There are broadly two approaches to discounting–an ethical or prescriptive approach based on what rates of discount should be applied, and a descriptive approach based on what rates of discount people (savers as well as investors) actually apply in their day-to-day decisions. For mitigation analysis, the country must base its decisions at least partly on discount rates that reflect the opportunity cost of capital. Rates that range from 4% to 6% would probably be justified in developed countries. The rate could be 10–12% or even higher in developing countries. It is more of a challenge to argue that climate change mitigation projects should face different rates, unless the mitigation project is of very long duration. The literature shows increasing attention to rates that decline over time and hence give more weight to benefits that occur in the long term. Note that these rates do not reflect private rates of return, which typically must be greater to justify a project, at around 10–25%.

7.2.4 Adaptation and Mitigation Costs and the Link Between Them

While most people appreciate that adaptation choices affect the costs of mitigation, this obvious point is often not addressed in climate policymaking. Policy is fragmented - with mitigation being seen as addressing climate change and adaptation seen as a means of reacting to natural hazards. Usually mitigation and adaptation are modelled separately as a necessary simplification to gain traction on an immense and complex issue. As a consequence, the costs of risk reduction action are frequently estimated separately, and therefore each measure is potentially biased. This realization suggests that more attention to the interaction of mitigation and adaptation, and its empirical ramification, is worthwhile, though uncertainty about the nature and timing of impacts, including surprises, will constrain the extent to which the associated costs can be fully internalized.

7.3 System Boundaries: Project, Sector, and Macro

Researchers make a distinction between project, sector, and economywide analyses. Project level analysis considers a “stand-alone” investment assumed to have insignificant secondary impacts on markets. Methods used for this level include CBA, CEA, and life-cycle analysis. Sector level analysis examines sectoral policies in a “partial-equilibrium” context in which all other variables are assumed to be exogenous. Economy-wide analysis explores how policies affect all sectors and markets, using various macroeconomic and general equilibrium models. A trade-off exists between the level of detail in the assessment and complexity of the system considered. This section presents some of the key assumptions made in cost analysis.

A combination of different modelling approaches is required for an effective assessment of climate change mitigation options. For example, detailed project assessment has been combined with a more general analysis of sectoral impacts, and macroeconomic carbon tax studies have been combined with the sectoral modelling of larger technology investment programmes.

7.3.1 Baselines

The baseline case, which by definition gives the emissions of GHGs in the absence of the climate change interventions being considered, is critical to the assessment of the costs of climate change mitigation. This is because the definition of the baseline scenario determines the potential for future GHG emissions reduction, as well as the costs of implementing these reduction policies. The baseline scenario also has a number of important implicit assumptions about future economic policies at the macroeconomic and sectoral levels, including sectoral structure, resource intensity, prices, and thereby technology choice.

7.3.2 Consideration of No Regrets Options

No regrets options are by definition actions to reduce GHG emissions that have negative net costs. Net costs are negative because these options generate direct or indirect benefits, such as those resulting from reductions in market failures, double dividends through revenue recycling and ancillary benefits, large enough to offset the costs of implementing the options. The no regrets issue reflects specific assumptions about the working and the efficiency of the economy, especially the existence and stability of a social welfare function, based on a social cost concept:

- Reduction of existing market or institutional failures and other barriers that impede adoption of cost-effective emission reduction measures can lower private costs compared to current practice. This can also reduce private costs overall.
- A double dividend related to recycling of the revenue of carbon taxes in such a way that it offsets distortionary taxes.

- Ancillary benefits and costs (or ancillary impacts), which can be synergies or trade-offs in cases in which the reduction of GHG emissions has joint impacts on other environmental policies (i.e., relating to local air pollution, urban congestion, or land and natural resource degradation).

Market Imperfections
The existence of a no regrets potential implies that market and institutions do not behave perfectly, because of market imperfections such as lack of information, distorted price signals, lack of competition, and/or institutional failures related to inadequate regulation, inadequate delineation of property rights, distortion-inducing fiscal systems, and limited financial markets. Reduction of market imperfections suggests it is possible to identify and implement policies that can correct these market and institutional failures without incurring costs larger than the benefits gained.

Double Dividend
The potential for a double dividend arising from climate mitigation policies was extensively studied during the 1990s. In addition to the primary aim of improving the environment (the first dividend), such policies, if conducted through revenue-raising instruments such as carbon taxes or auctioned emission permits, yield a second dividend, which can be set against the gross costs of these policies. All domestic GHG policies have an indirect economic cost from the interactions of the policy instruments with the fiscal system, but in the case of revenue-raising policies this cost is partly offset (or more than offset) if, for example, the revenue is used to reduce existing distortionary taxes. Whether these revenue-raising policies can reduce distortions in practice depends on whether revenues can be "recycled" to tax reduction.

Ancillary Benefits and Costs (Ancillary Impacts)
The definition of ancillary impacts is given above. As noted there, these can be positive as well as negative. It is important to recognize that gross and net mitigation costs cannot be established as a simple summation of positive and negative impacts, because the latter are interlinked in a very complex way. Climate change mitigation costs (gross and well as net costs) are only valid in relation to a comprehensive specific scenario and policy assumption structure.

The existence of no regrets potentials is a necessary, but not a sufficient, condition for the potential implementation of these options. The actual implementation also requires the development of a policy strategy that is complex as comprehensive enough to address these market and institutional failures and barriers.

7.3.3 Flexibility

For a wide variety of options, the costs of mitigation depend on what regulatory framework is adopted by national governments to reduce GHGs. In general, the more flexibility the framework allows, the lower the costs of achieving a given reduction. More flexibility and more trading partners can reduce costs. The opposite is expected with inflexible rules and few trading partners. Flexibility can be measured as the ability to reduce carbon emissions at the lowest cost, either domestically or internationally.

7.3.4 Development, Equity, and Sustainability Issues

Climate change mitigation policies implemented at a national level will, in most cases, have implications for short-term economic and social development, local environmental quality, and intra-generational equity. Mitigation cost assessments that follow this line can address these impacts on the basis of a decision-making framework that includes a number of side-impacts to the GHG emissions reduction policy objective. The goal of such an assessment is to inform decision makers about how different policy objectives can be met efficiently, given priorities of equity and other policy constraints (natural resources, environmental objectives). A number of international studies have applied such a broad decision-making framework to the assessment of development implications of CDM projects.

There are a number of key linkages between mitigation costing issues and broader development impacts of the policies, including macroeconomic impacts, employment creation, inflation, the marginal costs of public funds, capital availability, spillovers, and trade.

7.4 Special Issues Relating to Developing Countries and EITs

A number of special issues related to technology use should be considered as the critical determinants of climate change mitigation potential and related costs for developing countries. These include current technological development levels, technology transfer issues, capacity for innovation and diffusion, barriers to efficient technology use, institutional structure, human capacity aspects, and foreign exchange earnings.

Climate change studies in developing countries and EITs need to be strengthened in terms of methodology, data, and policy frameworks. Although a complete standardization of the methods is not possible, to achieve a meaningful comparison of results it is essential to use consistent methodologies, perspectives, and policy scenarios in different nations.

The following modifications to conventional approaches are suggested:

- Alternative development pathways should be analyzed with different patterns of investment in infrastructure, irrigation, fuel mix, and land-use policies.
- Macroeconomic studies should consider market transformation processes in the capital, labour, and power markets.

- Informal and traditional sector transactions should be included in national macroeconomic statistics. The value of non-commercial energy consumption and the unpaid work of household labour for non-commercial energy collection is quite significant and needs to be considered explicitly in economic analysis.
- The costs of removing market barriers should be considered explicitly.

7.5 Modelling Approaches to Cost Assessment

The modelling of climate mitigation strategies is complex and a number of modelling techniques have been applied including input-output models, macroeconomic models, computable general equilibrium (CGE) models, and energy sector based models. Hybrid models have also been developed to provide more detail on the structure of the economy and the energy sector. The appropriate use of these models depends on the subject of the evaluation and the availability of data.

As discussed in Section 6, the main categories of climate change mitigation policies include: market-oriented policies, technology-oriented policies, voluntary policies, and research and development policies. Climate change mitigation policies can include all four of the above policy elements. Most analytical approaches, however, only consider some of the four elements. Economic models, for example, mainly assess market-oriented policies and in some cases technology policies primarily those related to energy supply options, while engineering approaches mainly focus on supply and demand side technology policies. Both of these approaches are relatively weak in the representation of research and development and voluntary agreement policies.

8 Global, Regional, and National Costs and Ancillary Benefits

8.1 Introduction

The UNFCCC (Article 2) has as its ultimate goal the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous anthropogenic interference with the climate system"[14]. In addition, the Convention (Article 3.3) states that "policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible costs"[15]. This section reports on literature on the costs of greenhouse gas mitigation policies at the national, regional, and global levels. Net welfare gains or losses are reported, including (when available) the ancillary benefits of mitigation policies. These studies employ the full range of analytical tools described in the previous chapter. These range from technologically detailed bottom-up models to more aggregate top-down models, which link the energy sector to the rest of the economy.

8.2. Gross Costs of GHG Abatement in Technology-Detailed Models

In technology-detailed "bottom-up" models and approaches, the cost of mitigation is derived from the aggregation of technological and fuel costs such as: investments, operation and maintenance costs, and fuel procurement, but also (and this is a recent trend) revenues and costs from import and exports.

Models can be ranked along two classification axes. First, they range from simple engineering-economics calculations effected technology-by-technology, to integrated partial equilibrium models of whole energy systems. Second, they range from the strict calculation of direct technical costs of reduction to the consideration of observed technology-adoption behaviour of markets, and of the welfare losses due to demand reductions and revenue gains and losses due to changes in trade.

This leads to contrasting two generic approaches, namely the engineering-economics approach and least-cost equilibrium modelling. In the first approach, each technology is assessed independently via an accounting of its costs and savings. Once these elements have been estimated, a unit cost can be calculated for each action, and each action can be ranked according to its costs. This approach is very useful to point out the potentials for negative cost abatements due to the 'efficiency gap' between the best available technologies and technologies currently in use. However, its most important limitation is that studies neglect or do not treat in a systematic way the interdependence of the various actions under examination.

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[14] "The ultimate objective of this Convention and any related legal instruments that the Conference of Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at such a level that would prevent dangerous interference with the climate system. Such a level should be achieved within a timeframe 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."

[15] "The Parties should take precautionary measures to anticipate, prevent, or minimise the causes of climate change and mitigate its adverse effects. Where there are threats of serious irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that polices and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible costs. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out co-operatively by interested Parties."

