Summary for Policymakers

Climate Change 2001: Mitigation

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

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Based on a draft prepared by:
Tariq Banuri, Terry Barker, Igor Bashmakov, Kornelis Blok, Daniel Bouille, Renate Christ, Ogunlade Davidson, Jae Edmonds, Ken Gregory, Michael Grubb, Kirsten Halsnaes, Tom Heller, Jean-Charles Hourcade, Catrinus Jepma, Pekka Kauppi, Anil Markandya, Bert Metz, William Moomaw, Jose Roberto Moreira, Tsuneyuki Morita, Nebojsa Nakicenovic, Lynn Price, Richard Richels, John Robinson, Hans Holger Rogner, Jayant Sathaye, Roger Sedjo, Priyaradshi Shukla, Leena Srivastava, Rob Swart, Ferenc Toth, John Weyant

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Introduction

1. *This report assesses the scientific, technical, environmental, economic and social aspects of the mitigation of climate change*. Research in climate change mitigation[1] has continued since the publication of the IPCC Second Assessment Report (SAR), taking into account political changes such as the agreement on the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997, and is reported on here. The Report also draws on a number of IPCC Special Reports, notably the Special Report on Aviation and the Global Atmosphere, the Special Report on Methodological and Technological Issues in Technology Transfer (SRTT), the Special Report on Emissions Scenarios (SRES), and the Special Report on Land Use, Land Use Change and Forestry (SRLULUCF).

The Nature of the Mitigation Challenge

2. *Climate change*[2] *is a problem with unique characteristics*. It is global, long-term (up to several centuries), and involves complex interactions between climatic, environmental, economic, political, institutional, social and technological processes. This may have significant international and intergenerational implications in the context of broader societal goals such as equity and sustainable development. Developing a response to climate change is characterized by decision-making under uncertainty and risk, including the possibility of non-linear and/or irreversible changes (Sections 1.2.5, 1.3, 10.1.2, 10.1.4, 10.4.5).[3]

3. *Alternative development paths*[4] *can result in very different greenhouse gas emissions*. The SRES and the mitigation scenarios assessed in this report suggest that the type, magnitude, timing and costs of mitigation depend on different national circumstances and socio-economic, and technological development paths and the desired level of greenhouse gas concentration stabilization in the atmosphere (see *Figure SPM.1* for an example for total CO_2 emissions). Development paths leading to low emissions depend on a wide range of policy choices and require major policy changes in areas other than climate change (Sections 2.2.2, 2.3.2, 2.4.4, 2.5).

4. *Climate change mitigation will both be affected by, and have impacts on, broader socio-economic policies and trends, such as those relating to development, sustainability and equity.* Climate mitigation policies may promote sustainable development when they are consistent with such broader societal objectives. Some mitigation actions may yield extensive benefits in areas outside of climate change: for example, they may reduce health problems; increase employment; reduce negative environmental impacts (like air pollution); protect and enhance forests, soils and watersheds; reduce those subsidies and taxes which enhance greenhouse gas emissions; and induce technological change and diffusion, contributing to wider goals of sustainable development. Similarly, development paths that meet sustainable development objectives may result in lower levels of greenhouse gas emissions (Sections 1.3, 1.4, 2.2.3, 2.4.4, 2.5, 7.2.2, 8.2.4).

5. *Differences in the distribution of technological, natural and financial resources among and within nations and regions, and between generations, as well as differences in mitigation costs, are often key considerations in the analysis of climate change mitigation options*. Much of the debate about the future differentiation of contributions of countries to mitigation and related equity issues also considers these circumstances[5]. The challenge of addressing climate change raises an important issue of equity, namely the extent to which the impacts of climate change or mitigation policies create or exacerbate inequities both within and across nations and regions. Greenhouse gas stabilization scenarios assessed in this report (except those where stabilization occurs without new climate policies, e.g. B1) assume that developed countries and countries with economies in transition limit and reduce their greenhouse gas emissions first.[6]

[1] Mitigation is defined here as an anthropogenic intervention to reduce the sources of greenhouse gases or enhance their sinks.

[2] *Climate change* in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the UNFCCC, where *climate change* refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

[3] Section numbers refer to the main body of the Report.

[4] In this report "alternative development paths" refer to a variety of possible scenarios for societal values and consumption and production patterns in all countries, including but not limited to a continuation of today's trends. These paths do not include additional climate initiatives which means that no scenarios are included that explicitly assume implementation of the UNFCCC or the emission targets of the Kyoto Protocol, but do include assumptions about other policies that influence greenhouse gas emissions indirectly.

[5] Approaches to equity have been classified into a variety of categories, including those based on allocation, outcome, process, rights, liability, poverty, and opportunity, reflecting the diverse expectations of fairness used to judge policy processes and the corresponding outcomes (Sections 1.3, 10.2).

[6] Emissions from all regions diverge from baselines at some point. Global emissions diverge earlier and to a greater extent as stabilization levels are lower or underlying scenarios are higher. Such scenarios are uncertain, do not provide information on equity implications and how such changes may be achieved or who may bear any costs incurred.

