

**Contribution of Working Group III to the  
Fourth Assessment Report of the  
Intergovernmental Panel on Climate Change**

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**Summary for Policymakers**

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**Drafting authors:**

Terry Barker, Igor Bashmakov, Lenny Bernstein, Jean Bogner, Peter Bosch, Ritu Dave, Ogunlade Davidson, Brian Fisher, Michael Grubb, Sujata Gupta, Kirsten Halsnaes, BertJan Heij, Suzana Kahn Ribeiro, Shigeki Kobayashi, Mark Levine, Daniel Martino, Omar Masera Cerutti, Bert Metz, Leo Meyer, Gert-Jan Nabuurs, Adil Najam, Nebojsa Nakicenovic, Hans Holger Rogner, Joyashree Roy, Jayant Sathaye, Robert Schock, Priyaradshi Shukla, Ralph Sims, Pete Smith, Rob Swart, Dennis Tirpak, Diana Urge-Vorsatz, Zhou Dadi

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## A. Introduction

1. The Working Group III contribution to the IPCC Fourth Assessment Report (AR4) focuses on new literature on the scientific, technological, environmental, economic and social aspects of mitigation of climate change, published since the IPCC Third Assessment Report (TAR) and the Special Reports on CO<sub>2</sub> Capture and Storage (SRCCS) and on Safeguarding the Ozone Layer and the Global Climate System (SROC).

The following summary is organised into six sections after this introduction:

- Greenhouse gas (GHG) emission trends
- Mitigation in the short and medium term, across different economic sectors (until 2030)
- Mitigation in the long-term (beyond 2030)
- Policies, measures and instruments to mitigate climate change
- Sustainable development and climate change mitigation
- Gaps in knowledge.

References to the corresponding chapter sections are indicated at each paragraph in square brackets. An explanation of terms, acronyms and chemical symbols used in this SPM can be found in the glossary to the main report.

## B. Greenhouse gas emission trends

2. **Global greenhouse gas (GHG) emissions have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (*high agreement, much evidence*)<sup>1</sup>.**
  - Since pre-industrial times, increasing emissions of GHGs due to human activities have led to a marked increase in atmospheric GHG concentrations [1.3; Working Group I SPM].
  - Between 1970 and 2004, global emissions of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs and SF<sub>6</sub>, weighted by their global warming potential (GWP), have increased by 70% (24%

between 1990 and 2004), from 28.7 to 49 Gigatonnes of carbon dioxide equivalents (GtCO<sub>2</sub>-eq)<sup>2</sup> (see Figure SPM.1). The emissions of these gases have increased at different rates. CO<sub>2</sub> emissions have grown between 1970 and 2004 by about 80% (28% between 1990 and 2004) and represented 77% of total anthropogenic GHG emissions in 2004.

- The largest growth in global GHG emissions between 1970 and 2004 has come from the energy supply sector (an increase of 145%). The growth in direct emissions<sup>3</sup> from transport in this period was 120%, industry 65% and land use, land use change, and forestry (LULUCF)<sup>4</sup> 40%<sup>5</sup>. Between 1970 and 1990 direct emissions from agriculture grew by 27% and from buildings by 26%, and the latter remained at approximately at 1990 levels thereafter. However, the buildings sector has a high level of electricity use and hence the total of direct and indirect emissions in this sector is much higher (75%) than direct emissions [1.3, 6.1, 11.3, Figures 1.1 and 1.3].
- The effect on global emissions of the decrease in global energy intensity (-33%) during 1970 to 2004 has been smaller than the combined effect of global per capita income growth (77 %) and global population growth (69%); both drivers of increasing energy-related CO<sub>2</sub> emissions (Figure SPM.2). The long-term trend of a declining carbon intensity of energy supply reversed after 2000. Differences in terms of per capita income, per capita emissions, and energy intensity among countries remain significant. (Figure SPM.3). In 2004 UNFCCC Annex I countries held a 20% share in world population, produced 57% of world Gross Domestic Product based on Purchasing Power Parity (GDP<sub>ppp</sub>)<sup>6</sup> and accounted for 46% of global GHG emissions (Figure SPM.3) [1.3].
- The emissions of ozone depleting substances (ODS) controlled under the Montreal Protocol<sup>7</sup>, which are also GHGs, have declined significantly since the 1990s. By 2004 the emissions of these gases were about 20% of their 1990 level [1.3].
- A range of policies, including those on climate change, energy security<sup>8</sup>, and sustainable development, have been effective in reducing GHG emissions in different sectors and many countries. The scale of such measures, however, has not yet been large enough to counteract the global growth in emissions [1.3, 12.2].

1 Each headline statement has an “agreement/evidence” assessment attached that is supported by the bullets underneath. This does not necessarily mean that this level of “agreement/evidence” applies to each bullet. Endbox 1 provides an explanation of this representation of uncertainty.

2 The definition of carbon dioxide equivalent (CO<sub>2</sub>-eq) is the amount of CO<sub>2</sub> emission that would cause the same radiative forcing as an emitted amount of a well mixed greenhouse gas or a mixture of well mixed greenhouse gases, all multiplied with their respective GWPs to take into account the differing times they remain in the atmosphere [WGI AR4 Glossary].

3 Direct emissions in each sector do not include emissions from the electricity sector for the electricity consumed in the building, industry and agricultural sectors or of the emissions from refinery operations supplying fuel to the transport sector.

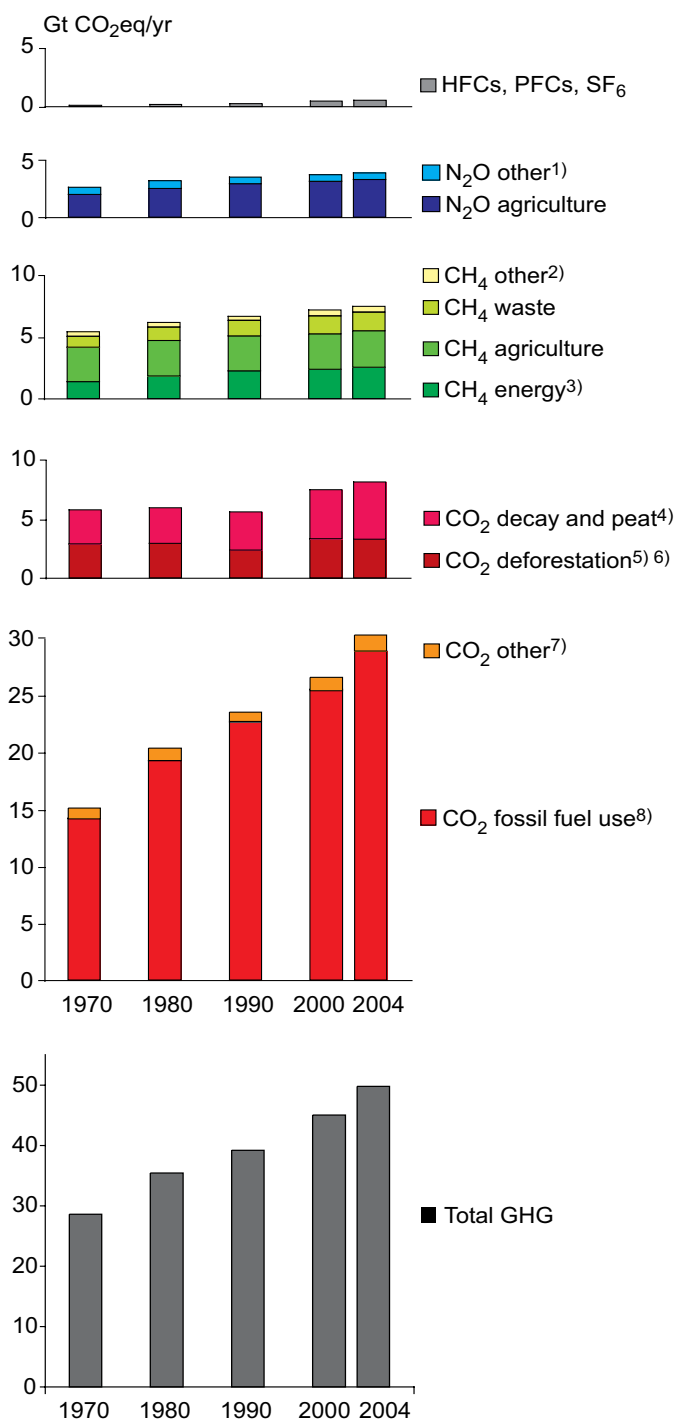
4 The term “land use, land use change and forestry” is used here to describe the aggregated emissions of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O from deforestation, biomass and burning, decay of biomass from logging and deforestation, decay of peat and peat fires [1.3.1]. This is broader than emissions from deforestation, which is included as a subset. The emissions reported here do not include carbon uptake (removals).

5 This trend is for the total LULUCF emissions, of which emissions from deforestation are a subset and, owing to large data uncertainties, is significantly less certain than for other sectors. The rate of deforestation globally was slightly lower in the 2000-2005 period than in the 1990-2000 period [9.2.1].

6 The GDP<sub>ppp</sub> metric is used for illustrative purposes only for this report. For an explanation of PPP and Market Exchange Rate (MER) GDP calculations, see footnote 12.

7 Halons, chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl chloroform (CH<sub>3</sub>CCl<sub>3</sub>), carbon tetrachloride (CCl<sub>4</sub>) and methyl bromide (CH<sub>3</sub>Br).