Partial equilibrium least-costs models have been constructed to remedy this defect, by considering all actions simultaneously and selecting the optimal bundle of actions in all sectors and at all time periods. These more integrated studies conclude higher total costs of GHG mitigation than the strict technology by technology studies. Based on an optimization framework they give very easily interpretable results that compare an optimal response to an optimal baseline; however, their limitation is that they rarely calibrate the base year of the model to the existing non optimal situation and implicitly assume an optimal baseline. They consequently provide no information about the negative cost potentials.

Since the publication of the SAR, the bottom-up approaches have produced a wealth of new results for both Annex I and non-Annex I countries, as well as for groups of countries. Furthermore, they have extended their scope much beyond the classical computations of direct abatement costs by inclusion of demand effects and some trade effects.

However, the modelling results show considerable variations from study to study, which are explained by a number of factors, some of which reflect the widely differing conditions that prevail in the countries studied (e.g., energy endowment, economic growth, energy intensity, industrial and trade structure), and others reflect modelling assumptions and assumptions about negative cost potentials.

However, as in the SAR, there is agreement on a no regrets potential resulting from the reduction of existing market imperfections, consideration of ancillary benefits, and inclusion of double dividends. This means that some mitigation actions can be realized at negative costs. The no regrets potential results from existing market or institutional imperfections that prevent cost-effective emission reduction measures from being taken. The key question is whether such imperfections can be removed cost-effectively by policy measures.

The second important policy message is that short and medium term marginal abatement costs, which govern most of the macroeconomic impacts of climate policies, are very sensitive to uncertainty regarding baseline scenarios (rate of growth and energy intensity) and technical costs. Even with significant negative cost options, marginal costs may rise quickly beyond a certain anticipated mitigation level. This risk is far lower in models allowing for carbon trading. Over the long term this risk is reduced as technical change curbs down the slope of marginal cost curves.

8.3 Costs of Domestic Policy to Mitigate Carbon Emissions

Particularly important for determining the gross mitigation costs is the magnitude of emissions reductions required in order to meet a given target, thus the emissions baseline is a critical factor. The growth rate of CO_2 depends on the growth rate in GDP, the rate of decline of energy use per unit of output, and the rate of decline of CO_2 emissions per unit of energy use.

In a multi-model comparison project that engaged more than a dozen modelling teams internationally, the gross costs of complying with the Kyoto Protocol were examined, using energy sector models. Carbon taxes are implemented to lower emissions and the tax revenue is recycled lump sum. The magnitude of the carbon tax provides a rough indication of the amount of market intervention that would be needed and equates the marginal abatement cost to meet a prescribed emissions target. The size of the tax required to meet a specific target will be determined by the marginal source of supply (including conservation) with and without the target. This in turn will depend on such factors as the size of the necessary emissions reductions, assumptions about the cost and availability of carbon-based and carbon-free technologies, the fossil fuel resource base, and short- and long-term price elasticities.

With no international emission trading, the carbon taxes necessary to meet the Kyoto restrictions in 2010 vary a lot among the models. Note from *Table TS.4*[16] that for the USA they are calculated to be in the range US$76 to US$322, for OECD Europe between US$20 and US$665, for Japan between US$97 and US$645, and finally for the rest of OECD (CANZ) between US$46 and US$425. All numbers are reported in 1990 dollars. Marginal abatement costs are in the range of US$20-US$135/tC if international trading is allowed. These models do not generally include no regrets measures or take account of the mitigation potential of CO_2 sinks and of greenhouse gases other than CO_2.

However, there is no strict correlation between the level of the carbon tax and GDP variation and welfare because of the influence of the country specifics (countries with a low share of fossil energy in their final consumption suffer less than others for the same level of carbon tax) and because of the content of the policies.

The above studies assume, to allow an easy comparison across countries, that the revenues from carbon taxes (or auctioned emissions permits) are recycled in a lump-sum fashion to the economy. The net social cost resulting from a given marginal cost of emissions constraint can be reduced if the revenues are targetted to finance cuts in the marginal rates of pre-existing distortionary taxes, such as income, payroll, and sales taxes. While recycling revenues in a lump-sum fashion confers no efficiency benefit, recycling through marginal rate cuts helps avoid some of the efficiency costs or dead-weight loss of existing taxes. This raises the possibility that revenue-neutral carbon taxes might offer a double dividend by (1) improving the environment and (2) reducing the costs of the tax system.

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[16] The highest figures cited in this sentence are all results from one model: the ABARE-GTEM model.

Table TS.4: *Energy Modelling Forum main results. Marginal abatement costs (in 1990 US$/tC; 2010 Kyoto target)*

Model	**No trading**				**Annex I trading**	**Global trading**
	US	**OECD-E**	**Japan**	**CANZ**		
ABARE-GTEM	322	665	645	425	106	23
AIM	153	198	234	147	65	38
CETA	168				46	26
Fund					14	10
G-Cubed	76	227	97	157	53	20
GRAPE		204	304		70	44
MERGE3	264	218	500	250	135	86
MIT-EPPA	193	276	501	247	76	
MS-MRT	236	179	402	213	77	27
Oxford	410	966	1074		224	123
RICE	132	159	251	145	62	18
SGM	188	407	357	201	84	22
WorldScan	85	20	122	46	20	5
Administration	154				43	18
EIA	251				110	57
POLES	135.8	135.3	194.6	131.4	52.9	18.4

Note: The results of the Oxford model are not included in the ranges cited in the TS and SPM because this model has not been subject to substantive academic review (and hence is inappropriate for IPCC assessment), and relies on data from the early 1980s for a key parametization that determines the model results. This model is entirely unrelated to the CLIMOX model, from the Oxford Institutes of Energy Studies, referred to in *Table TS.6*.

EMF-16. GDP losses (as a percentage of total GDP) associated with complying with the prescribed targets under the Kyoto Protocol. Four regions include the USA, OECD Europe (OECD-E), Japan, and Canada, Australia and New Zealand (CANZ). Scenarios include no trading, Annex B trading only, and full global trading.

One can distinguish a weak and a strong form of the double dividend. The weak form asserts that the costs of a given revenue-neutral environmental reform, when revenues are devoted to cuts in marginal rates of prior distortionary taxes, are reduced relative to the costs when revenues are returned in lump-sum fashion to households or firms. The strong form of the double-dividend assertion is that the costs of the revenue-neutral environmental tax reform are zero or negative. While the weak form of the double-dividend claim receives virtually universal support, the strong form of the double dividend assertion is controversial.

Where to recycle revenues from carbon taxes or auctioned permits depends upon the country specifics. Simulation results show that in economies that are especially inefficient or distorted along non-environmental lines, the revenue-recycling effect can indeed be strong enough to outweigh the primary cost and tax-interaction effect so that the strong double dividend may materialize. Thus, in several studies involving European economies, where tax systems may be highly distorted in terms of the relative taxation of labour, the strong double dividend can be obtained, in any case more frequently than in other recycling options. In contrast, most studies of carbon taxes or permits policies in the USA demonstrate that recycling through lower labour taxation is less efficient than through capital taxation; but they generally do not find a strong double dividend. Another conclusion is that even in cases of no strong double-dividend effect, one fares considerably better with a revenue-recycling policy in which revenues are used to cut marginal rates of prior taxes, than with a non-revenue recycling policy, like for example grandfathered quotas.

In all countries where CO_2 taxes have been introduced, some sectors have been exempted by the tax, or the tax is differentiated across sectors. Most studies conclude that tax exemptions raise economic costs relative to a policy involving uniform taxes. However, results differ in the magnitude of the costs of exemptions.

8.4 Distributional Effects of Carbon Taxes

As well as the total costs, the distribution of the costs is important for the overall evaluation of climate policies. A policy that leads to an efficiency gain may not be welfare improving overall if some people are in a worse position than before, and vice versa. Notably, if there is a wish to reduce the income differences in the society, the effect on the income distribution should be taken into account in the assessment.

The distributional effects of a carbon tax appear to be regressive unless the tax revenues are used either directly or indi-

Table TS.5: *Energy Modeling Forum main results. GDP loss in 2010 (in % of GDP; 2010 Kyoto target)*

	No trading				**Annex I trading**				**Global trading**			
Model	**US**	**OECD-E**	**Japan**	**CANZ**	**US**	**OECD-E**	**Japan**	**CANZ**	**US**	**OECD-E**	**Japan**	**CANZ**
ABARE-GTEM	1.96	0.94	0.72	1.96	0.47	0.13	0.05	0.23	0.09	0.03	0.01	0.04
AIM	0.45	0.31	0.25	0.59	0.31	0.17	0.13	0.36	0.20	0.08	0.01	0.35
CETA	1.93				0.67				0.43			
G-CUBED	0.42	1.50	0.57	1.83	0.24	0.61	0.45	0.72	0.06	0.26	0.14	0.32
GRAPE		0.81	0.19			0.81	0.10			0.54	0.05	
MERGE3	1.06	0.99	0.80	2.02	0.51	0.47	0.19	1.14	0.20	0.20	0.01	0.67
MS-MRT	1.88	0.63	1.20	1.83	0.91	0.13	0.22	0.88	0.29	0.03	0.02	0.32
Oxford	1.78	2.08	1.88		1.03	0.73	0.52		0.66	0.47	0.33	
RICE	0.94	0.55	0.78	0.96	0.56	0.28	0.30	0.54	0.19	0.09	0.09	0.19

Note: The results of the Oxford model are not included in the ranges cited in the TS and SPM because this model has not been subject to substantive academic review (and hence is inappropriate for IPCC assessment), and relies on data from the early 1980s for a key parametization that determines the model results. This model is entirely unrelated to the CLIMOX model, from the Oxford Institutes of Energy Studies, referred to in *Table TS.6*.

rectly in favour of the low-income groups. Recycling the tax revenue by reducing the labour tax may have more attractive distributional consequences than a lump-sum recycling, in which the recycled revenue is directed to both wage earners and capital owners. Reduced taxation of labour results in increased wages and favours those who earn their income mainly from labour. However, the poorest groups in the society may not even earn any income from labour. In this regard, reducing labour taxes may not always be superior to recycling schemes that distribute to all groups of a society and might reduce the regressive character of carbon taxes.

8.5 Aspects of International Emission Trading

It has long been recognized that international trade in emission quota can reduce mitigation costs. This will occur when countries with high domestic marginal abatement costs purchase emission quota from countries with low marginal abatement costs. This is often referred to as "where flexibility". That is, allowing reductions to take place where it is cheapest to do so regardless of geographical location. It is important to note that where the reductions take place is independent of who pays for the reductions.