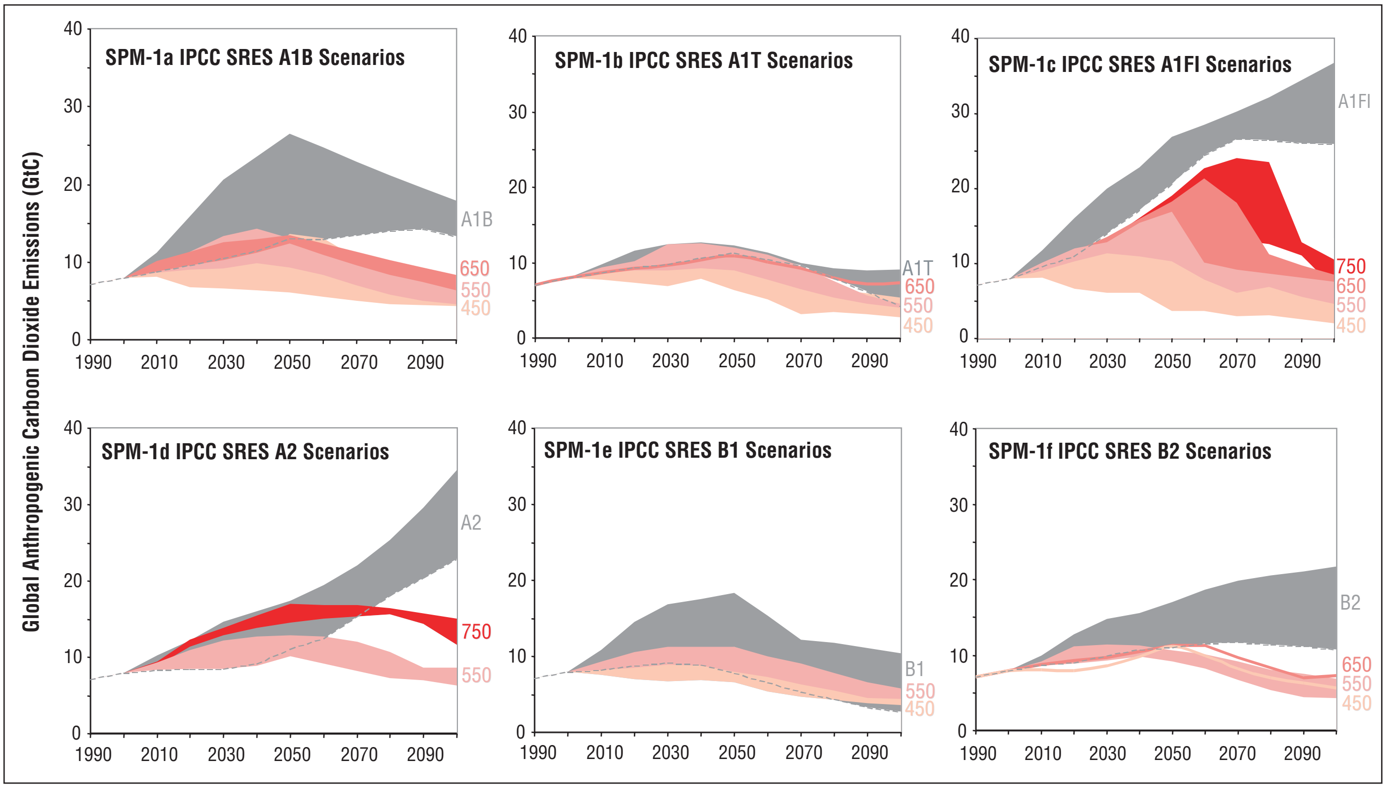

Figure SPM.1: *Comparison of reference and stabilization scenarios. The figure is divided into six parts, one for each of the reference scenario groups from the Special Report on Emissions Scenarios (SRES, see Box SPM.1). Each part of the figure shows the range of total global CO_2 emissions (gigatonnes 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 SPM.1a), non-fossil fuel A1T (Figure SPM.1b) and the fossil intensive A1FI (Figure SPM.1c)) with stabilization of CO_2 concentrations at 450, 550, 650 and 750 ppmv; for the A2 group with stabilization at 550 and 750 ppmv in Figure SPM.1d, the B1 group with stabilization at 450 and 550 ppmv in Figure SPM.1e, and the B2 group with stabilization at 450, 550 and 650 ppmv in Figure SPM.1f. The literature is not available to assess 1000 ppmv 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.*

6. *Lower emissions scenarios require different patterns of energy resource development. Figure SPM.2* compares the cumulative carbon emissions between 1990 and 2100 for various SRES scenarios to carbon contained in global fossil fuel reserves and resources[7]. This figure shows that there are abundant fossil fuel resources that will not limit carbon emissions during the 21st century. However, different from the relatively large coal and unconventional oil and gas deposits, the carbon in proven conventional oil and gas reserves, or in conventional oil resources, is much less than the cumulative carbon emissions associated with stabilization of carbon dioxide at levels of 450 ppmv or higher (the reference to a particular concentration level does not imply an agreed-upon desirability of stabilization at this level). 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 (Sections 2.5.1, 2.5.2, 3.8.3, 8.4).