8 Energy security refers to security of energy supply.



**Figure SPM.1:** Global Warming Potential (GWP) weighted global greenhouse gas emissions 1970-2004. 100 year GWPs from IPCC 1996 (SAR) were used to convert emissions to CO<sub>2</sub>-eq. (cf. UNFCCC reporting guidelines). CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs and SF<sub>6</sub> from all sources are included. The two CO<sub>2</sub> emission categories reflect CO<sub>2</sub> emissions from energy production and use (second from bottom) and from land use changes (third from the bottom) [Figure 1.1a].

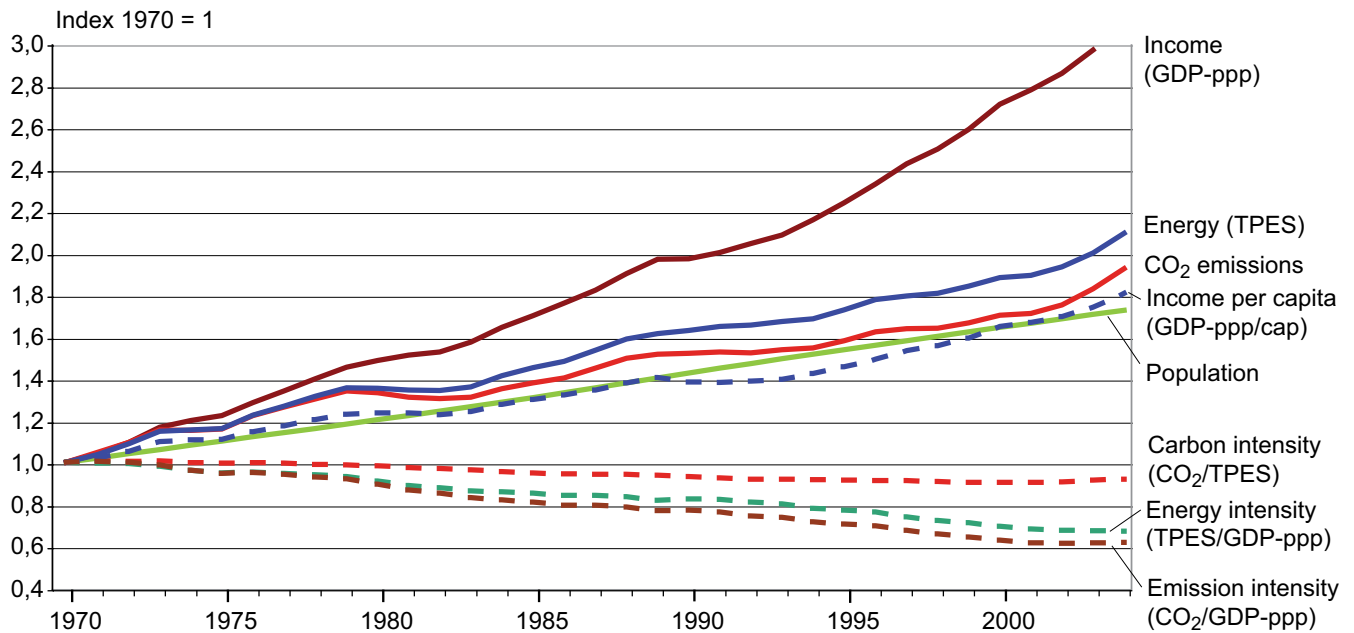
Notes:

1. Other N<sub>2</sub>O includes industrial processes, deforestation/savannah burning, waste water and waste incineration.
2. Other is CH<sub>4</sub> from industrial processes and savannah burning.
3. Including emissions from bioenergy production and use
4. CO<sub>2</sub> emissions from decay (decomposition) of above ground biomass that remains after logging and deforestation and CO<sub>2</sub> from peat fires and decay of drained peat soils.
5. As well as traditional biomass use at 10% of total, assuming 90% is from sustainable biomass production. Corrected for 10% carbon of biomass that is assumed to remain as charcoal after combustion.
6. For large-scale forest and scrubland biomass burning averaged data for 1997-2002 based on Global Fire Emissions Data base satellite data.
7. Cement production and natural gas flaring.
8. Fossil fuel use includes emissions from feedstocks.

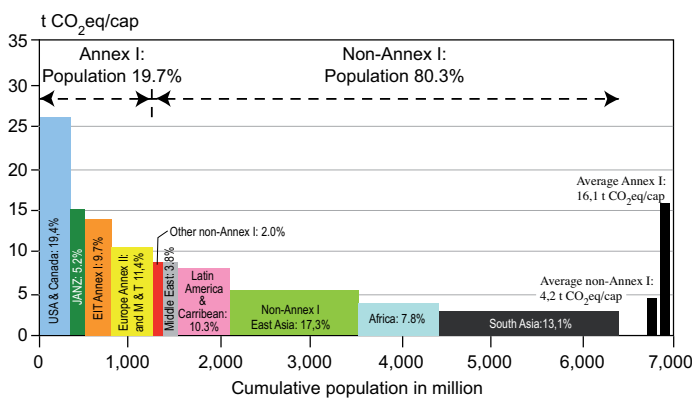
**3. With current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades (high agreement, much evidence).**

- The SRES (non-mitigation) scenarios project an increase of baseline global GHG emissions by a range of 9.7 GtCO<sub>2</sub>-eq to 36.7 GtCO<sub>2</sub>-eq (25-90%) between 2000 and 2030<sup>9</sup> (Box SPM.1 and Figure SPM.4). In these scenarios, fossil fuels are projected to maintain their dominant position in the global energy mix to 2030 and beyond. Hence CO<sub>2</sub> emissions between 2000 and 2030 from energy use are projected to grow 40 to 110% over that period. Two thirds to three quarters of this increase in energy CO<sub>2</sub> emissions is projected to come from non-Annex I regions, with their average per capita energy CO<sub>2</sub> emissions being projected to remain substantially lower (2.8-5.1 tCO<sub>2</sub>/cap) than those in Annex I regions (9.6-15.1 tCO<sub>2</sub>/cap) by 2030. According to SRES scenarios, their economies are projected to have a lower energy use per unit of GDP (6.2 – 9.9 MJ/US\$ GDP) than that of non-Annex I countries (11.0 – 21.6 MJ/US\$ GDP). [1.3, 3.2]

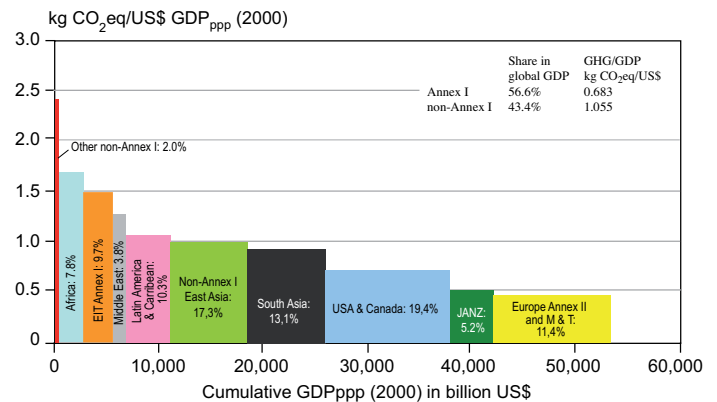
<sup>9</sup> The SRES 2000 GHG emissions assumed here are 39.8 GtCO<sub>2</sub>-eq, i.e. lower than the emissions reported in the EDGAR database for 2000 (45 GtCO<sub>2</sub>-eq). This is mostly due to differences in LULUCF emissions.



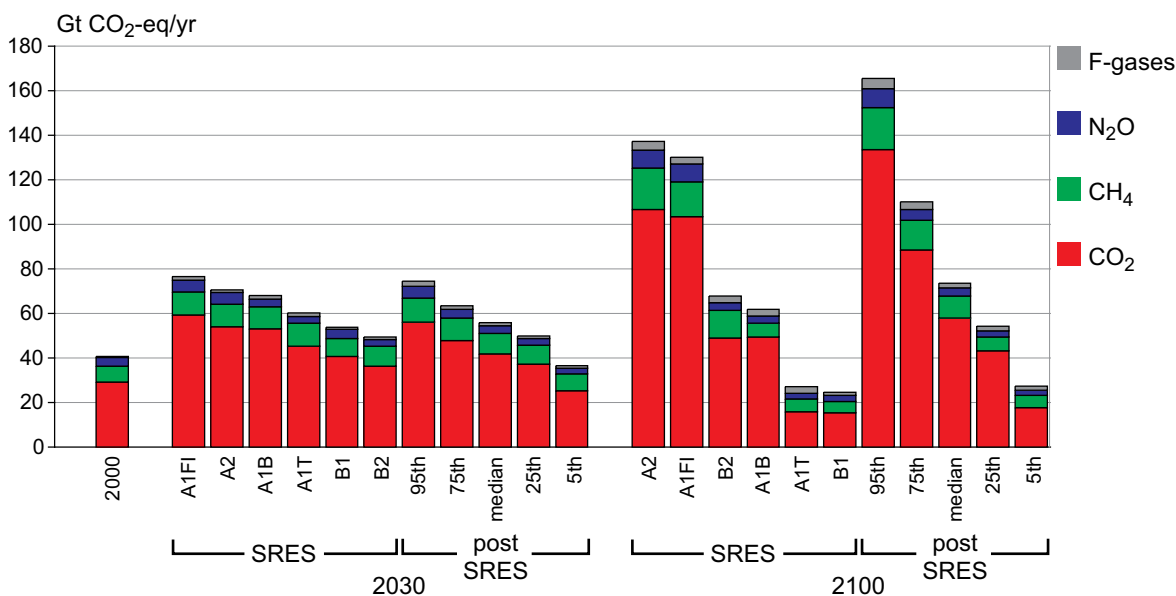
**Figure SPM.2:** Relative global development of Gross Domestic Product measured in PPP ( $GDP_{ppp}$ ), Total Primary Energy Supply (TPES),  $CO_2$  emissions (from fossil fuel burning, gas flaring and cement manufacturing) and Population (Pop). In addition, in dotted lines, the figure shows Income per capita ( $GDP_{ppp}/Pop$ ), Energy Intensity ( $TPES/GDP_{ppp}$ ), Carbon Intensity of energy supply ( $CO_2/TPES$ ), and Emission Intensity of the economic production process ( $CO_2/GDP_{ppp}$ ) for the period 1970-2004. [Figure 1.5]