"Where flexibility" can occur on a number of scales. It can be global, regional or at the country level. In the theoretical case of full global trading, all countries agree to emission caps and participate in the international market as buyers or sellers of emission allowances. The CDM may allow some of these cost reductions to be captured. When the market is defined at the regional level (e.g., Annex B countries), the trading market is more limited. Finally, trade may take place domestically with all emission reductions occurring in the country of origin.

Table TS.5 shows the cost reductions from emission trading for Annex B and full global trading compared to a no-trading case. The calculation is made by various models with both global and regional detail. In each instance, the goal is to meet the emission reduction targets contained in the Kyoto Protocol. All of the models show significant gains as the size of the trading market is expanded. The difference among models is due in part to differences in their baseline, the assumptions about the cost and availability of low-cost substitutes on both the supply and demand sides of the energy sector, and the treatment of short-term macro shocks. In general, all calculated gross costs for the non-trading case are below 2% of GDP (which is assumed to have increased significantly in the period considered) and in most cases below 1%. Annex B trading lowers the costs for the OECD region as a whole to less than 0.5% and regional impacts within this vary between 0.1% to 1.1%. Global trading in general would decrease these costs to well below 0.5% of GDP with OECD average below 0.2%.

The issue of the so-called "hot air"[17] also influences the cost of implementing the Kyoto Protocol. The recent decline in economic activity in Eastern Europe and the former Soviet Union has led to a decrease in their GHG emissions. Although this trend is eventually expected to reverse, for some countries emissions are still projected to lie below the constraint imposed by the Kyoto Protocol. If this does occur, these countries will have excess emission quota that may be sold to countries in search of low-cost options for meeting their own targets. The cost savings from trading are sensitive to the magnitude of "hot air".

Numerous assessments of reduction in projected GDP have been associated with complying with Kyoto-type limits. Most

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[17] Hot air: a few countries, notably those with economies in transition, have assigned amount units that appear to be well in excess of their anticipated emissions (as a result of economic downturn). This excess is referred to as hot air.

economic analyses have focused on gross costs of carbon emitting activities[18], ignoring the cost-saving potential of mitigating non-CO_2 gases and using carbon sequestration and neither taking into account environmental benefits (ancillary benefits and avoided climate change), nor using revenues to remove distortions. Including such possibilities could lower costs.

A constraint would lead to a reallocation of resources away from the pattern that is preferred in the absence of a limit and into potentially costly conservation and fuel substitution. Relative prices will also change. These forced adjustments lead to reductions in economic performance, which impact GDP. Clearly, the broader the permit trading market, the greater the opportunity for reducing overall mitigation costs. Conversely, limits on the extent to which a country can satisfy its obligations through the purchase of emissions quota can increase mitigation costs. Several studies have calculated the magnitude of the increase to be substantial falling in particular on countries with the highest marginal abatement costs. But another parameter likely to limit the savings from carbon trading is the very functioning of trading systems (transaction costs, management costs, insurance against uncertainty, and strategic behaviour in the use of permits).

8.6 Ancillary Benefits of Greenhouse Gas Mitigation

Policies aimed at mitigating greenhouse gases can have positive and negative side effects on society, not taking into account benefits of avoided climate change. This section assesses in particular those studies that evaluate the side effects of climate change mitigation. Therefore the term “ancillary benefits or costs” is used. There is little agreement on the definition, reach, and size of these ancillary benefits, and on methodologies for integrating them into climate policy. Criteria are established for reviewing the growing literature linking specific carbon mitigation policies to monetized ancillary benefits. Recent studies that take an economy-wide, rather than a sectoral, approach to ancillary benefits are described in the report and their credibility is examined (Chapter 9 presents sectoral analyses). In spite of recent progress in methods development, it remains very challenging to develop quantitative estimates of the ancillary effects, benefits and costs of GHG mitigation policies. Despite these difficulties, in the short term, ancillary benefits of GHG policies under some circumstances can be a significant fraction of private (direct) mitigation costs and in some cases they can be comparable to the mitigation costs. According to the literature, ancillary benefits may be of particular importance in developing countries, but this literature is as yet limited.

The exact magnitude, scale, and scope of these ancillary benefits and costs will vary with local geographical and baseline conditions. In some circumstances, where baseline conditions involve relatively low carbon emissions and population density, benefits may be low. The models most in use for ancillary benefit estimation – the computable general equilibrium (CGE) models – have difficulty in estimating ancillary benefits because they rarely have, and may not be able to have, the necessary spatial detail.

With respect to baseline considerations most of the literature on ancillary benefits systematically treats only government policies and regulations with respect to the environment. In contrast, other regulatory policy baseline issues, such as those relating to energy, transportation, and health, have been generally ignored, as have baseline issues that are not regulatory, such as those tied with technology, demography, and the natural resource base. For the studies reviewed here, the biggest share of the ancillary benefits is related to public health. A major component of uncertainty for modelling ancillary benefits for public health is the link between emissions and atmospheric concentrations, particularly in light of the importance of secondary pollutants. However, it is recognized that there are significant ancillary benefits in addition to those for public health that have not been quantified or monetized. At the same time, it appears that there are major gaps in the methods and models for estimating ancillary costs.

8.7 “Spillover” Effects[19] from Actions Taken in Annex B on Non-Annex B Countries

In a world where economies are linked by international trade and capital flows, abatement of one economy will have welfare impacts on other abating or non-abating economies. These impacts are called spillover effects, and include effects on trade, carbon leakage, transfer and diffusion of environmentally sound technology, and other issues (*Figure TS.8*).

As to the trade effects, the dominant finding of the effects of emission constraints in Annex B countries on non-Annex B countries in simulation studies prior to the Kyoto Protocol was that Annex B abatement would have a predominantly adverse impact on non-Annex B regions. In simulations of the Kyoto Protocol, the results are more mixed with some non-Annex B regions experiencing welfare gains and other losses. This is mainly due to a milder target in the Kyoto simulations than in pre-Kyoto simulations. It was also universally found that most non-Annex B economies that suffered welfare losses under uniform independent abatement would suffer smaller welfare losses under emissions trading.

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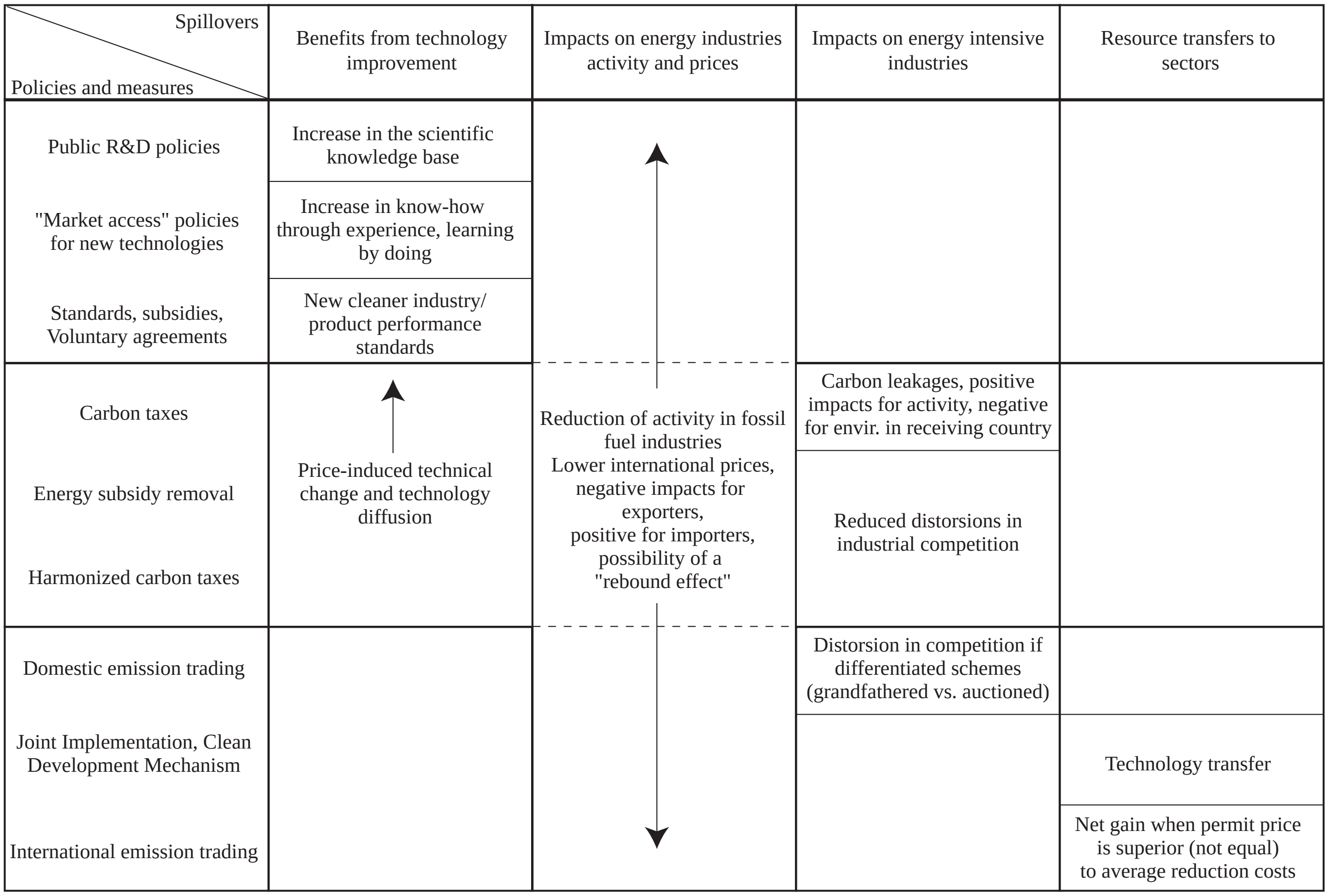
[18] Although some studies include multi-gas analysis, much research is needed on this potential both intertemporally and regionally.

[19] “Spillovers” from domestic mitigation strategies are the effects that these strategies have on other countries. Spillover effects can be positive or negative and include effects on trade, carbon leakage, transfer and diffusion of environmentally sound technology, and other issues.