[7] 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, Working Group II). Examples of unconventional fossil fuel resources include tar sands, shale oil, other heavy oil, coal bed methane, deep geopressured gas, gas in acquifers, *etc*.

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

A1. The A1 storyline and scenario family describes 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 describes 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 continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward 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 describes 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 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.

Options to Limit or Reduce Greenhouse Gas Emissions and Enhance Sinks

7. *Significant technical progress relevant to greenhouse gas emissions reduction has been made since the SAR in 1995 and has been faster than anticipated*. Advances are taking place in a wide range of technologies at different stages of development, e.g., the market introduction of wind turbines, the rapid elimination of industrial by-product gases such as N_2O from adipic acid production and perfluorocarbons from aluminium production, efficient hybrid engine cars, the advancement of fuel cell technology, and the demonstration of underground carbon dioxide storage. Technological options for emissions reduction include improved efficiency of end use devices and energy conversion technologies, shift to low-carbon and renewable biomass fuels, zero-emissions technologies, improved energy management, reduction of industrial by-product and process gas emissions, and carbon removal and storage (Section 3.1, 4.7).

Table SPM.1 summarizes the results from many sectoral studies, largely at the project, national and regional level with some at the global levels, providing estimates of potential greenhouse gas emission reductions in the 2010 to 2020 timeframe. Some key findings are:

- Hundreds of technologies and practices for end-use energy efficiency in buildings, transport and manufacturing industries account for more than half of this potential (Sections 3.3, 3.4, 3.5).
- At least up to 2020, energy supply and conversion will remain dominated by relatively cheap and abundant fossil fuels. Natural gas, where transmission is economically feasible, will play an important role in emission reduction together with conversion efficiency improvement, and greater use of combined cycle and/or co-generation plants (Section 3.8.4).
- Low-carbon energy supply systems can make an important contribution through biomass from forestry and agricultural by-products, municipal and industrial waste to energy, dedicated biomass plantations, where suitable land and water are available, landfill methane, wind energy and hydropower, and through the use and lifetime extension of nuclear power plants. After 2010, emissions from fossil and/or biomass-fueled power plants could be reduced substantially through pre- or post-combustion carbon removal and storage. Environmental, safety, reliability and proliferation concerns may constrain the use of some of these technologies (Section 3.8.4).