**Figure SPM.3a:** Year 2004 distribution of regional per capita GHG emissions (all Kyoto gases, including those from land-use) over the population of different country groupings. The percentages in the bars indicate a regions share in global GHG emissions [Figure 1.4a].



**Figure SPM.3b:** Year 2004 distribution of regional GHG emissions (all Kyoto gases, including those from land-use) per US\$ of  $GDP_{ppp}$  over the  $GDP_{ppp}$  of different country groupings. The percentages in the bars indicate a regions share in global GHG emissions [Figure 1.4b].



**Figure SPM.4:** Global GHG emissions for 2000 and projected baseline emissions<sup>10</sup> for 2030 and 2100 from IPCC SRES and the post-SRES literature. The figure provides the emissions from the six illustrative SRES scenarios. It also provides the frequency distribution of the emissions in the post-SRES scenarios (5<sup>th</sup>, 25<sup>th</sup>, median, 75<sup>th</sup>, 95<sup>th</sup> percentile), as covered in Chapter 3. F-gases cover HFCs, PFCs and SF<sub>6</sub> [1.3, 3.2, Figure 1.7].

**4. Baseline emissions scenarios published since SRES<sup>10</sup>, are comparable in range to those presented in the IPCC Special Report on Emission Scenarios (SRES) (25- 135 GtCO<sub>2</sub>-eq/yr in 2100, see Figure SPM.4) (high agreement, much evidence).**

- Studies since SRES used lower values for some drivers for emissions, notably population projections. However, for those studies incorporating these new population projections, changes in other drivers, such as economic growth, resulted in little change in overall emission levels. Economic growth projections for Africa, Latin America and the Middle East to 2030 in post-SRES baseline scenarios are lower than in SRES, but this has only minor effects on global economic growth and overall emissions [3.2].

- Representation of aerosol and aerosol precursor emissions, including sulphur dioxide, black carbon, and organic carbon, which have a net cooling effect<sup>11</sup> has improved. Generally, they are projected to be lower than reported in SRES [3.2].
- Available studies indicate that the choice of exchange rate for GDP (MER or PPP) does not appreciably affect the projected emissions, when used consistently<sup>12</sup>. The differences, if any, are small compared to the uncertainties caused by assumptions on other parameters in the scenarios, e.g. technological change [3.2].

<sup>10</sup> Baseline scenarios do not include additional climate policy above current ones; more recent studies differ with respect to UNFCCC and Kyoto Protocol inclusion.

<sup>11</sup> See AR4 WG I report, Chapter 10.2.

<sup>12</sup> Since TAR, there has been a debate on the use of different exchange rates in emission scenarios. Two metrics are used to compare GDP between countries. Use of MER is preferable for analyses involving internationally traded products. Use of PPP, is preferable for analyses involving comparisons of income between countries at very different stages of development. Most of the monetary units in this report are expressed in MER. This reflects the large majority of emissions mitigation literature that is calibrated in MER. When monetary units are expressed in PPP, this is denoted by GDP<sub>PPP</sub>.

### Box SPM.1: The emission scenarios of the IPCC Special Report on Emission 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.

*This box summarizing the SRES scenarios is taken from the Third Assessment Report and has been subject to prior line by line approval by the Panel.*

### Box SPM.2: Mitigation potential and analytical approaches

The concept of “mitigation potential” has been developed to assess the scale of GHG reductions that could be made, relative to emission baselines, for a given level of carbon price (expressed in cost per unit of carbon dioxide equivalent emissions avoided or reduced). Mitigation potential is further differentiated in terms of “market potential” and “economic potential”.

**Market potential** is the mitigation potential based on private costs and private discount rates<sup>13</sup>, which might be expected to occur under forecast market conditions, including policies and measures currently in place, noting that barriers limit actual uptake [2.4].

<sup>13</sup> Private costs and discount rates reflect the perspective of private consumers and companies; see Glossary for a fuller description.

*(Box SPM.2 Continued)*

**Economic potential** is the mitigation potential, which takes into account social costs and benefits and social discount rates<sup>14</sup>, assuming that market efficiency is improved by policies and measures and barriers are removed [2.4].

Studies of market potential can be used to inform policy makers about mitigation potential with existing policies and barriers, while studies of economic potentials show what might be achieved if appropriate new and additional policies were put into place to remove barriers and include social costs and benefits. The economic potential is therefore generally greater than the market potential.

Mitigation potential is estimated using different types of approaches. There are two broad classes – “bottom-up” and “top-down” approaches, which primarily have been used to assess the economic potential.

**Bottom-up studies** are based on assessment of mitigation options, emphasizing specific technologies and regulations. They are typically sectoral studies taking the macro-economy as unchanged. Sector estimates have been aggregated, as in the TAR, to provide an estimate of global mitigation potential for this assessment.

**Top-down studies** assess the economy-wide potential of mitigation options. They use globally consistent frameworks and aggregated information about mitigation options and capture macro-economic and market feedbacks.

Bottom-up and top-down models have become more similar since the TAR as top-down models have incorporated more technological mitigation options and bottom-up models have incorporated more macroeconomic and market feedbacks as well as adopting barrier analysis into their model structures. Bottom-up studies in particular are useful for the assessment of specific policy options at sectoral level, e.g. options for improving energy efficiency, while top-down studies are useful for assessing cross-sectoral and economy-wide climate change policies, such as carbon taxes and stabilization policies. However, current bottom-up and top-down studies of economic potential have limitations in considering life-style choices, and in including all externalities such as local air pollution. They have limited representation of some regions, countries, sectors, gases, and barriers. The projected mitigation costs do not take into account potential benefits of avoided climate change.

### Box SPM.3: Assumptions in studies on mitigation portfolios and macro-economic costs

Studies on mitigation portfolios and macro-economic costs assessed in this report are based on top-down modelling. Most models use a global least cost approach to mitigation portfolios and with universal emissions trading, assuming transparent markets, no transaction cost, and thus perfect implementation of mitigation measures throughout the 21<sup>st</sup> century. Costs are given for a specific point in time.

Global modelled costs will increase if some regions, sectors (e.g. land-use), options or gases are excluded. Global modelled costs will decrease with lower baselines, use of revenues from carbon taxes and auctioned permits, and if induced technological learning is included. These models do not consider climate benefits and generally also co-benefits of mitigation measures, or equity issues.

### Box SPM.4: Modelling induced technological change

Relevant literature implies that policies and measures may induce technological change. Remarkable progress has been achieved in applying approaches based on induced technological change to stabilisation studies; however, conceptual issues remain. In the models that adopt these approaches, projected costs for a given stabilization level are reduced; the reductions are greater at lower stabilisation levels.

<sup>14</sup> Social costs and discount rates reflect the perspective of society. Social discount rates are lower than those used by private investors; see Glossary for a fuller description.



## C. Mitigation in the short and medium term (until 2030)

5. **Both bottom-up and top-down studies indicate that there is substantial economic potential for the mitigation of global GHG emissions over the coming decades, that could offset the projected growth of global emissions or reduce emissions below current levels (*high agreement, much evidence*).**

Uncertainties in the estimates are shown as ranges in the tables below to reflect the ranges of baselines, rates of technological change and other factors that are specific to the different approaches. Furthermore, uncertainties also arise from the limited information for global coverage of countries, sectors and gases.

### Bottom-up studies:

- In 2030, the economic potential estimated for this assessment from bottom-up approaches (see Box SPM.2) is presented in Table SPM.1 below and Figure SPM.5A. For reference: emissions in 2000 were equal to 43 GtCO<sub>2</sub>-eq. [11.3]:

- Studies suggest that mitigation opportunities with net negative costs<sup>15</sup> have the potential to reduce emissions by around 6 GtCO<sub>2</sub>-eq/yr in 2030. Realizing these requires dealing with implementation barriers [11.3].
- No one sector or technology can address the entire mitigation challenge. All assessed sectors contribute to the total (see Figure SPM.6). The key mitigation technologies and practices for the respective sectors are shown in Table SPM 3 [4.3, 4.4, 5.4, 6.5, 7.5, 8.4, 9.4, 10.4].