Spillovers / Policies and measures	Benefits from technology improvement	Impacts on energy industries activity and prices	Impacts on energy intensive industries	Resource transfers to sectors
Public R&D policies	Increase in the scientific knowledge base			
"Market access" policies for new technologies	Increase in know-how through experience, learning by doing			
Standards, subsidies, Voluntary agreements	New cleaner industry/ product performance standards			
Carbon taxes	Price-induced technical change and technology diffusion	Reduction of activity in fossil fuel industries Lower international prices, negative impacts for exporters, positive for importers, possibility of a "rebound effect"	Carbon leakages, positive impacts for activity, negative for envir. in receiving country	
Energy subsidy removal			Reduced distorsions in industrial competition	
Harmonized carbon taxes				
Domestic emission trading			Distorsion in competition if differentiated schemes (grandfathered vs. auctioned)	
Joint Implementation, Clean Development Mechanism				Technology transfer
International emission trading				Net gain when permit price is superior (not equal) to average reduction costs

Figure TS.8: *"Spillovers" from domestic mitigation strategies are the effects that these strategies have on other countries. Spillover effects can be positive or negative and include effects on trade, carbon leakage, transfer and diffusion of environmentally sound technology, and other issues.*

A reduction in Annex B emissions will tend to result in an increase in non-Annex B emissions reducing the environmental effectiveness of Annex B abatement. This is called "carbon leakage", and can occur in the order of 5%-20% through a possible relocation of carbon-intensive industries because of reduced Annex B competitiveness in the international marketplace, lower producer prices of fossil fuels in the international market, and changes in income due to better terms of trade.

While the SAR reported that there was a high variance in estimates of carbon leakage from the available models, there has been some reduction in the variance of estimates obtained in the subsequent years. However, this may largely result from the development of new models based on reasonably similar assumptions and data sources. Such developments do not necessarily reflect more widespread agreement about appropriate behavioural assumptions. One robust result seems to be that carbon leakage is an increasing function of the stringency of the abatement strategy. This means that leakage may be a less serious problem under the Kyoto target than under the more stringent targets considered previously. Also emission leakage is lower under emissions trading than under independent abatement. Exemptions for energy-intensive industries found in practice, and other factors, make the higher model estimates for carbon leakage unlikely, but would raise aggregate costs.

Carbon leakage may also be influenced by the assumed degree of competitiveness in the world oil market. While most studies assume a competitive oil market, studies considering imperfect competition find lower leakage if OPEC is able to exercise a degree of market power over the supply of oil and therefore reduce the fall in the international oil price. Whether or not OPEC acts as a cartel can have a reasonably significant effect on the loss of wealth to OPEC and other oil producers and on the level of permit prices in Annex B regions (see also Section 9.2).

The third spillover effect mentioned above, the transfer and diffusion of environmentally sound technology, is related to induced technical change (see Section 8.10). The transfer of environmentally sound technologies and know-how, not included in models, may lead to lower leakage and especially on the longer term may more than offset the leakage.

8.8 Summary of the Main Results for Kyoto Targets

The cost estimates for Annex B countries to implement the Kyoto Protocol vary between studies and regions, and depend strongly upon the assumptions regarding the use of the Kyoto mechanisms, and their interactions with domestic measures. The great majority of global studies reporting and comparing these costs use international energy-economic models. Nine of these studies suggest the following GDP impacts[20]:

Annex II countries[21]: In the absence of emissions trading between Annex B countries[22], the majority of global studies show reductions in projected GDP of about 0.2% to 2% in 2010 for different Annex II regions. With full emissions trading between Annex B countries, the estimated reductions in 2010 are between 0.1% and 1.1% of projected GDP[23]. These studies encompass a wide range of assumptions. Models whose results are reported here assume full use of emissions trading without transaction cost. Results for cases that do not allow Annex B trading assume full domestic trading within each region. Models do not include sinks or non-CO_2 greenhouse gases. They do not include the CDM, negative cost options, ancillary benefits, or targeted revenue recycling.

For all regions costs are also influenced by the following factors:

- Constraints on the use of Annex B trading, high transaction costs in implementing the mechanisms and inefficient domestic implementation could raise costs.
- Inclusion in domestic policy and measures of the no regrets possibilities[2], use of the CDM, sinks, and inclusion of non-CO_2 greenhouse gases, could lower costs. Costs for individual countries can vary more widely.

The models show that the Kyoto mechanisms, are important in controlling risks of high costs in given countries, and thus can complement domestic policy mechanisms. Similarly, they can minimize risks of inequitable international impacts and help to level marginal costs. The global modelling studies reported above show national marginal costs to meet the Kyoto targets from about US$20/tC up to US$600/tC without trading, and a range from about US$15/tC up to US$150/tC with Annex B trading. The cost reductions from these mechanisms may depend on the details of implementation, including the compatibility of domestic and international mechanisms, constraints, and transaction costs.

Economies in transition: For most of these countries, GDP effects range from negligible to a several percent increase. This reflects opportunities for energy efficiency improvements not available to Annex II countries. Under assumptions of drastic energy efficiency improvement and/or continuing economic recessions in some countries, the assigned amounts may exceed projected emissions in the first commitment period. In this case, models show increased GDP through revenues from trading assigned amounts. However, for some economies in transition, implementing the Kyoto Protocol will have similar impacts on GDP as for Annex II countries.

Non-Annex I countries: Emission constraints in Annex I countries have well established, albeit varied "spillover" effects[24] on non-Annex I countries.

- Oil-exporting, non-Annex I countries: Analyses report costs differently, including, *inter alia*, reductions in projected GDP and reductions in projected oil revenues[25]. The study reporting the lowest costs shows reductions of 0.2% of projected GDP with no emissions trading, and less than 0.05% of projected GDP with Annex B emissions trading in 2010[26]. The study reporting the highest costs shows reductions of 25% of projected oil revenues with no emissions trading, and 13% of projected oil revenues with Annex B emissions trading in 2010. These studies do not consider policies and measures[27] other than Annex B emissions trading, that

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[20] Many other studies incorporating more precisely the country specifics and diversity of targetted policies provide a wider range of net cost estimates**.**

[21] Annex II countries: Group of countries included in Annex II to the UNFCCC, including all developed countries in the Organisation of Economic Co-operation and Development.

[22] Annex B countries: Group of countries included in Annex B in the Kyoto Protocol that have agreed to a target for their greenhouse gas emissions, including all the Annex I countries (as amended in 1998) but Turkey and Belarus.

[23] Many metrics can be used to present costs. For example, if the annual costs to developed countries associated with meeting Kyoto targets with full Annex B trading are in the order of 0.5% of GDP, this represents US$125 billion (1000 million) per year, or US$125 per person per year by 2010 in Annex II (SRES assumptions). This corresponds to an impact on economic growth *rates* over ten years of less than 0.1 percentage point.

[24] Spillover effects here incorporate only economic effects, not environmental effects.

[25] Details of the six studies reviewed are found in *Table 9.4* of the underlying report.

[26] These estimated costs can be expressed as differences in GDP growth rates over the period 2000-2010. With no emissions trading, GDP growth rate is reduced by 0.02 percentage points/year; with Annex B emissions trading, growth rate is reduced by less than 0.005 percentage points/year.

[27] These policies and measures include: those for non-CO_2 gases and non-energy sources of all gases; offsets from sinks; industry restructuring (e.g., from energy producer to supplier of energy services); use of OPEC's market power; and actions (e.g. of Annex B Parties) related to funding, insurance, and the transfer of technology. In addition, the studies typically do not include the following policies and effects that can reduce the total cost of mitigation: the use of tax revenues to reduce tax burdens or finance other mitigation measures; environmental ancillary benefits of reductions in fossil fuel use; and induced technological change from mitigation policies.

could lessen the impact on non-Annex I, oil-exporting countries, and therefore tend to overstate both the costs to these countries and overall costs.

The effects on these countries can be further reduced by removal of subsidies for fossil fuels, energy tax restructuring according to carbon content, increased use of natural gas, and diversification of the economies of non-Annex I, oil-exporting countries.

- Other non-Annex I countries: They may be adversely affected by reductions in demand for their exports to OECD nations and by the price increase of those carbon-intensive and other products they continue to import. These countries may benefit from the reduction in fuel prices, increased exports of carbon-intensive products and the transfer of environmentally sound technologies and know-how. The net balance for a given country depends on which of these factors dominates. Because of these complexities, the breakdown of winners and losers remains uncertain.
- Carbon leakage:[28] The possible relocation of some carbon-intensive industries to non-Annex I countries and wider impacts on trade flows in response to changing prices may lead to leakage in the order of 5-20%. Exemptions, for example for energy-intensive industries, make the higher model estimates for carbon leakage unlikely, but would raise aggregate costs. The transfer of environmentally sound technologies and know-how, not included in models, may lead to lower leakage and especially on the longer term may more than offset the leakage.

8.9 The Costs of Meeting a Range of Stabilization Targets

Cost-effectiveness studies with a century timescale estimate that the costs of stabilizing CO_2 concentrations in the atmosphere increase as the concentration stabilization level declines. Different baselines can have a strong influence on absolute costs. While there is a moderate increase in the costs when passing from a 750ppmv to a 550ppmv concentration stabilization level, there is a larger increase in costs passing from 550ppmv to 450ppmv unless the emissions in the baseline scenario are very low. These results, however, do not incorporate carbon sequestration and gases other than CO_2, and did not examine the possible effect of more ambitious targets on induced technological change[29]. In particular, the choice of the reference scenario has a strong influence. Recent studies using the IPCC SRES reference scenarios as baselines against which to analyze stabilization clearly show that the average reduction in projected GDP in most of the stabilization scenarios reviewed here is under 3% of the baseline value (the maximum reduction across all the stabilization scenarios reached 6.1% in a given year). At the same time, some scenarios (especially in the A1T group) showed an increase in GDP compared to the baseline because of apparent positive economic feedbacks of technology development and transfer. The GDP reduction (averaged across storylines and stabilization levels) is lowest in 2020 (1%), reaches a maximum in 2050 (1.5%), and declines by 2100 (1.3%). However, in the scenario groups with the highest baseline emissions (A2 and A1FI), the size of the GDP reduction increases throughout the modelling period. Due to their relatively small scale when compared to absolute GDP levels, GDP reductions in the post-SRES stabilization scenarios do not lead to significant declines in GDP growth rates over this century. For example, the annual 1990-2100 GDP growth rate across all the stabilization scenarios was reduced on average by only 0.003% per year, with a maximum reduction reaching 0.06% per year.