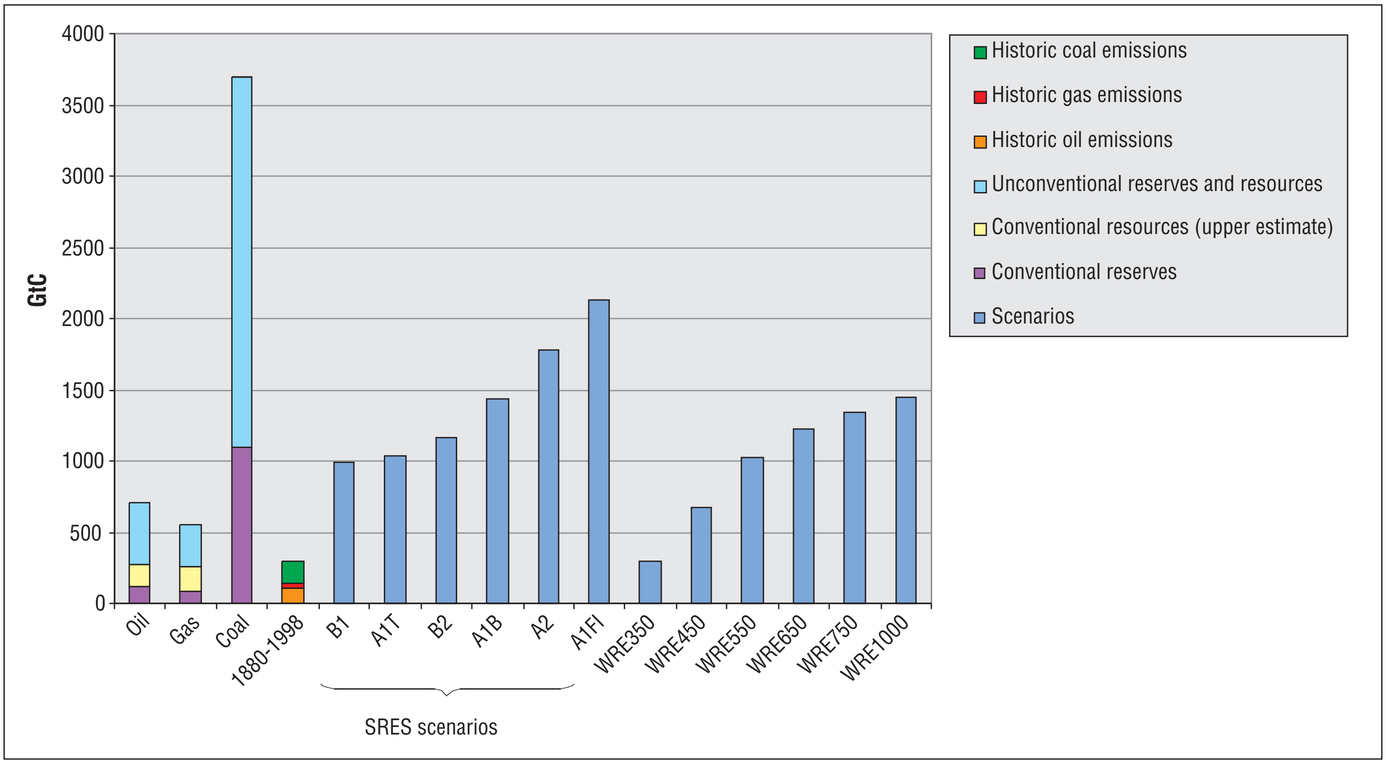

Figure SPM.2: *Carbon in oil, gas and coal reserves and resources compared with historic fossil fuel carbon emissions 1860–1998, and with cumulative carbon emissions from a range of SRES scenarios and TAR stabilization scenarios up until 2100. Data for reserves and resources are shown in the left hand columns (Section 3.8.2). 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 12,000GtC 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.*

- In agriculture, methane and nitrous oxide emissions can be reduced, such as those from livestock enteric fermentation, rice paddies, nitrogen fertilizer use and animal wastes (Section 3.6).
- Depending on application, emissions of fluorinated gases can be minimized through process changes, improved recovery, recycling and containment, or avoided through the use of alternative compounds and technologies (Section 3.5 and Chapter 3 Appendix).

The potential emissions reductions found in *Table SPM.1* for sectors were aggregated to provide estimates of global potential emissions reductions taking account of potential overlaps between and within sectors and technologies to the extent possible given the information available in the underlying studies. Half of these 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, affecting 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 involve additional implementation costs, which in some cases may be substantial, the possible need for supporting policies (such as those described in Paragraph 18), increased research and development, effective technology transfer and overcoming other barriers (Paragraph 17). These issues, together with costs and benefits not included in this evaluation are discussed in Paragraphs 11, 12 and 13.

The various global, regional, national, sector and project studies assessed in this report have different scopes and assumptions. Studies do not exist for every sector and region. The range of emissions reductions reported in *Table SPM.1* reflects the uncertainties (see *Box SPM.2*) of the underlying studies on which they are based (Sections 3.3-3.8).

Table SPM.1: *Estimates of potential global greenhouse gas emission reductions in 2010 and in 2020 (Sections 3.3-3.8 and Chapter 3 Appendix)*

Sector		**Historic emissions in 1990 (MtC_{eq}/yr)**	**Historic C_{eq} annual growth rate in 1990-1995 (%)**	**Potential emission reductions in 2010 (MtC_{eq}/yr)**	**Potential emission reductions in 2020 (MtC_{eq}/yr)**	**Net direct costs per tonne of carbon avoided**
Buildings[a]	CO_2 only	1,650	1.0	700-750	1,000-1,100	Most reductions are available at negative net direct costs.
Transport	CO_2 only	1,080	2.4	100-300	300-700	Most studies indicate net direct costs less than US$25/tC but two suggest net direct costs will exceed US$50/tC.
Industry -energy efficiency -material efficiency	CO_2 only	2,300	0.4	 300-500 ~200	 700-900 ~600	 More than half available at net negative direct costs. Costs are uncertain.
Industry	Non-CO_2 gases	170		~100	~100	N_2O emissions reduction costs are US$0-US$10/tC_{eq}.
Agriculture[b]	CO_2 only Non-CO_2 gases	210 1,250-2,800	 n.a	 150-300	 350-750	Most reductions will cost between US$0-100/$tC_{eq.}$ with limited opportunities for negative net direct cost options.
Waste[b]	CH_4 only	240	1.0	~200	~200	About 75% of the savings as methane recovery from landfills at net negative direct cost; 25% at a cost of US$20/$tC_{eq}$.
Montreal Protocol replacement applications	Non-CO_2 gases	0	n.a.	~100	n.a.	About half of reductions due to difference in study baseline and SRES baseline values. Remaining half of the reductions available at net direct costs below US$200/$tC_{eq}$.
Energy supply and conversion[c]	CO_2 only	(1,620)	1.5	50-150	350-700	Limited net negative direct cost options exist; many options are available for less than US$100/$tC_{eq}$.
Total		**6,900–8,400**[d]		**1,900–2,600**[e]	**3,600–5,050**[e]	

[a] Buildings include appliances, buildings, and the building shell.

[b] The range for agriculture is mainly caused by large uncertainties about CH_4, N_2O and soil related emissions of CO_2. Waste is dominated by landfill methane and the other sectors could be estimated with more precision as they are dominated by fossil CO_2.