### Top-down studies:

- Top-down studies calculate an emission reduction for 2030 as presented in Table SPM.2 below and Figure SPM.5B. The global economic potentials found in the top-down studies are in line with bottom-up studies (see Box SPM.2), though there are considerable differences at the sectoral level [3.6].
- The estimates in Table SPM.2 were derived from stabilization scenarios, i.e., runs towards long-run stabilization of atmospheric GHG concentration [3.6].

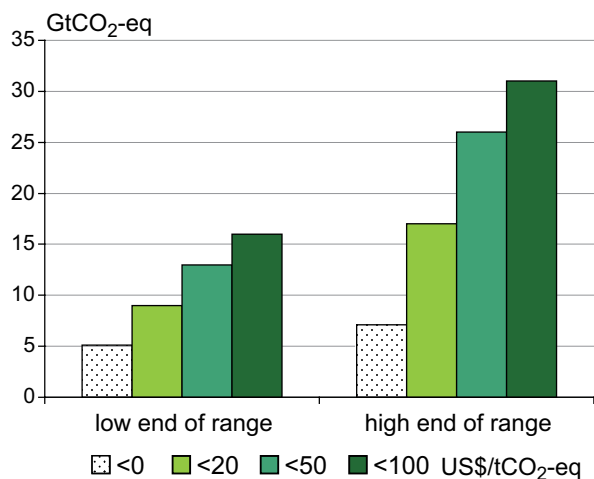
**Table SPM.1:** Global economic mitigation potential in 2030 estimated from bottom-up studies.

Carbon price (US\$/tCO <sub>2</sub> -eq)	Economic potential (GtCO <sub>2</sub> -eq/yr)	Reduction relative to SRES A1 B (68 GtCO <sub>2</sub> -eq/yr) (%)	Reduction relative to SRES B2 (49 GtCO <sub>2</sub> -eq/yr) (%)
0	5-7	7-10	10-14
20	9-17	14-25	19-35
50	13-26	20-38	27-52
100	16-31	23-46	32-63

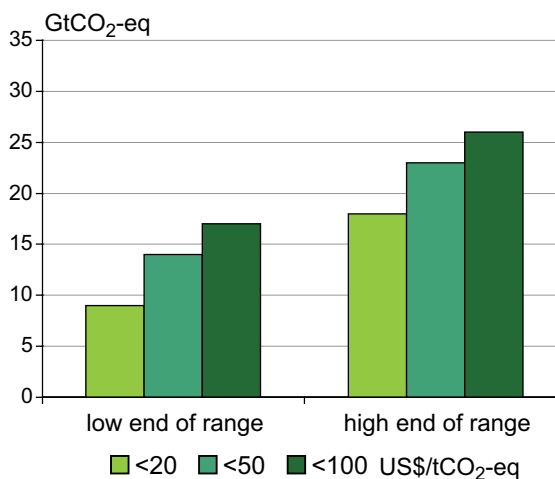
**Table SPM.2:** Global economic mitigation potential in 2030 estimated from top-down studies.

Carbon price (US\$/tCO <sub>2</sub> -eq)	Economic potential (GtCO <sub>2</sub> -eq/yr)	Reduction relative to SRES A1 B (68 GtCO <sub>2</sub> -eq/yr) (%)	Reduction relative to SRES B2 (49 GtCO <sub>2</sub> -eq/yr) (%)
20	9-18	13-27	18-37
50	14-23	21-34	29-47
100	17-26	25-38	35-53

15 In this report, as in the SAR and the TAR, options with net negative costs (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 (see Box SPM.1).



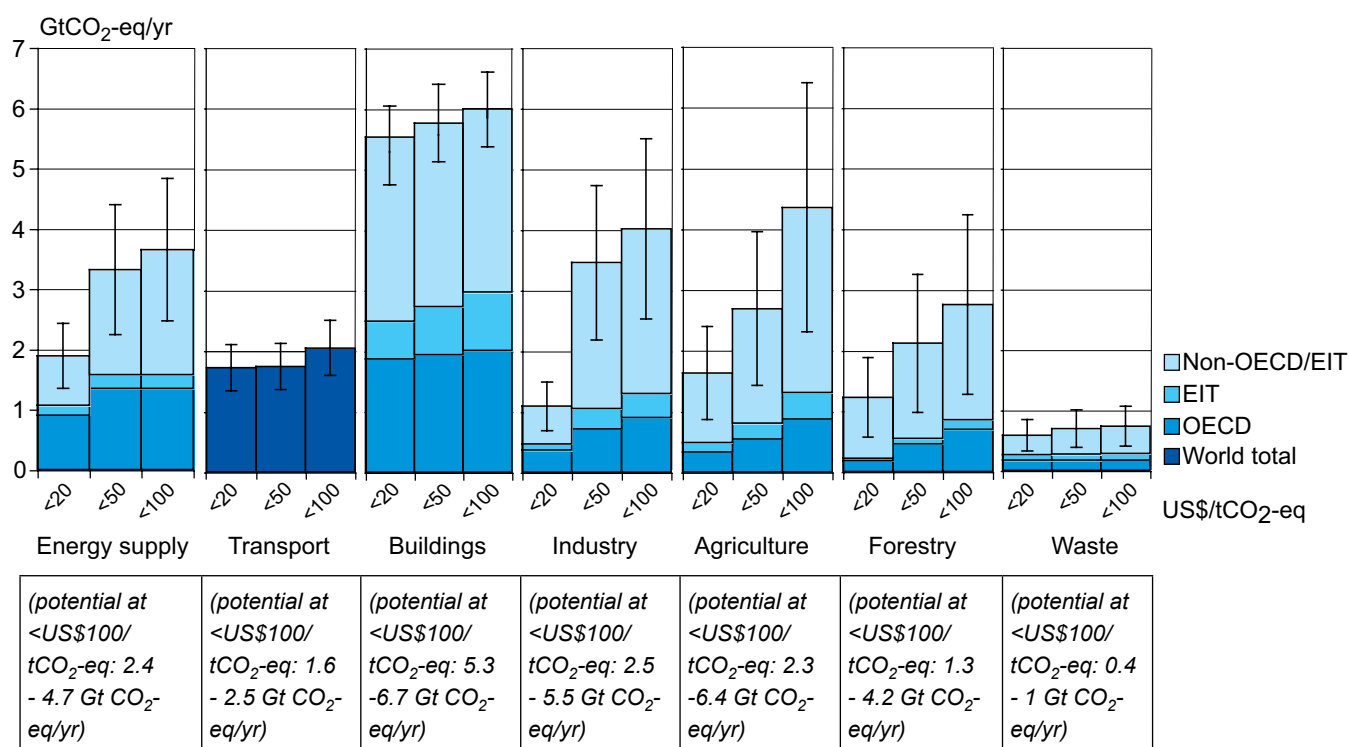
**Figure SPM.5A:** Global economic mitigation potential in 2030 estimated from bottom-up studies (data from Table SPM.1)



**Figure SPM.5B:** Global economic mitigation potential in 2030 estimated from top-down studies (data from Table SPM.2)

**Table SPM.3:** Key mitigation technologies and practices by sector. Sectors and technologies are listed in no particular order. Non-technological practices, such as lifestyle changes, which are cross-cutting, are not included in this table (but are addressed in paragraph 7 in this SPM).

Sector	Key mitigation technologies and practices currently commercially available	Key mitigation technologies and practices projected to be commercialized before 2030
Energy supply [4.3, 4.4]	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of Carbon Capture and Storage (CCS, e.g. storage of removed CO <sub>2</sub> from natural gas).	CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and waves energy, concentrating solar, and solar PV.
Transport [5.4]	More fuel efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning.	Second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries.
Buildings [6.5]	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycle of fluorinated gases.	Integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar PV integrated in buildings.
Industry [7.5]	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO <sub>2</sub> gas emissions; and a wide array of process-specific technologies.	Advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture.
Agriculture [8.4]	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH <sub>4</sub> emissions; improved nitrogen fertilizer application techniques to reduce N <sub>2</sub> O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency.	Improvements of crops yields.
Forestry/forests [9.4]	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use.	Tree species improvement to increase biomass productivity and carbon sequestration. Improved remote sensing technologies for analysis of vegetation/ soil carbon sequestration potential and mapping land use change.
Waste management [10.4]	Landfill methane recovery; waste incineration with energy recovery; composting of organic waste; controlled waste water treatment; recycling and waste minimization.	Biocovers and biofilters to optimize CH <sub>4</sub> oxidation.



**Figure SPM.6:** Estimated sectoral economic potential for global mitigation for different regions as a function of carbon price in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments. A full explanation of the derivation of this figure is found in Section 11.3.

Notes:

1. The ranges for global economic potentials as assessed in each sector are shown by vertical lines. The ranges are based on end-use allocations of emissions, meaning that emissions of electricity use are counted towards the end-use sectors and not to the energy supply sector.
2. The estimated potentials have been constrained by the availability of studies particularly at high carbon price levels.
3. Sectors used different baselines. For industry the SRES B2 baseline was taken, for energy supply and transport the WEO 2004 baseline was used; the building sector is based on a baseline in between SRES B2 and A1B; for waste, SRES A1B driving forces were used to construct a waste specific baseline, agriculture and forestry used baselines that mostly used B2 driving forces.
4. Only global totals for transport are shown because international aviation is included [5.4].
5. Categories excluded are: non-CO<sub>2</sub> emissions in buildings and transport, part of material efficiency options, heat production and cogeneration in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10-15%.