The concentration of CO_2 in the atmosphere is determined more by cumulative rather than by year-by-year emissions. That is, a particular concentration target can be reached through a variety of emissions pathways. A number of studies suggest that the choice of emissions pathway can be as important as the target itself in determining overall mitigation costs. The studies fall into two categories: those that assume that the target is known and those that characterize the issue as one of decision making under uncertainty.

For studies that assume that the target is known, the issue is one of identifying the least-cost mitigation pathway for achieving the prescribed target. Here the choice of pathway can be seen as a carbon budget problem. This problem has been so far addressed in terms of CO_2 only and very limited treatment has been given to non-CO_2 GHGs. A concentration target defines an allowable amount of carbon to be emitted into the atmosphere between now and the date at which the target is to be achieved. The issue is how best to allocate the carbon budget over time.

Most studies that have attempted to identify the least-cost pathway for meeting a particular target conclude that such as pathway tends to depart gradually from the model's baseline in the early years with more rapid reductions later on. There are several reasons why this is so. A gradual near-term transition from the world's present energy system minimizes premature retirement of existing capital stock, provides time for technology

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[28] Carbon leakage is defined here as the increase in emissions in non-Annex B countries resulting from implementation of reductions in Annex B, expressed as a percentage of Annex B reductions.

[29] Induced technological change is an emerging field of inquiry. None of the literature reviewed in TAR on the relationship between the century-scale CO_2 concentrations and costs reported results for models employing induced technological change. Models with induced technological change under some circumstances show that century-scale concentrations can differ, with similar GDP growth but under different policy regimes (Section 8.4.1.4).

development, and avoids premature lock-in to early versions of rapidly developing low-emission technology. On the other hand, more aggressive near-term action would decrease environmental risks associated with rapid climatic changes, stimulate more rapid deployment of existing low-emission technologies (see also Section 8.10), provide strong near-term incentives to future technological changes that may help to avoid lock-in to carbon intensive technologies, and allow for later tightening of targets should that be deemed desirable in light of evolving scientific understanding.

It should also be noted that the lower the concentration target, the smaller the carbon budget, and hence the earlier the departure from the baseline. However, even with higher concentration targets, the more gradual transition from the baseline does not negate the need for early action. All stabilization 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 into the marketplace. An immediate and sustained commitment to R&D is required if low-carbon low-cost substitutes are to be available when needed.

The above addresses the issue of mitigation costs. It is also important to examine the environmental impacts of choosing one emission pathway over another. This is because different emission pathways imply not only different emission reduction costs, but also different benefits in terms of avoided environmental impacts (see Section 10).

The assumption that the target is known with certainty is, of course, an oversimplification. Fortunately, the UNFCCC recognizes the dynamic nature of the decision problem. It calls for periodic reviews "in light of the best scientific information on climate change and its impacts." Such a sequential decision making process aims to identify short-term hedging strategies in the face of long-term uncertainties. The relevant question is not "what is the best course of action for the next hundred years" but rather "what is the best course for the near-term given the long-term uncertainties."

Several studies have attempted to identify the optimal near-term hedging strategy based on the uncertainty regarding the long-term objective. These studies find that the desirable amount of hedging depends upon one's assessment of the stakes, the odds, and the cost of mitigation. The risk premium – the amount that society is willing to pay to avoid risk – ultimately is a political decision that differs among countries.

8.10 The Issue of Induced Technological Change

Most models used to assess the costs of meeting a particular mitigation objective tend to oversimplify the process of technical change. Typically, the rate of technical change is assumed to be independent of the level of emissions control. Such change is referred to as autonomous. In recent years, the issue of induced technical change has received increased attention. Some argue that such change might substantially lower and perhaps even eliminate the costs of CO_2 abatement policies. Others are much less sanguine about the impact of induced technical change.

Recent research suggests that the effect on timing depends on the source of technological change. When the channel for technological change is R&D, the induced technological change makes it preferable to concentrate more abatement efforts in the future. The reason is that technological change lowers the costs of future abatement relative to current abatement, making it more cost-effective to place more emphasis on future abatement. But, when the channel for technological change is learning-by-doing, the presence of induced technological change has an ambiguous impact on the optimal timing of abatement. On the one hand, induced technical change makes future abatement less costly, which suggests emphasizing future abatement efforts. On the other hand, there is an added value to current abatement because such abatement contributes to experience or learning and helps reduce the costs of future abatement. Which of these two effects dominates depends on the particular nature of the technologies and cost functions.

Certain social practices may resist or enhance technological change. Therefore, public awareness-raising and education may help encourage social change to an environment favourable for technological innovation and diffusion. This represents an area for further research.

9 Sectoral Costs and Ancillary Benefits of Mitigation

9.1 Differences between Costs of Climate Change Mitigation Evaluated Nationally and by Sector

Policies adopted to mitigate global warming will have implications for specific sectors, such as the coal industry, the oil and gas industry, electricity, manufacturing, transportation, and households. A sectoral assessment helps to put the costs in perspective, to identify the potential losers and the extent and location of the losses, and to identify the sectors that may benefit. However, it is worth noting that the available literature to make this assessment is limited: there are few comprehensive studies of the sectoral effects of mitigation, compared with those on the macro GDP effects, and they tend to be for Annex I countries and regions.

There is a fundamental problem for mitigation policies. It is well established that, compared to the situation for potential gainers, the potential sectoral losers are easier to identify, and their losses are likely to be more immediate, more concentrated, and more certain. The potential sectoral gainers (apart from the renewables sector and perhaps the natural gas sector) can only expect a small, diffused, and rather uncertain gain, spread over a long period. Indeed many of those who may gain do not exist, being future generations and industries yet to develop.

It is also well established that the overall effects on GDP of mitigation policies and measures, whether positive or negative, conceal large differences between sectors. In general, the energy intensity and the carbon intensity of the economies will decline. The coal and perhaps the oil industries are expected to lose substantial proportions of their traditional output relative to those in the reference scenarios, though the impact of this on the industries will depend on diversification, and other sectors may increase their outputs but by much smaller proportions. Reductions in fossil fuel output below the baseline will not impact all fossil fuels equally. Fuels have different costs and price sensitivities; they respond differently to mitigation policies. Energy-efficiency technology is fuel and combustion device-specific, and reductions in demand can affect imports differently from output. Energy-intensive sectors, such as heavy chemicals, iron and steel, and mineral products, will face higher costs, accelerated technical or organizational change, or loss of output (again relative to the reference scenario) depending on their energy use and the policies adopted for mitigation.

Industries concerned directly with mitigation are likely to benefit from action. These industries include renewable and nuclear electricity, producers of mitigation equipment (incorporating energy- and carbon-saving technologies), agriculture and forestry producing energy crops, and research services producing energy and carbon-saving R&D. They may benefit in the long term from the availability of financial and other resources that would otherwise have been taken up in fossil fuel production. They may also benefit from reductions in tax burdens if taxes are used for mitigation and the revenues recycled as reductions in employer, corporate, or other taxes. Those studies that report reductions in GDP do not always provide a range of recycling options, suggesting that policy packages increasing GDP have not been explored. The extent and nature of the benefits will vary with the policies followed. Some mitigation policies can lead to net overall economic benefits, implying that the gains from many sectors will outweigh the losses for coal and other fossil fuels, and energy-intensive industries. In contrast, other less-well-designed policies can lead to overall losses.

It is worth placing the task faced by mitigation policy in an historical perspective. CO_2 emissions have tended to grow more slowly than GDP in a number of countries over the past 40 years. The reasons for such trends vary but include:

- a shift away from coal and oil and towards nuclear and gas as the source of energy;
- improvements in energy efficiency by industry and households; and
- a shift from heavy manufacturing towards more service and information-based economic activity.

These trends will be encouraged and strengthened by mitigation policies.

9.2 Selected Specific Sectoral Findings on Costs of Climate Change Mitigation

9.2.1 Coal

Within this broad picture, certain sectors will be substantially affected by mitigation. Relative to the reference case, the coal industry, producing the most carbon-intensive of products, faces almost inevitable decline in the long term, relative to the baseline projection. Technologies still under development, such as CO_2 removal and storage from coal-burning plants and in-situ gasification, could play a future role in maintaining the output of coal whilst avoiding CO_2 and other emissions. Particularly large effects on the coal sector are expected from policies such as the removal of fossil fuel subsidies or the restructuring of energy taxes so as to tax the carbon content rather than the energy content of fuels. It is a well-established finding that removal of the subsidies would result in substantial reductions in GHG emissions, as well as stimulating economic growth. However, the effects in specific countries depend heavily on the type of subsidy removed and the commercial viability of alternative energy sources, including imported coal.

9.2.2 Oil

The oil industry also faces a potential relative decline, although this may be moderated by lack of substitutes for oil in transportation, substitution away from solid fuels towards liquid fuels in electricity generation, and the diversification of the industry into energy supply in general.

Table TS.6 shows a number of model results for the impacts of implementation of the Kyoto Protocol on oil exporting countries. Each model uses a different measure of impact, and many use different groups of countries in their definition of oil exporters. However, the studies all show that the use of the flexibility mechanisms will reduce the economic cost to oil producers.

Thus, studies show a wide range of estimates for the impact of GHG mitigation policies on oil production and revenue. Much of these differences are attributable to the assumptions made about: the availability of conventional oil reserves, the degree of mitigation required, the use of emission trading, control of GHGs other than CO_2, and the use of carbon sinks. However, all studies show a net growth in both oil production and revenue to at least 2020, and significantly less impact on the real price of oil than has resulted from market fluctuations over the past 30 years. *Figure TS.9* shows the projection of real oil prices to 2010 from the IEA's 1998 *World Energy Outlook*, and the effect of Kyoto implementation from the G-cubed model, the study which shows the largest fall in Organization of Oil Exporting Countries (OPEC) revenues in *Table TS.6*. The 25% loss in OPEC revenues in the non-trading scenario implies a 17% fall in oil prices shown for 2010 in the figure; this is reduced to a fall of just over 7% with Annex I trading.

Table TS.6: *Costs of Kyoto Protocol implementation for oil exporting region/countries [a]*

Model [b]	**Without trading [c]**	**With Annex-I trading**	**With "global trading"**
G-Cubed	-25% oil revenue	-13% oil revenue	-7% oil revenue
GREEN	-3% real income	"Substantially reduced loss"	N/a
GTEM	0.2% GDP loss	<0.05% GDP loss	N/a
MS-MRT	1.39% welfare loss	1.15% welfare loss	0.36% welfare loss
OPEC Model	-17% OPEC revenue	-10% OPEC revenue	-8% OPEC revenue
CLIMOX	N/A	-10% some oil exporters' revenues	N/A

[a] The definition of oil exporting country varies: for G-Cubed and the OPEC model it is the OPEC countries, for GREEN it is a group of oil exporting countries, for GTEM it is Mexico and Indonesia, for MS-MRT it is OPEC + Mexico, and for CLIMOX it is West Asian and North African oil exporters.