[c] Included in sector values above. Reductions include electricity generation options only (fuel switching to gas/nuclear, CO_2 capture and storage, improved power station efficiencies, and renewables).

[d] Total includes all sectors reviewed in Chapter 3 for all six gases. It excludes non-energy related sources of CO_2 (cement production, 160MtC; gas flaring, 60MtC; and land use change, 600-1,400MtC) and energy used for conversion of fuels in the end-use sector totals (630MtC). If petroleum refining and coke oven gas were added, global 1990 CO_2 emissions of 7,100MtC would increase by 12%. Note that forestry emissions and their carbon sink mitigation options are not included.

[e] The baseline SRES scenarios (for six gases included in the Kyoto Protocol) project a range of emissions of 11,500–14,000MtC_{eq} for 2010 and of 12,000–16,000MtC_{eq} for 2020. The emissions reduction estimates are most compatible with baseline emissions trends in the SRES-B2 scenario. The potential reductions take into account regular turn-over of capital stock. They are not limited to cost-effective options, but exclude options with costs above US$100/$tC_{eq}$ (except for Montreal Protocol gases) or options that will not be adopted through the use of generally accepted policies.

8. *Forests, agricultural lands, and other terrestrial ecosystems offer significant carbon mitigation potential. Although not necessarily permanent, conservation and sequestration of carbon may allow time for other options to be further developed and implemented.* Biological mitigation can occur by three strategies: (a) conservation of existing carbon pools, (b) sequestration by increasing the size of carbon pools, and (c) substitution of sustainably produced biological products, e.g. wood for energy intensive construction products and biomass for fossil fuels (Sections 3.6, 4.3). Conservation of threatened carbon pools may help to avoid emissions, if leakage can be prevented, and can only become sustainable if the socio-economic drivers for deforestation and other losses of carbon pools can be addressed. Sequestration reflects the biological dynamics of growth, often starting slowly, passing through a maximum, and then declining over decades to centuries.

Conservation and sequestration result in higher carbon stocks, but can lead to higher future carbon emissions if these ecosystems are severely disturbed by either natural or direct/indirect human-induced disturbances. Even though natural disturbances are normally followed by re-sequestration, activities to manage such disturbances can play an important role in limiting carbon emissions. Substitution benefits can, in principle, continue indefinitely. Appropriate management of land for crop, timber and sustainable bio-energy production, may increase benefits for climate change mitigation. Taking into account competition for land use and the SAR and SRLULUCF assessments, the estimated global potential of biological mitigation options is in the order of 100GtC (cumulative), although there are substantial uncertainties associated with this estimate, by 2050, equivalent to about 10% to 20% of potential fossil fuel emissions during that period. Realization of this potential depends upon land and water availability as well as the rates of adoption of different land management practices. The largest biological potential for atmospheric carbon mitigation is in subtropical and tropical regions. Cost estimates reported to date of biological mitigation vary significantly from US$0.1/tC to about US$20/tC in several tropical countries and from US$20/tC to US$100/tC in non-tropical countries. Methods of financial analysis and carbon accounting have not been comparable. Moreover, the cost calculations do not cover, in many instances, inter alia, costs for infrastructure, appropriate discounting, monitoring, data collection and implementation costs, 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. These biological mitigation options may have social, economic and environmental benefits beyond reductions in atmospheric CO_2, if implemented appropriately (e.g., biodiversity, watershed protection, enhancement of sustainable land management and rural employment). However, if implemented inappropriately, they may pose risks of negative impacts (e.g., loss of biodiversity, community disruption and ground-water pollution). Biological mitigation options may reduce or increase non-CO_2 greenhouse gas emissions (Sections 4.3, 4.4).

9. *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*[8] *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.* To achieve stabilization at these levels, the scenarios suggest that a very significant reduction in world carbon emissions per unit of GDP from 1990 levels will be necessary. Technological improvement and technology transfer play a critical role in the stabilization scenarios assessed in this report. For the crucial energy sector, almost all greenhouse gas mitigation and concentration stabilization scenarios are characterized by the introduction of efficient technologies for both energy use and supply, and of low- or no-carbon energy. However, no single technology option will provide all of the emissions reductions needed. Reduction options in non-energy sources and non-CO_2 greenhouse gases will also provide significant potential for reducing emissions. Transfer of technologies between countries and regions will widen the choice of options at the regional level and economies of scale and learning will lower the costs of their adoption (Sections 2.3.2, 2.4, 2.5).

10. *Social learning and innovation, and changes in institutional structure could contribute to climate change mitigation.* Changes in collective rules and individual behaviours may have significant effects on greenhouse gas emissions, but take place within a complex institutional, regulatory and legal setting. Several studies suggest that current incentive systems can encourage resource intensive production and consumption patterns that increase greenhouse gas emissions in all sectors, e.g. transport and housing. In the shorter term, there are opportunities to influence through social innovations individual and organizational behaviours. In the longer term such innovations, in combination with technological change, may further enhance socio-economic potential, particularly if preferences and cultural norms shift towards lower emitting and sustainable behaviours. These innovations frequently meet with resistance, which may be addressed by encouraging greater public participation in the decision-making processes. This can help contribute to new approaches to sustainability and equity (Sections 1.4.3, 5.3.8, 10.3.2, 10.3.4).