**6. In 2030 macro-economic costs for multi-gas mitigation, consistent with emissions trajectories towards stabilization between 445 and 710 ppm CO<sub>2</sub>-eq, are estimated at between a 3% decrease of global GDP and a small increase, compared to the baseline (see Table SPM.4). However, regional costs may differ significantly from global averages (high agreement, medium evidence) (see Box SPM.3 for the methodologies and assumptions of these results).**

- The majority of studies conclude that reduction of GDP relative to the GDP baseline increases with the stringency of the stabilization target.
- Depending on the existing tax system and spending of the revenues, modelling studies indicate that costs may be substantially lower under the assumption that revenues from carbon taxes or auctioned permits under an emission trading system are used to promote low-carbon technologies or reform of existing taxes [11.4].

- Studies that assume the possibility that climate change policy induces enhanced technological change also give lower costs. However, this may require higher upfront investment in order to achieve costs reductions thereafter (see Box SPM.4) [3.3, 3.4, 11.4, 11.5, 11.6].
- Although most models show GDP losses, some show GDP gains because they assume that baselines are non-optimal and mitigation policies improve market efficiencies, or they assume that more technological change may be induced by mitigation policies. Examples of market inefficiencies include unemployed resources, distortionary taxes and/or subsidies [3.3, 11.4].
- A multi-gas approach and inclusion of carbon sinks generally reduces costs substantially compared to CO<sub>2</sub> emission abatement only [3.3].
- Regional costs are largely dependent on the assumed stabilization level and baseline scenario. The allocation regime is also important, but for most countries to a lesser extent than the stabilization level [11.4, 13.3].

**Table SPM.4:** Estimated global macro-economic costs in 2030<sup>a)</sup> for least-cost trajectories towards different long-term stabilization levels.<sup>b), c)</sup>

Stabilization levels (ppm CO <sub>2</sub> -eq)	Median GDP reduction <sup>d)</sup> (%)	Range of GDP reduction <sup>d), e)</sup> (%)	Reduction of average annual GDP growth rates <sup>d), f)</sup> (percentage points)
590-710	0.2	-0.6-1.2	<0.06
535-590	0.6	0.2-2.5	<0.1
445-535 <sup>g)</sup>	not available	<3	<0.12

## Notes:

- a) For a given stabilization level, GDP reduction would increase over time in most models after 2030. Long-term costs also become more uncertain. [Figure 3.25]  
b) Results based on studies using various baselines.  
c) Studies vary in terms of the point in time stabilization is achieved; generally this is in 2100 or later.  
d) This is global GDP based market exchange rates.  
e) The median and the 10<sup>th</sup> and 90<sup>th</sup> percentile range of the analyzed data are given.  
f) The calculation of the reduction of the annual growth rate is based on the average reduction during the period till 2030 that would result in the indicated GDP decrease in 2030.  
g) The number of studies that report GDP results is relatively small and they generally use low baselines.

## 7. Changes in lifestyle and behaviour patterns can contribute to climate change mitigation across all sectors. Management practices can also have a positive role (*high agreement, medium evidence*).

- Lifestyle changes can reduce GHG emissions. Changes in lifestyles and consumption patterns that emphasize resource conservation can contribute to developing a low-carbon economy that is both equitable and sustainable [4.1, 6.7].
- Education and training programmes can help overcome barriers to the market acceptance of energy efficiency, particularly in combination with other measures [Table 6.6].
- Changes in occupant behaviour, cultural patterns and consumer choice and use of technologies can result in considerable reduction in CO<sub>2</sub> emissions related to energy use in buildings [6.7].
- Transport Demand Management, which includes urban planning (that can reduce the demand for travel) and provision of information and educational techniques (that can reduce car usage and lead to an efficient driving style) can support GHG mitigation [5.1].
- In industry, management tools that include staff training, reward systems, regular feedback, documentation of existing practices can help overcome industrial organization barriers, reduce energy use, and GHG emissions [7.3].

## 8. While studies use different methodologies, in all analyzed world regions near-term health co-benefits from reduced air pollution as a result of actions to reduce GHG emissions can be substantial and may offset a substantial fraction of mitigation costs (*high agreement, much evidence*).

- Including co-benefits other than health, such as increased energy security, and increased agricultural production and reduced pressure on natural ecosystems, due to decreased tropospheric ozone concentrations, would further enhance cost savings [11.8].
- Integrating air pollution abatement and climate change mitigation policies offers potentially large cost reductions compared to treating those policies in isolation [11.8].

## 9. Literature since TAR confirms that there may be effects from Annex I countries' action on the global economy and global emissions, although the scale of carbon leakage remains uncertain (*high agreement, medium evidence*).

- Fossil fuel exporting nations (in both Annex I and non-Annex I countries) may expect, as indicated in TAR<sup>16</sup>, lower demand and prices and lower GDP growth due to mitigation policies. The extent of this spill over<sup>17</sup> depends strongly on assumptions related to policy decisions and oil market conditions [11.7].
- Critical uncertainties remain in the assessment of carbon leakage<sup>18</sup>. Most equilibrium modelling support the conclusion in the TAR of economy-wide leakage from Kyoto action in the order of 5-20%, which would be less if competitive low-emissions technologies were effectively diffused [11.7].

## 10. New energy infrastructure investments in developing countries, upgrades of energy infrastructure in industrialized countries, and policies that promote energy security, can, in many cases, create opportunities to achieve GHG emission reductions<sup>19</sup> compared to baseline scenarios. Additional co-benefits are country-

<sup>16</sup> See TAR WG III (2001) SPM paragraph 16.

<sup>17</sup> Spill over effects of mitigation in a cross-sectoral perspective are the effects of mitigation policies and measures in one country or group of countries on sectors in other countries.

<sup>18</sup> Carbon leakage is defined as the increase in CO<sub>2</sub> emissions outside the countries taking domestic mitigation action divided by the reduction in the emissions of these countries.

<sup>19</sup> See table SPM.1 and Figure SPM.6

specific but often include air pollution abatement, balance of trade improvement, provision of modern energy services to rural areas and employment (*high agreement, much evidence*).

- Future energy infrastructure investment decisions, expected to total over 20 trillion US\$<sup>20</sup> between now and 2030, will have long term impacts on GHG emissions, because of the long life-times of energy plants and other infrastructure capital stock. The widespread diffusion of low-carbon technologies may take many decades, even if early investments in these technologies are made attractive. Initial estimates show that returning global energy-related CO<sub>2</sub> emissions to 2005 levels by 2030 would require a large shift in the pattern of investment, although the net additional investment required ranges from negligible to 5-10% [4.1, 4.4, 11.6].
- It is often more cost-effective to invest in end-use energy efficiency improvement than in increasing energy supply to satisfy demand for energy services. Efficiency improvement has a positive effect on energy security, local and regional air pollution abatement, and employment [4.2, 4.3, 6.5, 7.7, 11.3, 11.8].
- Renewable energy generally has a positive effect on energy security, employment and on air quality. Given costs relative to other supply options, renewable electricity, which accounted for 18% of the electricity supply in 2005, can have a 30-35% share of the total electricity supply in 2030 at carbon prices up to 50 US\$/tCO<sub>2</sub>-eq [4.3, 4.4, 11.3, 11.6, 11.8].
- The higher the market prices of fossil fuels, the more low-carbon alternatives will be competitive, although price volatility will be a disincentive for investors. Higher priced conventional oil resources, on the other hand, may be replaced by high carbon alternatives such as from oil sands, oil shales, heavy oils, and synthetic fuels from coal and gas, leading to increasing GHG emissions, unless production plants are equipped with CCS [4.2, 4.3, 4.4, 4.5].
- Given costs relative to other supply options, nuclear power, which accounted for 16% of the electricity supply in 2005, can have an 18% share of the total electricity supply in 2030 at carbon prices up to 50 US\$/tCO<sub>2</sub>-eq, but safety, weapons proliferation and waste remain as constraints [4.2, 4.3, 4.4]<sup>21</sup>.
- CCS in underground geological formations is a new technology with the potential to make an important contribution to mitigation by 2030. Technical, economic and regulatory developments will affect the actual contribution [4.3, 4.4, 7.3].

**11. There are multiple mitigation options in the transport sector<sup>19</sup>, but their effect may be counteracted by growth in the sector. Mitigation options are faced with many barriers, such as consumer preferences and lack of policy frameworks (*medium agreement, medium evidence*).**

- Improved vehicle efficiency measures, leading to fuel savings, in many cases have net benefits (at least for light-duty vehicles), but the market potential is much lower than the economic potential due to the influence of other consumer considerations, such as performance and size. There is not enough information to assess the mitigation potential for heavy-duty vehicles. Market forces alone, including rising fuel costs, are therefore not expected to lead to significant emission reductions [5.3, 5.4].
- Biofuels might play an important role in addressing GHG emissions in the transport sector, depending on their production pathway. Biofuels used as gasoline and diesel fuel additives/substitutes are projected to grow to 3% of total transport energy demand in the baseline in 2030. This could increase to about 5-10%, depending on future oil and carbon prices, improvements in vehicle efficiency and the success of technologies to utilise cellulose biomass [5.3, 5.4].
- Modal shifts from road to rail and to inland and coastal shipping and from low-occupancy to high-occupancy passenger transportation<sup>22</sup>, as well as land-use, urban planning and non-motorized transport offer opportunities for GHG mitigation, depending on local conditions and policies [5.3, 5.5].
- Medium term mitigation potential for CO<sub>2</sub> emissions from the aviation sector can come from improved fuel efficiency, which can be achieved through a variety of means, including technology, operations and air traffic management. However, such improvements are expected to only partially offset the growth of aviation emissions. Total mitigation potential in the sector would also need to account for non-CO<sub>2</sub> climate impacts of aviation emissions [5.3, 5.4].
- Realizing emissions reductions in the transport sector is often a co-benefit of addressing traffic congestion, air quality and energy security [5.5].