[b] The models all considere the global economy to 2010 with mitigation according to the Kyoto Protocol targets (usually in the models, applied to CO_2 mitigation by 2010 rather than GHG emissions for 2008 to 2012) achieved by imposing a carbon tax or auctioned emission permits with revenues recycled through lump-sum payments to consumers; no co-benefits, such as reductions in local air pollution damages, are taken into account in the results.

[c] "Trading" denotes trading in emission permits between countries.

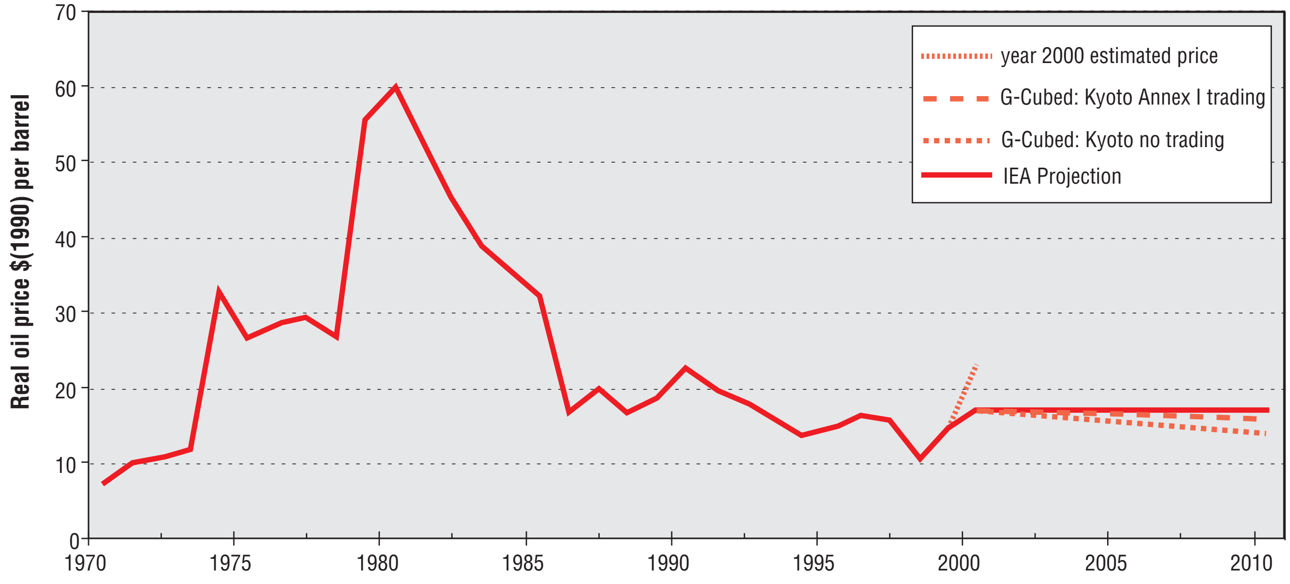
These studies typically do not consider some or all of the following policies and measures that could lessen the impact on oil exporters:

- policies and measures for non-CO_2 GHGs or non-energy sources of all GHGs;
- offsets from sinks;
- industry restructuring (e.g., from energy producer to supplier of energy services);
- the use of OPEC's market power; and
- actions (e.g., of Annex B Parties) related to funding, insurance, and the transfer of technology.

In addition, the studies typically do not include the following policies and effects that can reduce the total cost of mitigation:

- the use of tax revenues to reduce tax burdens or finance other mitigation measures;
- environmental co- or ancillary benefits of reductions in fossil fuel use; and
- induced technical change from mitigation policies.

As a result, the studies may tend to overstate both the costs to oil exporting countries and overall costs.



Note: The oil price shown is that of UK Brent deflated by the US GDP deflator. The year 2000 estimated price is based on actual prices January to August and futures prices September to December.

Figure TS.9: *Real oil prices and the effects of Kyoto implementation.*

9.2.3 *Gas*

Modelling studies suggest that mitigation policies may have the least impact on oil, the most impact on coal, with the impact on gas somewhere between; these findings are established but incomplete. The high variation across studies for the effects of mitigation on gas demand is associated with the importance of its availability in different locations, its specific demand patterns, and the potential for gas to replace coal in power generation.

These results are different from recent trends, which show natural gas usage growing faster than the use of either coal or oil. They can be explained as follows. In the transport sector, the largest user of oil, current technology and infrastructure will not allow much switching from oil to non-fossil fuel alternatives in Annex I countries before about 2020. Annex B countries can only meet their Kyoto Protocol commitments by reducing overall energy use and this will result in a reduction in natural gas demand, unless this is offset by a switch towards natural gas for power generation. The modelling of such a switch remains limited in these models.

9.2.4 *Electricity*

In general as regards the effects on the electricity sector, mitigation policies either mandate or directly provide incentives for increased use of zero-emitting technologies (such as nuclear, hydro, and other renewables) and lower-GHG-emitting generation technologies (such as combined cycle natural gas). Or, second, they drive their increased use indirectly by more flexible approaches that place a tax on or require a permit for emission of GHGs. Either way, the result will be a shift in the mix of fuels used to generate electricity towards increased use of the zero- and lower-emitting generation technologies, and away from the higher-emitting fossil fuels.

Nuclear power would have substantial advantages as a result of GHG mitigation policies, because power from nuclear fuel produces negligible GHGs. In spite of this advantage, nuclear power is not seen as the solution to the global warming problem in many countries. The main issues are (1) the high costs compared to alternative CCGTs, (2) public acceptance involving operating safety and waste, (3) safety of radioactive waste management and recycling of nuclear fuel, (4) the risks of nuclear fuel transportation, and (5) nuclear weapons proliferation.

9.2.5 *Transport*

Unless highly efficient vehicles (such as fuel cell vehicles) become rapidly available, there are few options available to reduce transport energy use in the short term, which do not involve significant economic, social, or political costs. No government has yet demonstrated policies that can reduce the overall demand for mobility, and all governments find it politically difficult to contemplate such measures. Substantial additional improvements in aircraft energy efficiency are most likely to be accomplished by policies that increase the price of, and therefore reduce the amount of, air travel. Estimated price elasticities of demand are in the range of -0.8 to -2.7. Raising the price of air travel by taxes faces a number of political hurdles. Many of the bilateral treaties that currently govern the operation of the air transport system contain provisions for exemptions of taxes and charges, other than for the cost of operating and improving the system.

9.3 Sectoral Ancillary Benefits of Greenhouse Gas Mitigation

The direct costs for fossil fuel consumption are accompanied by environmental and public health benefits associated with a reduction in the extraction and burning of the fuels. These benefits come from a reduction in the damages caused by these activities, especially a reduction in the emissions of pollutants that are associated with combustion, such as SO_2, NO_x, CO and other chemicals, and particulate matter. This will improve local and regional air and water quality, and thereby lessen damage to human, animal, and plant health, and to ecosystems. If all the pollutants associated with GHG emissions are removed by new technologies or end-of-pipe abatement (for example, flue gas desulphurization on a power station combined with removal of all other non-GHG pollutants), then this ancillary benefit will no longer exist. But such abatement is limited at present and it is expensive, especially for small-scale emissions from dwellings and cars (See also Section 8.6).

9.4 The Effects of Mitigation on Sectoral Competitiveness

Mitigation policies are less effective if they lead to loss of international competitiveness or the migration of GHG-emitting industries from the region implementing the policy (so-called carbon leakage). The estimated effects, reported in the literature, on international price competitiveness are small while those on carbon leakage appear to beat the stage of competing explanations, with large differences depending on the models and the assumptions used. There are several reasons for expecting that such effects will not be substantial. First, mitigation policies actually adopted use a range of instruments and usually include special treatment to minimize adverse industrial effects, such as exemptions for energy-intensive industries. Second, the models assume that any migrating industries will use the average technology of the area to which they will move; however, instead they may adopt newer, lower CO_2-emitting technologies. Third, the mitigation policies also encourage low-emission technologies and these also may migrate, reducing emissions in industries in other countries (see also Section 8.7).

9.5 Why the Results of Studies Differ

The results in the studies assessed come from different approaches and models. A proper interpretation of the results requires an understanding of the methods adopted and the underlying assumptions of the models and studies. Large differences in results can arise from the use of different reference scenarios or baselines. And the characteristics of the baseline can markedly affect the quantitative results of modelling mitigation policy. For example, if air quality is assumed to be satisfactory in the baseline, then the potential for air-quality ancillary benefits in any GHG mitigation scenario is ruled out by assumption. Even with similar or the same baseline assumptions, the studies yield different results.

As regards the costs of mitigation, these differences appear to be largely caused by different approaches and assumptions, with the most important being the type of model adopted. Bottom-up engineering models assuming new technological opportunities tend to show benefits from mitigation. Top-down general equilibrium models appear to show lower costs than top-down time-series econometric models. The main assumptions leading to lower costs in the models are that:

- new flexible instruments, such as emission trading and joint implementation, are adopted;
- revenues from taxes or permit sales are returned to the economy by reducing burdensome taxes; and
- ancillary benefits, especially from reduced air pollution, are included in the results.

Finally, long-term technological progress and diffusion are largely given in the top-down models; different assumptions or a more integrated, dynamic treatment could have major effects on the results.

10 Decision Analytical Frameworks

10.1 Scope for and New Developments in Analyses for Climate Change Decisions

Decision making frameworks (DMFs) related to climate change involve multiple levels ranging from global negotiations to individual choices and a diversity of actors with different resource endowments, and diverging values and aspirations. This explains why it is difficult to arrive at a management strategy that is acceptable for all. The dynamic interplay among economic sectors and related social interest groups makes it difficult to arrive at a national position to be represented at international fora in the first place. The intricacies of international climate negotiations result from the manifold often-ambiguous national positions as well as from the linkages of climate change policy with other socio-economic objectives.

No DMF can reproduce the above diversity in its full richness. Yet analysts have made significant progress in several directions since SAR. First, they integrate an increasing number of issues into a single analytical framework in order to provide an internally consistent assessment of closely related components, processes, and subsystems. The resulting integrated assessment models (IAMs) cited in Chapter 9, and indeed throughout the whole report, provide useful insights into a number of climate policy issues for policymakers. Second, scientists pay increasing attention to the broader context of climate related issues that have been ignored or paid marginal attention previously. Among other factors, this has fostered the integration of development, sustainability and equity issues into the present report.