[8] "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.

Box SPM.2. Approaches to Estimating Costs and Benefits, and their Uncertainties

For a variety of factors, significant differences and uncertainties surround specific quantitative estimates of the costs and benefits of mitigation options. The SAR described two categories of approaches to estimating costs and benefits: bottom-up approaches, which build up from assessments of specific technologies and sectors, such as those described in Paragraph 7, and top-down modelling studies, which proceed from macroeconomic relationships, such as those discussed in Paragraph 13. These two approaches lead to differences in the estimates of costs and benefits, which have been narrowed since the SAR. Even if these differences were resolved, other uncertainties would remain. The potential impact of these uncertainties can be usefully assessed by examining the effect of a change in any given assumption on the aggregate cost results, provided any correlation between variables is adequately dealt with.

The Costs and Ancillary[9] Benefits of Mitigation Actions

11. *Estimates of cost and benefits of mitigation actions differ because of (i) how welfare is measured, (ii) the scope and methodology of the analysis, and (iii) the underlying assumptions built into the analysis. As a result, estimated costs and benefits may not reflect the actual costs and benefits of implementing mitigation actions.* With respect to (i) and (ii), costs and benefits estimates, *inter alia*, depend on revenue recycling, and whether and how the following are considered: implementation and transaction cost, distributional impacts, multiple gases, land-use change options, benefits of avoided climate change, ancillary benefits, no regrets opportunities[10] and valuation of externalities and non-market impacts. Assumptions include, *inter alia*:

- Demographic change, the rate and structure of economic growth; increases in personal mobility, technological innovation such as improvements in energy efficiency and the availability of low-cost energy sources, flexibility of capital investments and labour markets, prices, fiscal distortions in the no-policy (baseline) scenario.
- The level and timing of the mitigation target.
- Assumptions regarding implementation measures, e.g. the extent of emissions trading, the Clean Development Mechanism (CDM) and Joint Implementation (JI), regulation, and voluntary agreements[11] and the associated transaction costs.
- Discount rates: the long time scales make discounting assumptions critical and there is still no consensus on appropriate long-term rates, though the literature shows increasing attention to rates that decline over time and hence give more weight to benefits that occur in the long term. These discount rates should be distinguished from the higher rates that private agents generally use in market transactions.

(Sections 7.2, 7.3, 8.2.1, 8.2.2, 9.4)

12. *Some sources of greenhouse gas emissions can be limited at no or negative net social cost to the extent that policies can exploit no regrets opportunities* (Sections 7.3.4, 9.2.1)*:*

- *Market imperfections.* 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.
- *Ancillary benefits.* Climate change mitigation measures will have effects on other societal issues. For example, reducing carbon emissions in many cases will result in the simultaneous reduction in local and regional air pollution. It is likely that mitigation strategies will also affect transportation, agriculture, land-use practices and waste management and will have an impact on other issues of social concern, such as employment, and energy security. However, not all of the effects will be positive; careful policy selection and design can better ensure positive effects and minimize negative impacts. In some cases, the magnitude of ancillary benefits of mitigation may be comparable to the costs of the mitigating measures, adding to the no regrets potential, although estimates are difficult to make and vary widely (Sections 7.3.3, 8.2.4, 9.2.2-9.2.8, 9.2.10).
- *Double dividend.* Instruments (such as taxes or auctioned permits) provide revenues to the government. If used to finance reductions in existing distortionary taxes ("revenue recycling"), these revenues reduce the economic cost of achieving greenhouse gas reductions. The magnitude of this offset depends on the existing tax structure, type of tax cuts, labour market conditions, and method of recycling. Under some circumstances, it is possible that the economic benefits may exceed the costs of mitigation (Sections 7.3.3, 8.2.2, 9.2.1).

[9] Ancillary benefits are the ancillary, or side effects, of policies aimed exclusively at climate change mitigation. Such policies have an impact not only on greenhouse gas emissions, but also on resource use efficiency, like reduction in emissions of local and regional air pollutants associated with fossil fuel use, and on issues such as transportation, agriculture, land-use practices, employment, and fuel security. Sometimes these benefits are referred to as "ancillary impacts" to reflect that in some cases the benefits may be negative.

[10] In this report, as in the SAR, no regrets opportunities 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.

[11] A voluntary agreement is an agreement between a government authority and one or more private parties, as well as a unilateral commitment that is recognized by the public authority, to achieve environmental objectives or to improve environmental performance beyond compliance.