**12. Energy efficiency options<sup>19</sup> for new and existing buildings could considerably reduce CO<sub>2</sub> emissions with net economic benefit. Many barriers exist against tapping this potential, but there are also large co-benefits (*high agreement, much evidence*).**

- By 2030, about 30% of the projected GHG emissions in the building sector can be avoided with net economic benefit [6.4, 6.5].

<sup>20</sup> 20 trillion = 20000 billion= 20\*10<sup>12</sup>.

<sup>21</sup> Austria could not agree with this statement.

<sup>22</sup> Including rail, road and marine mass transit and carpooling.

- Energy efficient buildings, while limiting the growth of CO<sub>2</sub> emissions, can also improve indoor and outdoor air quality, improve social welfare and enhance energy security [6.6, 6.7].
  - Opportunities for realising GHG reductions in the building sector exist worldwide. However, multiple barriers make it difficult to realise this potential. These barriers include availability of technology, financing, poverty, higher costs of reliable information, limitations inherent in building designs and an appropriate portfolio of policies and programs [6.7, 6.8].
  - The magnitude of the above barriers is higher in the developing countries and this makes it more difficult for them to achieve the GHG reduction potential of the building sector [6.7].
- 13. The economic potential in the industrial sector<sup>19</sup> is predominantly located in energy intensive industries. Full use of available mitigation options is not being made in either industrialized or developing nations (high agreement, much evidence).**
- Many industrial facilities in developing countries are new and include the latest technology with the lowest specific emissions. However, many older, inefficient facilities remain in both industrialized and developing countries. Upgrading these facilities can deliver significant emission reductions [7.1, 7.3, 7.4].
  - The slow rate of capital stock turnover, lack of financial and technical resources, and limitations in the ability of firms, particularly small and medium-sized enterprises, to access and absorb technological information are key barriers to full use of available mitigation options [7.6].
- 14. Agricultural practices collectively can make a significant contribution at low cost<sup>19</sup> to increasing soil carbon sinks, to GHG emission reductions, and by contributing biomass feedstocks for energy use (medium agreement, medium evidence).**
- A large proportion of the mitigation potential of agriculture (excluding bioenergy) arises from soil carbon sequestration, which has strong synergies with sustainable agriculture and generally reduces vulnerability to climate change [8.4, 8.5, 8.8].
  - Stored soil carbon may be vulnerable to loss through both land management change and climate change [8.10].
  - Considerable mitigation potential is also available from reductions in methane and nitrous oxide emissions in some agricultural systems [8.4, 8.5].
- There is no universally applicable list of mitigation practices; practices need to be evaluated for individual agricultural systems and settings [8.4].
  - Biomass from agricultural residues and dedicated energy crops can be an important bioenergy feedstock, but its contribution to mitigation depends on demand for bioenergy from transport and energy supply, on water availability, and on requirements of land for food and fibre production. Widespread use of agricultural land for biomass production for energy may compete with other land uses and can have positive and negative environmental impacts and implications for food security [8.4, 8.8].
- 15. Forest-related mitigation activities can considerably reduce emissions from sources and increase CO<sub>2</sub> removals by sinks at low costs<sup>19</sup>, and can be designed to create synergies with adaptation and sustainable development (high agreement, much evidence)<sup>23</sup>.**
- About 65% of the total mitigation potential (up to 100 US\$/tCO<sub>2</sub>-eq) is located in the tropics and about 50% of the total could be achieved by reducing emissions from deforestation [9.4].
  - Climate change can affect the mitigation potential of the forest sector (i.e., native and planted forests) and is expected to be different for different regions and sub-regions, both in magnitude and direction [9.5].
  - Forest-related mitigation options can be designed and implemented to be compatible with adaptation, and can have substantial co-benefits in terms of employment, income generation, biodiversity and watershed conservation, renewable energy supply and poverty alleviation [9.5, 9.6, 9.7].
- 16. Post-consumer waste<sup>24</sup> is a small contributor to global GHG emissions<sup>25</sup> (<5%), but the waste sector can positively contribute to GHG mitigation at low cost<sup>19</sup> and promote sustainable development (high agreement, much evidence).**
- Existing waste management practices can provide effective mitigation of GHG emissions from this sector: a wide range of mature, environmentally effective technologies are commercially available to mitigate emissions and provide co-benefits for improved public health and safety, soil protection and pollution prevention, and local energy supply [10.3, 10.4, 10.5].
  - Waste minimization and recycling provide important indirect mitigation benefits through the conservation of energy and materials [10.4].

<sup>23</sup> Tuvalu noted difficulties with the reference to “low costs” as Chapter 9, page 15 of the WG III report states that: “the cost of forest mitigation projects rise significantly when opportunity costs of land are taken into account”.

<sup>24</sup> Industrial waste is covered in the industry sector.

<sup>25</sup> GHGs from waste include landfill and wastewater methane, wastewater N<sub>2</sub>O, and CO<sub>2</sub> from incineration of fossil carbon.

- Lack of local capital is a key constraint for waste and wastewater management in developing countries and countries with economies in transition. Lack of expertise on sustainable technology is also an important barrier [10.6].

**17. Geo-engineering options, such as ocean fertilization to remove CO<sub>2</sub> directly from the atmosphere, or blocking sunlight by bringing material into the upper atmosphere, remain largely speculative and unproven, and with the risk of unknown side-effects. Reliable cost estimates for these options have not been published (medium agreement, limited evidence) [11.2].**

## D. Mitigation in the long term (after 2030)

**18. In order to stabilize the concentration of GHGs in the atmosphere, emissions would need to peak and decline thereafter. The lower the stabilization level, the more quickly this peak and decline would need to occur. Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilization levels (see Table SPM.5, and Figure SPM. 8)<sup>26</sup> (high agreement, much evidence).**

- Recent studies using multi-gas reduction have explored lower stabilization levels than reported in TAR [3.3].
- Assessed studies contain a range of emissions profiles for achieving stabilization of GHG concentrations<sup>27</sup>. Most of these studies used a least cost approach and include both early and delayed emission reductions (Figure SPM.7) [Box SPM.2]. Table SPM.5 summarizes the required emissions levels for different groups of stabilization concentrations and the associated equilibrium global mean temperature increase<sup>28</sup>, using the ‘best estimate’ of climate sensitivity (see also Figure SPM.8 for the likely range of uncertainty)<sup>29</sup>. Stabilization at lower concentration and related equilibrium temperature levels advances the date when emissions need to peak, and requires greater emissions reductions by 2050 [3.3].

**Table SPM.5: Characteristics of post-TAR stabilization scenarios [Table TS 2, 3.10]<sup>a)</sup>**

Category	Radiative forcing (W/m <sup>2</sup> )	CO <sub>2</sub> concentration <sup>c)</sup> (ppm)	CO <sub>2</sub> -eq concentration <sup>c)</sup> (ppm)	Global mean temperature increase above pre-industrial at equilibrium, using “best estimate” climate sensitivity <sup>b), c)</sup> (°C)	Peaking year for CO <sub>2</sub> emissions <sup>d)</sup>	Change in global CO <sub>2</sub> emissions in 2050 (% of 2000 emissions) <sup>d)</sup>	No. of assessed scenarios
I	2.5-3.0	350-400	445-490	2.0-2.4	2000-2015	-85 to -50	6
II	3.0-3.5	400-440	490-535	2.4-2.8	2000-2020	-60 to -30	18
III	3.5-4.0	440-485	535-590	2.8-3.2	2010-2030	-30 to +5	21
IV	4.0-5.0	485-570	590-710	3.2-4.0	2020-2060	+10 to +60	118
V	5.0-6.0	570-660	710-855	4.0-4.9	2050-2080	+25 to +85	9
VI	6.0-7.5	660-790	855-1130	4.9-6.1	2060-2090	+90 to +140	5
Total							177