Climate change is profoundly different from most other environmental problems with which humanity has grappled. A combination of several features lends the climate problem its uniqueness. They include public good issues raising from the concentration of GHGs in the atmosphere that requires collective global action, the multiplicity of decision makers ranging from global down to the micro level of firms and individuals, and the heterogeneity of emissions and their consequences around the world. Moreover, the long-term nature of climate change originates from the fact that it is the concentration of GHGs that matters rather than their annual emissions and this feature raises the thorny issues of intergenerational transfers of wealth and environmental goods and bads. Next, human activities associated with climate change are widespread, which makes narrowly defined technological solutions impossible, and the interactions of climate policy with other broad socio-economic policies are strong. Finally, large uncertainties or in some areas even ignorance characterize many aspects of the problem and require a risk management approach to be adopted in all DMFs that deal with climate change.

Policymakers therefore have to grapple with great uncertainties in choosing the appropriate responses. A wide variety of tools have been applied to help them make fundamental choices. Each of those decision analysis frameworks (DAFs) has its own merits and shortcoming through its ability to address some of the above features well, but other facets less adequately. Recent analyses with well-established tools such as cost–benefit analysis as well as newly developed frameworks like the tolerable windows or safe landing approach provide fresh insights into the problem.

Figure TS.10a shows the results of a cost-effectiveness analysis exploring the optimal hedging strategy when uncertainty with respect to the long-term stabilization target is not resolved until 2020, suggesting that abatement over the next few years would be economically valuable if there is a significant probability of having to stay below ceilings that would be otherwise reached within the characteristic time scales of the systems producing greenhouse gases. The degree of near-term hedging in the above analysis is sensitive to the date of resolution of uncertainty, the inertia in the energy system, and the fact that the ultimate concentration target (once it has been revealed) must be met at all costs. Other experiments, such as those with cost-benefit models framed as a Bayesian decision analysis

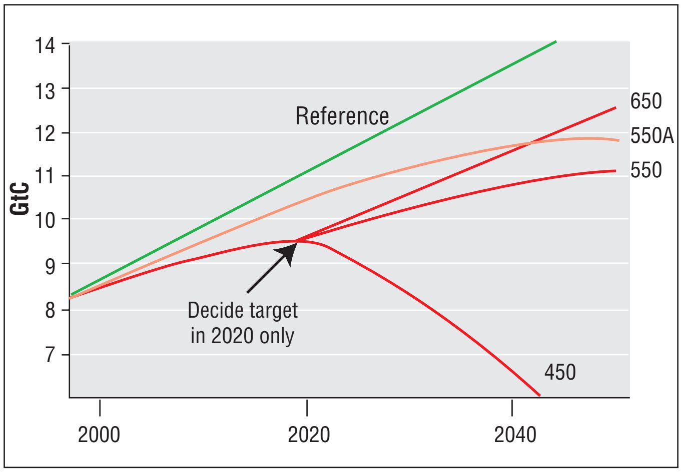


Figure TS.10a: *Optimal carbon dioxide emissions strategy, using a cost-effectiveness approach.*

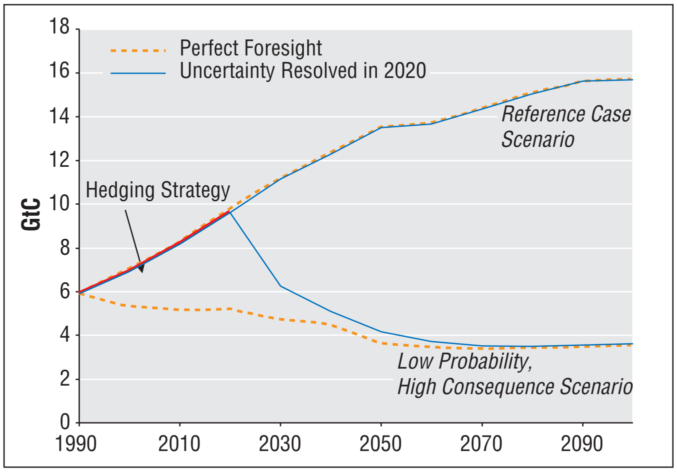


Figure TS.10b: *Optimal hedging strategy for low probability, high consequence scenario using a cost-benefits optimization approach.*

problem show that optimal near-term (next two decades) emission paths diverge only modestly under perfect foresight, and hedging even for low-probability, high-consequence scenarios (see *Figure TS.10b*). However, decisions about near-term climate policies may have to be made while the stabilization target is still being debated. Decision-making therefore should consider appropriate hedging against future resolution of that target and possible revision of the scientific insights in the risks of climate change. There are significant differences in the two approaches. With a cost-effectiveness analysis, the target must be made regardless of costs. With a cost-benefit analysis, costs and benefits are balanced at the margin. Nevertheless, the basic message is quite similar and involves the explicit incorporation of uncertainty and its sequential resolution over time. The desirable amount of hedging depends upon one's assessment of the stakes, the odds, and the costs of policy measures. The risk premium – the amount that society is willing to pay to reduce risk – ultimately is a political decision that differs among countries.

Cost-effectiveness analyses seek the lowest cost of achieving an environmental target by equalizing the marginal costs of mitigation across space and time. Long-term cost-effectiveness studies estimate the costs of stabilizing atmospheric CO_2 concentrations at different levels and find that the costs of the 450ppmv ceiling are substantially greater than those of the 750ppmv limit. Rather than seeking a single optimal path, the tolerable windows/safe landing approach seeks to delineate the complete array of possible emission paths that satisfy externally defined climate impact and emission cost constraints. Results indicate that delaying near-term effective emission reductions can drastically reduce the future range of options for relatively tight climate change targets, while less tight targets offer more near-term flexibility.

10.2 International Regimes and Policy Options

The structure and characteristics of international agreements on climate change will have a significant influence on the effectiveness and costs and benefits of mitigation. The effectiveness and the costs and benefits of an international climate change regime (such as the Kyoto Protocol or other possible future agreements) depend on the number of signatories to the agreement and their abatement targets and/or policy commitment. At the same time, the number of signatories depends on the question of how equitably the commitments of participants are shared. Economic efficiency (minimizing costs by maximizing participation) and equity (the allocation of emissions limitation commitments) are therefore strongly linked.

There is a three-way relationship between the design of the international regime, the cost-effectiveness/efficiency of climate policies, and the equity of the consequent economic outcomes. As a consequence, it is crucial to design the international regime in a way that is considered both efficient and equitable. The literature presents different theoretical strategies to optimize an international regime. For example, it can be made attractive for countries to join the group that commits to specific targets for limitation and reduction of emissions by increasing the equity of a larger agreement – and therefore its efficiency – through measures like an appropriate distribution of targets over time, the linkage of the climate debate with other issues ("issue linkage"), the use of financial transfers to affected countries ("side payments"), or technology transfer agreements.

Two other important concerns shape the design of an international regime: "implementation" and "compliance". The effectiveness of the regime, which is a function of both implementation and compliance, is related to actual changes of behaviour that promote the goals of the accord. *Implementation* refers to the translation of international accords into domestic law, policy, and regulations by national governments. *Compliance* is related to whether and to what extent countries do in fact adhere to provisions of an accord. *Monitoring, reporting,* and *verification* are essential for the effectiveness of international environmental regimes, as the systematic monitoring, assessment, and handling of implementation failures have been so far relatively rare. Nonetheless, efforts to provide "systems of implementation review" are growing, and are already incorporated into the UNFCCC structure. The challenge for the future is to make them more effective, especially by improving data on national emissions, policies, and measures.

10.3 Linkages to National and Local Sustainable Development Choices

Much of the ambiguity related to sustainable development and climate change arises from the lack of measurements that could provide policymakers with essential information on the alternative choices at stake, how those choices affect clear and recognizable social, economic, and environmental critical issues, and also provide a basis for evaluating their performance in achieving goals and targets. Therefore, indicators are indispensable to make the concept of sustainable development operational. At the national level important steps in the direction of defining and designing different sets of indicators have been undertaken; however, much work remains to be done to translate sustainability objectives into practical terms.

It is difficult to generalize about sustainable development policies and choices. Sustainability implies and requires diversity, flexibility, and innovation. Policy choices are meant to introduce changes in technological patterns of natural resource use, production and consumption, structural changes in the production systems, spatial distribution of population and economic activities, and behavioural patterns. Climate change literature has by and large addressed the first three topics, while the relevance of choices and decisions related to behavioural patterns and lifestyles has been paid scant attention. Consumption patterns in the industrialized countries are an important reason for climate change. If people changed their preferences this could alleviate climate change considerably. To change consumption patterns, however, people must not only change their behaviour but also change themselves because these patterns are an essential element of lifestyles and, therefore, of self-esteem. Yet, apart from climate change there are other reasons to do so as well as indications that this change can be fostered politically.

A critical requirement of sustainable development is a capacity to design policy measures that, without hindering development and consistent with national strategies, could exploit potential synergies between national economic growth objectives and environmentally focused policies. Climate change mitigation strategies offer a clear example of how co-ordinated and harmonized policies can take advantage of the synergies between the implementation of mitigation options and broader objectives. Energy efficiency improvements, including energy conservation, switch to low carbon content fuels, use of renewable energy sources and the introduction of more advanced non conventional energy technologies, are expected to have significant impacts on curbing actual GHG emission tendencies. Similarly, the adoption of new technologies and practices in agriculture and forestry activities as well as the adoption of clean production processes could make substantial contributions to the GHG mitigation effort. Depending on the specific context in which they are applied, these options may entail positive side effects or double dividends, which in some cases are worth undertaking whether or not there are climate-related reasons for doing so.

Sustainable development requires radical technological and related changes in both developed and developing countries. Technological innovation and the rapid and widespread transfer and implementation of individual technological options and choices, as well as overall technological systems, constitute major elements of global strategies to achieve both climate stabilization and sustainable development. However, technology transfer requires more than technology itself. An enabling environment for the successful transfer and implementation of technology plays a crucial role, particularly in developing countries. If technology transfer is to bring about economic and social benefits it must take into account the local cultural traditions and capacities as well as the institutional and organizational circumstances required to handle, operate, replicate, and improve the technology on a continuous basis.