13. *The cost estimates for Annex B countries to implement the Kyoto Protocol vary between studies and regions as indicated in Paragraph 11, 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[12] (Sections 7.3.5, 8.3.1, 9.2.3, 10.4.4):

Annex II countries[13]: In the absence of emissions trading between Annex B countries[14], 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[15]. These studies encompass a wide range of assumptions as listed in Paragraph 11. Models whose results are reported in this paragraph 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[10] identified in Paragraph 12, 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 per cent 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 due to revenues from trading assigned amounts. However, for some economies in transition, implementing the Kyoto Protocol will have similar impact on GDP as for Annex II countries.

14. *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, gases other than CO_2 and did not examine the possible effect of more ambitious targets on induced technological change[16]. Costs associated with each concentration level depend on numerous factors including the rate of discount, distribution of emission reductions over time, policies and measures employed, and particularly the choice of the baseline scenario: for scenarios characterized by a focus on local and regional sustainable development for example, total costs of stabilizing at a particular level are significantly lower than for other scenarios[17] (Sections 2.5.2, 8.4.1, 10.4.6).

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[12] Many other studies incorporating more precisely the country specifics and diversity of targeted policies provide a wider range of net cost estimates (Section 8.2.2).

[13] 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.

[14] 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.

[15] 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.

[16] 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).

[17] See *Figure SPM.1* for the influence of reference scenarios on the magnitude of the required mitigation effort to reach a given stabilization level.

15. *Under any greenhouse gas mitigation effort, the economic costs and benefits are distributed unevenly between sectors; to a varying degree, the costs of mitigation actions could be reduced by appropriate policies*. In general, it is easier to identify activities, which stand to suffer economic costs compared to those which may benefit, and the economic costs are more immediate, more concentrated and more certain. Under mitigation policies, coal, possibly oil and gas, and certain energy-intensive sectors, such as steel production, are most likely to suffer an economic disadvantage. Other industries including renewable energy industries and services can be expected to benefit in the long term from price changes and the availability of financial and other resources that would otherwise have been devoted to carbon-intensive sectors. Policies such as the removal of subsidies from fossil fuels may increase total societal benefits through gains in economic efficiency, while use of the Kyoto mechanisms could be expected to reduce the net economic cost of meeting Annex B targets. Other types of policies, for example exempting carbon-intensive industries, redistribute the costs but increase total societal costs at the same time. Most studies show that the distributional effects of a carbon tax can have negative income effects on low-income groups unless the tax revenues are used directly or indirectly to compensate such effects (Section 9.2.1).

16. *Emission constraints in Annex I countries have well established, albeit varied "spillover" effects*[18] *on non-Annex I countries* (Sections 8.3.2, 9.3).

- *Oil-exporting, non-Annex I countries: Analyses report costs differently, including, inter alia*, *reductions in projected GDP and reductions in projected oil revenues*[19]. 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[20]. 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[21] other than Annex B emissions trading, that 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*[22]. *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%* (Section 8.3.2.2). 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.

Ways and Means for Mitigation

17. *The successful implementation of greenhouse gas mitigation options needs to overcome many technical, economic, political, cultural, social, behavioural and/or institutional barriers which prevent the full exploitation of the technological, economic and social opportunities of these mitigation options.* The potential mitigation opportunities and types of barriers vary by region and sector, and over time. This is caused by the wide variation in mitigation capacity. The poor in any country are faced with limited opportunities to adopt technologies or change their social behaviour, particularly if they are not part of a cash economy, and most countries could benefit from

[18] Spillover effects incorporate only economic effects, not environmental effects.

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

[20] 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.

[21] 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.

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

innovative financing and institutional reform and removing barriers to trade. In the industrialized countries, future opportunities lie primarily in removing social and behavioural barriers; in countries with economies in transition, in price rationalization; and in developing countries, in price rationalization, increased access to data and information, availability of advanced technologies, financial resources, and training and capacity building. Opportunities for any given country, however, might be found in the removal of any combination of barriers (Sections 1.5, 5.3, 5.4).

18. *National responses to climate change can be more effective if deployed as a portfolio of policy instruments to limit or reduce greenhouse gas emissions.* The portfolio of national climate policy instruments may include - according to national circumstances - emissions/carbon/energy taxes, tradable or non-tradable permits, provision and/or removal of subsidies, deposit/refund systems, technology or performance standards, energy mix requirements, product bans, voluntary agreements, government spending and investment, and support for research and development. Each government may apply different evaluation criteria, which may lead to different portfolios of instruments. The literature in general gives no preference for any particular policy instrument. Market based instruments may be cost-effective in many cases, especially where capacity to administer them is developed. Energy efficiency standards and performance regulations are widely used, and may be effective in many countries, and sometimes precede market based instruments. Voluntary agreements have recently been used more frequently, sometimes preceding the introduction of more stringent measures. Information campaigns, environmental labelling, and green marketing, alone or in combination with incentive subsidies, are increasingly emphasized to inform and shape consumer or producer behaviour. Government and/or privately supported research and development is important in advancing the long-term application and transfer of mitigation technologies beyond the current market or economic potential (Section 6.2).