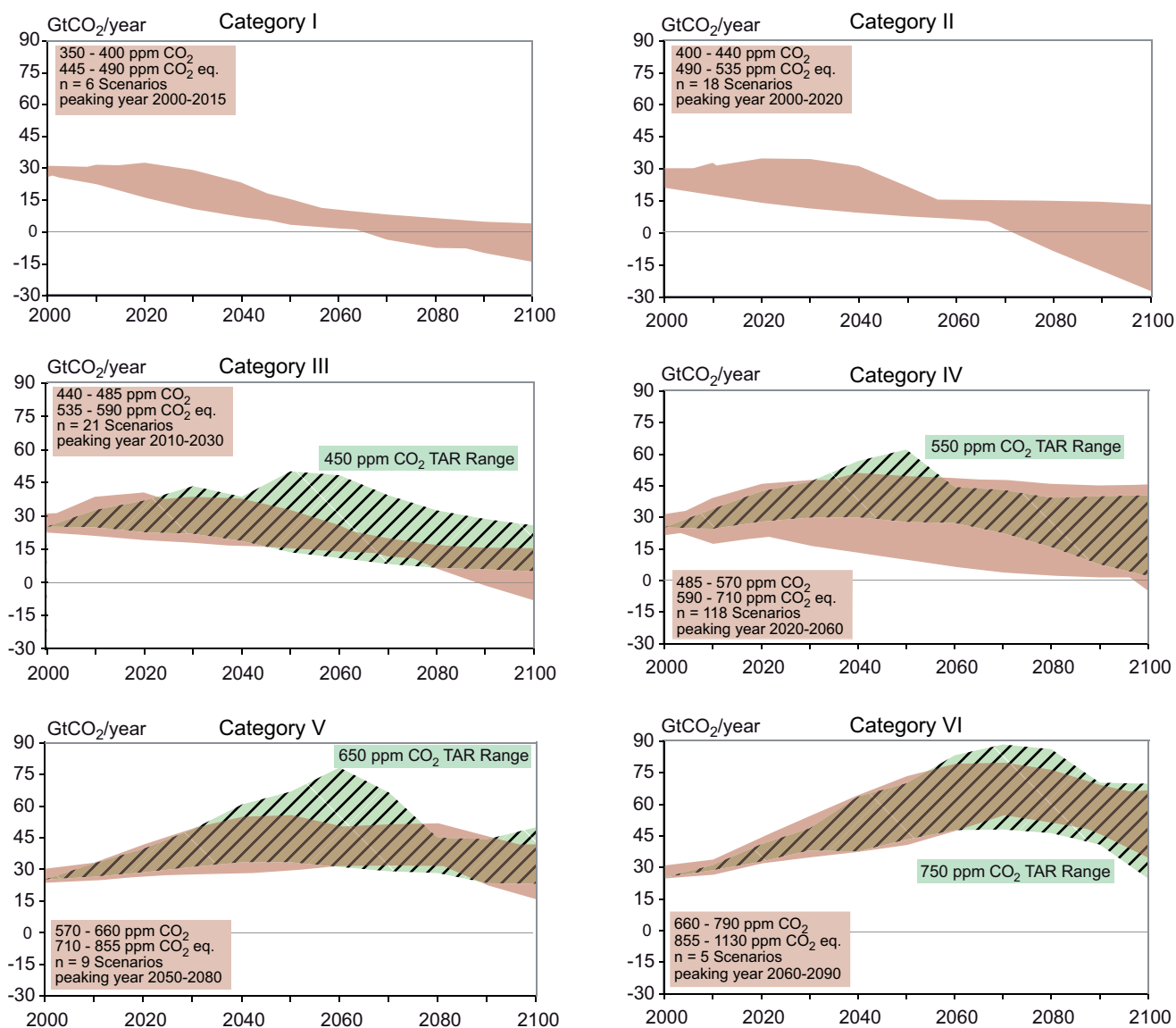
- a) The understanding of the climate system response to radiative forcing as well as feedbacks is assessed in detail in the AR4 WGI Report. Feedbacks between the carbon cycle and climate change affect the required mitigation for a particular stabilization level of atmospheric carbon dioxide concentration. These feedbacks are expected to increase the fraction of anthropogenic emissions that remains in the atmosphere as the climate system warms. Therefore, the emission reductions to meet a particular stabilization level reported in the mitigation studies assessed here might be underestimated.
- b) The best estimate of climate sensitivity is 3°C [WG 1 SPM].
- c) Note that global mean temperature at equilibrium is different from expected global mean temperature at the time of stabilization of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150.
- d) Ranges correspond to the 15<sup>th</sup> to 85<sup>th</sup> percentile of the post-TAR scenario distribution. CO<sub>2</sub> emissions are shown so multi-gas scenarios can be compared with CO<sub>2</sub>-only scenarios.

<sup>26</sup> Paragraph 2 addresses historical GHG emissions since pre-industrial times.

<sup>27</sup> Studies vary in terms of the point in time stabilization is achieved; generally this is around 2100 or later.

<sup>28</sup> The information on global mean temperature is taken from the AR4 WGI report, chapter 10.8. These temperatures are reached well after concentrations are stabilized.

<sup>29</sup> The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is not a projection but is defined as the global average surface warming following a doubling of carbon dioxide concentrations [AR4 WGI SPM].



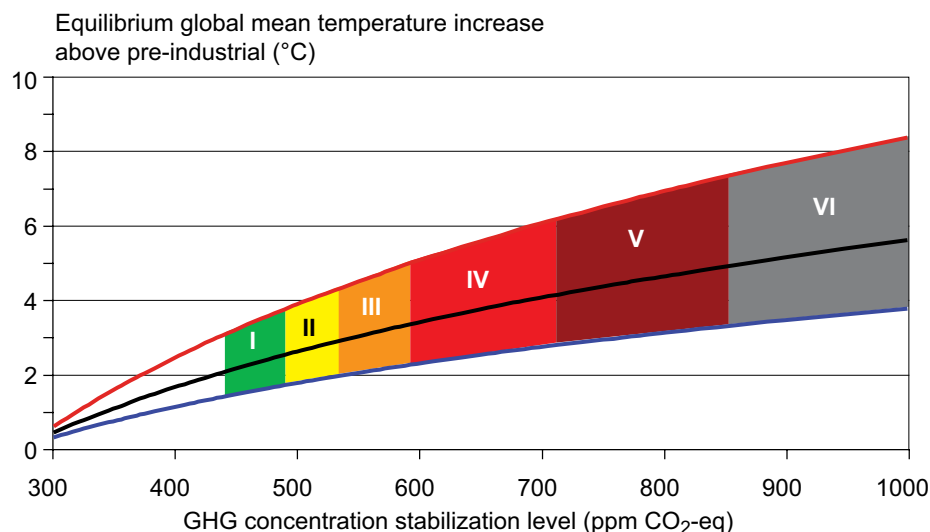
**Figure SPM.7:** Emissions pathways of mitigation scenarios for alternative categories of stabilization levels (Category I to VI as defined in the box in each panel). The pathways are for CO<sub>2</sub> emissions only. Light brown shaded areas give the CO<sub>2</sub> emissions for the post-TAR emissions scenarios. Green shaded and hatched areas depict the range of more than 80 TAR stabilization scenarios. Base year emissions may differ between models due to differences in sector and industry coverage. To reach the lower stabilization levels some scenarios deploy removal of CO<sub>2</sub> from the atmosphere (negative emissions) using technologies such as biomass energy production utilizing carbon capture and storage. [Figure 3.17]

**19. The range of stabilization levels assessed can be achieved by deployment of a portfolio of technologies that are currently available and those that are expected to be commercialised in coming decades. This assumes that appropriate and effective incentives are in place for development, acquisition, deployment and diffusion of technologies and for addressing related barriers (*high agreement, much evidence*).**

- The contribution of different technologies to emission reductions required for stabilization will vary over time, region and stabilization level.
  - o Energy efficiency plays a key role across many scenarios for most regions and timescales.

- o For lower stabilization levels, scenarios put more emphasis on the use of low-carbon energy sources, such as renewable energy and nuclear power, and the use of CO<sub>2</sub> capture and storage (CCS). In these scenarios improvements of carbon intensity of energy supply and the whole economy need to be much faster than in the past.
- o Including non-CO<sub>2</sub> and CO<sub>2</sub> land-use and forestry mitigation options provides greater flexibility and cost-effectiveness for achieving stabilization. Modern bioenergy could contribute substantially to the share of renewable energy in the mitigation portfolio.