The process of integrating and internalizing climate change and sustainable development policies into national development agendas requires new problem solving strategies and decision-making approaches. This task implies a twofold effort. On one hand, sustainable development discourse needs greater analytical and intellectual rigor (methods, indicators, etc.) to make this concept advance from theory to practice. On the other hand, climate change discourse needs to be aware of both the restrictive set of assumptions underlying the tools and methods applied in the analysis, and the social and political implications of scientific constructions of climate change. Over recent years a good deal of analytical work has addressed the problem in both directions. Various approaches have been explored to transcend the limits of the standard views and decision frameworks in dealing with issues of uncertainty, complexity, and the contextual influences of human valuation and decision making. A common theme emerges: the emphasis on participatory decision making frameworks for articulating new institutional arrangements.

10.4 Key Policy-relevant Scientific Questions

Different levels of globally agreed limits for climate change (or for corresponding atmospheric GHG concentrations), entail different balances of mitigation costs and net damages for individual nations. Considering the uncertainties involved and future learning, climate stabilization will inevitably be an iterative process: nation states determine their own national targets based on their own exposure and their sensitivity to other countries' exposure to climate change. The global target emerges from consolidating national targets, possibly involving side payments, in global negotiations. Simultaneously, agreement on burden sharing and the agreed global target determines national costs. Compared to the expected net damages associated with the global target, nation states might reconsider their own national targets, especially as new information becomes available on global and regional patterns and impacts of climate change. This is then the starting point for the next round of negotiations. It follows from the above that establishing the "magic number" (i.e., the upper limit for global climate change or GHG concentration in the atmosphere) will be a long process and its source will primarily be the policy process, hopefully helped by improving science.

Looking at the key dilemmas in climate change decision making, the following conclusions emerge (see also *Table TS.7*):

- a carefully crafted portfolio of mitigation, adaptation, and learning activities appears to be appropriate over the next few decades to hedge against the risk of intolerable magnitudes and/or rates of climate change (impact side) and against the need to undertake painfully drastic emission reductions if the resolution of uncertainties reveals that climate change and its impacts might imply high risks;
- emission reduction is an important form of mitigation, but the mitigation portfolio includes a broad range of other activities, including investments to develop low-cost non-carbon, energy efficient and carbon management technologies that will make future CO_2 mitigation less expensive;
- timing and composition of mitigation measures (investment into technological development or immediate emission reductions) is highly controversial because of the technological features of energy systems, and the range of uncertainties involved in the impacts of different emission paths;
- international flexibility instruments help reduce the costs of emission reductions, but they raise a series of implementation and verification issues that need to be balanced against the cost savings;
- while there is a broad consensus to use the Pareto optimality[30] as the efficiency principle, there is no agreement on the best equity principle on wich to build an equitable international regime. Efficiency and equity are important concerns in negotiating emission limitation schemes, and they are not mutually exclusive. Therefore, equity will play an important role in determining the distribution of emissions allowances and/or within compensation schemes following emission trading that could lead to a disproportionately high level of burden on certain countries. Finally, it could be more important to build a regime on the combined implications of the various equity principles rather than to select any one particular equity principle. Diffusing non-carbon, energy-efficient, as well as other GHG reducing technologies worldwide could make a significant contribution to reducing emissions over the short term, but many barriers hamper technology transfer, including market imperfections, political problems, and the often-neglected transaction costs;
- some obvious linkages exist between current global and continental environmental problems and attempts of the international community to resolve them, but the potential synergies of jointly tackling several of them have not yet been thoroughly explored, let alone exploited.

Mitigation and adaptation decisions related to anthropogenically induced climate change differ. Mitigation decisions involve many countries, disperse benefits globally over decades to centuries (with some near-term ancillary benefits), are driven by public policy action, based on information available today, and the relevant regulation will require rigorous enforcement. In contrast, adaptation decisions involve a shorter time span between outlays and returns, related costs and benefits accrue locally, and their implementation involves local public policies and private adaptation of the affected social agents, both based on improving information. Local mitigation and adaptive capacities vary significantly across regions and over time. A portfolio of mitigation and adaptation policies will depend on local or national priorities and preferred approaches in combination with international responsibilities.

Given the large uncertainties characterizing each component of the climate change problem, it is difficult for decision makers to establish a globally acceptable level of stabilizing GHG concentrations today. Studies appraised in Chapter10 support the obvious expectations that lower stabilization targets involve substantially higher mitigation costs and relatively more ambitious near-term emission reductions on the one hand, but, as reported by WGII, lower targets induce significantly smaller bio/geophysical impacts and thus induce smaller damages and adaptation costs.

11 Gaps in Knowledge

Important gaps in own knowledge on which additional research could be useful to support future assessments include:

- *Further exploration of the regional, country, and sector specific potentials of technological and social innovation options, including:*
  - – The short, medium, and long-term potential and costs of both CO_2 and non-CO_2, non-energy mitigation options;

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[30] Pareto optimum is a requirement or status that an individual's welfare could not be further improved without making others in the society worse off.

Table TS.7: *Balancing the near-term mitigation portfolio*

Issue	**Favouring modest early abatement**	**Favouring stringent early abatement**
Technology development	• Energy technologies are changing and improved versions of existing technologies are becoming available, even without policy intervention. • Modest early deployment of rapidly improving technologies allows learning-curve cost reductions, without premature lock-in to existing, low-productivity technology. • The development of radically advanced technologies will require investment in basic research.	• Availability of low-cost measures may have substantial impact on emissions trajectories. • Endogenous (market-induced) change could accelerate development of low-cost solutions (learning-by-doing). • Clustering effects highlight the importance of moving to lower emission trajectories. • Induces early switch of corporate energy R&D from fossil frontier developments to low carbon technologies.
Capital stock and inertia	• Beginning with initially modest emissions limits avoids premature retirement of existing capital stocks and takes advantage of the natural rate of capital stock turnover. • It also reduces the switching cost of existing capital and prevents rising prices of investments caused by crowding out effects.	• Exploit more fully natural stock turnover by influencing new investments from the present onwards. • By limiting emissions to levels consistent with low CO_2 concentrations, preserves an option to limit CO_2 concentrations to low levels using current technology. • Reduces the risks from uncertainties in stabilization constraints and hence the risk of being forced into very rapid reductions that would require premature capital retirement later.
Social effects and inertia	• Gradual emission reduction reduces the extent of induced sectoral unemployment by giving more time to retrain the workforce and for structural shifts in the labour market and education. • Reduces welfare losses associated with the need for fast changes in people's lifestyles and living arrangements.	• Especially if lower stabilization targets would be required ultimately , stronger early action reduces the maximum rate of emissions abatement required subsequently and reduces associated transitional problems, disruption, and the welfare losses associated with the need for faster later changes in people's lifestyles and living arrangements.
Discounting and intergenerational equity	• Reduces the present value of future abatement costs (*ceteris paribus*), but possibly reduces future relative costs by furnishing cheap technologies and increasing future income levels.	• Reduces impacts and (*ceteris paribus*) reduces their present value.
Carbon cycle and radiative change	• Small increase in near-term, transient CO_2 concentration. • More early emissions absorbed, thus enabling higher total carbon emissions this century under a given stabilization constraint (to be compensated by lower emissions thereafter).	• Small decrease in near-term, transient CO_2 concentration. • Reduces peak rates in temperature change.
Climate change impacts	• Little evidence on damages from multi-decade episodes of relatively rapid change in the past.	• Avoids possibly higher damages caused by faster rates of climate change.

  - Understanding of technology diffusion across different regions;
  - Identifying opportunities in the area of social innovation leading to decreased greenhouse gas emissions;
  - Comprehensive analysis of the impact of mitigation measures on C flows in and out of the terrestrial system; and
  - Some basic inquiry in the area of geo-engineering.

- *Economic, social, and institutional issues related to climate change mitigation in all countries. Priority areas include*:
  - Much more analysis of regionally specific mitigation options, barriers, and policies is recommended as these are conditioned by the regions' mitigative capacity;
  - The implications of mitigation on equity;
  - Appropriate methodologies and improved data sources for climate change mitigation and capacity building in the area of integrated assessment;
  - Strengthening future research and assessments, especially in developing countries.

- *Methodologies for analysis of the potential of mitigation options and their cost, with special attention to comparability of results. Examples include*:
  - Characterizing and measuring barriers that inhibit greenhouse gas-reducing action;
  - Make mitigation modelling techniques more consistent, reproducible, and accessible;
  - Modelling technology learning; improving analytical tools for evaluating ancillary benefits, e.g. assigning the costs of abatement to greenhouse gases and to other pollutants;
  - Systematically analyzing the dependency of costs on baseline assumptions for various greenhouse gas stabilization scenarios;
  - Developing decision analytical frameworks for dealing with uncertainty as well as socio-economic and ecological risk in climate policymaking;
  - Improving global models and studies, their assumptions, and their consistency in the treatment and reporting of non-Annex I countries and regions.

- *Evaluating climate mitigation options in the context of development, sustainability, and equity. Examples include:*
  - More research is needed on the balance of options in the areas of mitigation and adaptation and of the mitigative and adaptive capacity in the context of DES;
  - Exploration of alternative development paths including sustainable consumption patterns in all sectors, including the transportation sector, and integrated analysis of mitigation and adaptation;
  - Identifying opportunities for synergy between explicit climate policies and general policies promoting sustainable development;
  - Integration of inter- and intragenerational equity in climate change mitigation studies;
  - Implications of equity assessments;
  - Analysis of scientific, technical, and economic aspects of implications of options under a wide variety of stabilization regimes;
  - Determining what kinds of policies interact with what sorts of socio-economic conditions to result in futures characterized by low CO_2 emissions;
  - Investigation on how changes in societal values may be encouraged to promote sustainable development; and
  - Evaluating climate mitigation options in the context of and for synergy with potential or actual adaptive measures.

- *Development of engineering-economic, end-use, and sectoral studies of GHG emissions mitigation potentials for specific regions and/or countries of the world, focusing on:*
  - Identification and assessment of mitigation technologies and measures that are required to deviate from "business-as-usual" in the short term (2010, 2020);
  - Development of standardized methodologies for quantifying emissions reductions and costs of mitigation technologies and measures;
  - Identification of barriers to the implementation of the mitigation technologies and measures;
  - Identification of opportunities to increase adoption of GHG emissions mitigation technologies and measures through connections with ancillary benefits as well as furtherance of the DES goals; and
  - Linking the results of the assessments to specific policies and programmes that can overcome the identified barriers as well as leverage the identified ancillary benefits.