19. *The effectiveness of climate change mitigation can be enhanced when climate policies are integrated with the non-climate objectives of national and sectorial policy development and be turned into broad transition strategies to achieve the long-term social and technological changes required by both sustainable development and climate change mitigation.* Just as climate policies can yield ancillary benefits that improve wellbeing, non-climate policies may produce climate benefits. It may be possible to significantly reduce greenhouse gas emissions by pursuing climate objectives through general socio-economic policies. In many countries, the carbon intensity of energy systems may vary depending on broader programmmes for energy infrastructure development, pricing, and tax policies. Adopting state-of-the-art environmentally sound technologies may offer particular opportunity for environmentally sound development while avoiding greenhouse gas intensive activities. Specific attention can foster the transfer of those technologies to small and medium size enterprises. Moreover, taking ancillary benefits into account in comprehensive national development strategies can lower political and institutional barriers for climate-specific actions (Sections 2.2.3, 2.4.4, 2.4.5, 2.5.1, 2.5.2, 10.3.2, 10.3.4).

20. *Co-ordinated actions among countries and sectors may help to reduce mitigation cost, address competitiveness concerns, potential conflicts with international trade rules, and carbon leakage. A group of countries that wants to limit its collective greenhouse gas emissions could agree to implement well-designed international instruments.* Instruments assessed in this report and being developed in the Kyoto Protocol are emissions trading; Joint Implementation (JI); the Clean Development Mechanism (CDM); other international instruments also assessed in this report include co-ordinated or harmonized emission/carbon/energy taxes; an emission/carbon/energy tax; technology and product standards; voluntary agreements with industries; direct transfers of financial resources and technology; and co-ordinated creation of enabling environments such as reduction of fossil fuel subsidies. Some of these have been considered only in some regions to date (Sections 6.3, 6.4.2, 10.2.7, 10.2.8).

21. *Climate change decision-making is essentially a sequential process under general uncertainty.* The literature suggests that a prudent risk management strategy requires a careful consideration of the consequences (both environmental and economic), their likelihood and society's attitude toward risk. The latter is likely to vary from country to country and perhaps even from generation to generation. This report therefore confirms the SAR finding that the value of better information about climate change processes and impacts and society's responses to them is likely to be great. Decisions about near-term climate policies are in the process of being made while the concentration stabilization target is still being debated. The literature suggests a step-by-step resolution aimed at stabilizing greenhouse gas concentrations. This will also involve balancing the risks of either insufficient or excessive action. The relevant question is not "what is the best course for the next 100 years", but rather "what is the best course for the near term given the expected long-term climate change and accompanying uncertainties" (Section 10.4.3).

22. *This report confirms the finding in the SAR that earlier actions, including a portfolio of emissions mitigation, technology development and reduction of scientific uncertainty, increase flexibility in moving towards stabilization of atmospheric concentrations of greenhouse gases. The desired mix of options varies with time and place.* Economic modelling studies completed since the SAR indicate that a gradual near-term transition from the world's present energy system towards a less carbon-emitting economy minimizes costs associated with

premature retirement of existing capital stock. It also provides time for technology development, and avoids premature lock-in to early versions of rapidly developing low-emission technology. On the other hand, more rapid near-term action would decrease environmental and human risks associated with rapid climatic changes.

It would also stimulate more rapid deployment of existing low-emission technologies, 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 (Sections 2.3.2, 2.5.2, 8.4.1, 10.4.2, 10.4.3).

23. *There is an inter-relationship between the environmental effectiveness of an international regime, the cost-effectiveness of climate policies and the equity of the agreement.* Any international regime can be designed in a way that enhances both its efficiency and its equity. The literature assessed in this report on coalition formation in international regimes presents different strategies that support these objectives, including how to make it more attractive to join a regime through appropriate distribution of efforts and provision of incentives. While analysis and negotiation often focus on reducing system costs, the literature also recognizes that the development of an effective regime on climate change must give attention to sustainable development and non-economic issues (Sections 1.3, 10.2).

Gaps in Knowledge

24. *Advances have been made since previous IPCC assessments in the understanding of the scientific, technical, environmental, and economic and social aspects of mitigation of climate change. Further research is required, however, to strengthen future assessments and to reduce uncertainties as far as possible in order that sufficient information is available for policy making about responses to climate change, including research in developing countries.*

The following are high priorities for further narrowing gaps between current knowledge and policy making needs:

- *Further exploration of the regional, country and sector specific potentials of technological and social innovation options.* This includes research on the short, medium and long-term potential and costs of both CO_2 and non-CO_2, non-energy mitigation options; 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 carbon 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: analysis of regionally specific mitigation options and barriers; the implications of equity assessments; 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 the 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; making 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 policy making; 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: exploration of alternative development paths, including sustainable consumption patterns in all sectors, including the transportation sector; integrated analysis of mitigation and adaptation; identifying opportunities for synergy between explicit climate policies and general policies promoting sustainable development; integration of intra- and inter-generational equity in climate change mitigation analysis; implications of equity assessments; analysis of scientific, technical and economic implications of options under a wide variety of stabilization regimes.