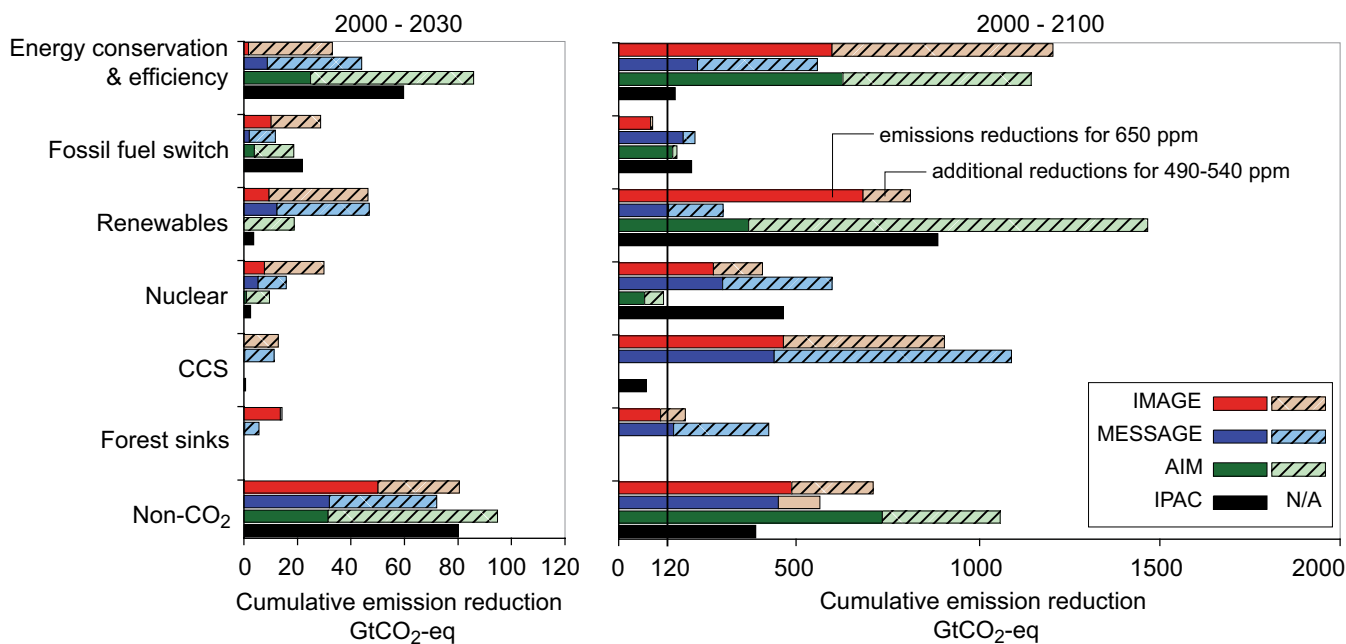




**Figure SPM.8:** Stabilization scenario categories as reported in Figure SPM.7 (coloured bands) and their relationship to equilibrium global mean temperature change above pre-industrial, using (i) “best estimate” climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of likely range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of likely range of climate sensitivity of 2°C (blue line at bottom of shaded area). Coloured shading shows the concentration bands for stabilization of greenhouse gases in the atmosphere corresponding to the stabilization scenario categories I to VI as indicated in Figure SPM.7. The data are drawn from AR4 WGI, Chapter 10.8.

- o For illustrative examples of portfolios of mitigation options, see figure SPM.9 [3.3, 3.4].
- Investments in and world-wide deployment of low-GHG emission technologies as well as technology improvements through public and private Research,

Development & Demonstration (RD&D) would be required for achieving stabilization targets as well as cost reduction. The lower the stabilization levels, especially those of 550 ppm CO<sub>2</sub>-eq or lower, the greater the need for more efficient RD&D efforts and investment in new



**Figure SPM.9:** Cumulative emissions reductions for alternative mitigation measures for 2000 to 2030 (left-hand panel) and for 2000-2100 (right-hand panel). The figure shows illustrative scenarios from four models (AIM, IMAGE, IPAC and MESSAGE) aiming at the stabilization at 490-540 ppm CO<sub>2</sub>-eq and levels of 650 ppm CO<sub>2</sub>-eq, respectively. Dark bars denote reductions for a target of 650 ppm CO<sub>2</sub>-eq and light bars the additional reductions to achieve 490-540 ppm CO<sub>2</sub>-eq. Note that some models do not consider mitigation through forest sink enhancement (AIM and IPAC) or CCS (AIM) and that the share of low-carbon energy options in total energy supply is also determined by inclusion of these options in the baseline. CCS includes carbon capture and storage from biomass. Forest sinks include reducing emissions from deforestation. [Figure 3.23]

technologies during the next few decades. This requires that barriers to development, acquisition, deployment and diffusion of technologies are effectively addressed.

- Appropriate incentives could address these barriers and help realize the goals across a wide portfolio of technologies. [2.7, 3.3, 3.4, 3.6, 4.3, 4.4, 4.6].

**20. In 2050<sup>30</sup> global average macro-economic costs for multi-gas mitigation towards stabilization between 710 and 445 ppm CO<sub>2</sub>-eq, are between a 1% gain to a 5.5% decrease of global GDP (see Table SPM.6). For specific countries and sectors, costs vary considerably from the global average. (See Box SPM.3 and SPM.4 for the methodologies and assumptions and paragraph 5 for explanation of negative costs) (*high agreement, medium evidence*).**

**21. Decision-making about the appropriate level of global mitigation over time involves an iterative risk management process that includes mitigation and adaptation, taking into account actual and avoided climate change damages, co-benefits, sustainability, equity, and attitudes to risk. Choices about the scale and timing of GHG mitigation involve balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay [*high agreement, much evidence*].**

- Limited and early analytical results from integrated analyses of the costs and benefits of mitigation indicate that these are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilization level where benefits exceed costs [3.5].

- Integrated assessment of the economic costs and benefits of different mitigation pathways shows that the economically optimal timing and level of mitigation depends upon the uncertain shape and character of the assumed climate change damage cost curve. To illustrate this dependency:

- o if the climate change damage cost curve grows slowly and regularly, and there is good foresight (which increases the potential for timely adaptation), later and less stringent mitigation is economically justified;
- o alternatively if the damage cost curve increases steeply, or contains non-linearities (e.g. vulnerability thresholds or even small probabilities of catastrophic events), earlier and more stringent mitigation is economically justified [3.6].

- Climate sensitivity is a key uncertainty for mitigation scenarios that aim to meet a specific temperature level. Studies show that if climate sensitivity is high then the timing and level of mitigation is earlier and more stringent than when it is low [3.5, 3.6].
- Delayed emission reductions lead to investments that lock in more emission-intensive infrastructure and development pathways. This significantly constrains the opportunities to achieve lower stabilization levels (as shown in Table SPM.5) and increases the risk of more severe climate change impacts [3.4, 3.1, 3.5, 3.6]

**Table SPM.6:** Estimated global macro-economic costs in 2050 relative to the baseline for least-cost trajectories towards different long-term stabilization targets<sup>a)</sup> [3.3, 13.3]

Stabilization levels (ppm CO <sub>2</sub> -eq)	Median GDP reduction <sup>b)</sup> (%)	Range of GDP reduction <sup>b), c)</sup> (%)	Reduction of average annual GDP growth rates <sup>b), d)</sup> (percentage points)
590-710	0.5	-1 - 2	<0.05
535-590	1.3	slightly negative - 4	<0.1
445-535 <sup>e)</sup>	not available	<5.5	<0.12

Notes:

a) This corresponds to the full literature across all baselines and mitigation scenarios that provide GDP numbers.

b) This is global GDP based market exchange rates.

c) The median and the 10<sup>th</sup> and 90<sup>th</sup> percentile range of the analyzed data are given.

d) The calculation of the reduction of the annual growth rate is based on the average reduction during the period until 2050 that would result in the indicated GDP decrease in 2050.

e) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.

<sup>30</sup> Cost estimates for 2030 are presented in paragraph 5.

## E. Policies, measures and instruments to mitigate climate change

### 22. A wide variety of national policies and instruments are available to governments to create the incentives for mitigation action. Their applicability depends on national circumstances and an understanding of their interactions, but experience from implementation in various countries and sectors shows there are advantages and disadvantages for any given instrument (*high agreement, much evidence*).

- Four main criteria are used to evaluate policies and instruments: environmental effectiveness, cost effectiveness, distributional effects, including equity, and institutional feasibility [13.2].
- All instruments can be designed well or poorly, and be stringent or lax. In addition, monitoring to improve implementation is an important issue for all instruments. General findings about the performance of policies are: [7.9, 12.2, 13.2]
  - o *Integrating climate policies in broader development policies* makes implementation and overcoming barriers easier.
  - o *Regulations and standards* generally provide some certainty about emission levels. They may be preferable to other instruments when information or other barriers prevent producers and consumers from responding to price signals. However, they may not induce innovations and more advanced technologies.
  - o *Taxes and charges* can set a price for carbon, but cannot guarantee a particular level of emissions. Literature identifies taxes as an efficient way of internalizing costs of GHG emissions.
  - o *Tradable permits* will establish a carbon price. The volume of allowed emissions determines their environmental effectiveness, while the allocation of permits has distributional consequences. Fluctuation in the price of carbon makes it difficult to estimate the total cost of complying with emission permits.
  - o *Financial incentives* (subsidies and tax credits) are frequently used by governments to stimulate the development and diffusion of new technologies. While economic costs are generally higher than for the instruments listed above, they are often critical to overcome barriers.
  - o *Voluntary agreements* between industry and governments are politically attractive, raise awareness among stakeholders, and have played a role in the evolution of many national policies. The majority of agreements has not achieved significant emissions reductions beyond business as usual. However, some recent agreements, in a few countries, have accelerated the application of best available technology and led to measurable emission reductions.

- o *Information instruments* (e.g. awareness campaigns) may positively affect environmental quality by promoting informed choices and possibly contributing to behavioural change, however, their impact on emissions has not been measured yet.
- o *RD&D* can stimulate technological advances, reduce costs, and enable progress toward stabilization.
- Some corporations, local and regional authorities, NGOs and civil groups are adopting a wide variety of voluntary actions. These voluntary actions may limit GHG emissions, stimulate innovative policies, and encourage the deployment of new technologies. On their own, they generally have limited impact on the national or regional level emissions [13.4].
- Lessons learned from specific sector application of national policies and instruments are shown in Table SPM.7.

### 23. Policies that provide a real or implicit price of carbon could create incentives for producers and consumers to significantly invest in low-GHG products, technologies and processes. Such policies could include economic instruments, government funding and regulation (*high agreement, much evidence*).

- An effective carbon-price signal could realize significant mitigation potential in all sectors [11.3, 13.2].
- Modelling studies, consistent with stabilization at around 550 ppm CO<sub>2</sub>-eq by 2100 (see Box SPM.3), show carbon prices rising to 20 to 80 US\$/tCO<sub>2</sub>-eq by 2030 and 30 to 155 US\$/tCO<sub>2</sub>-eq by 2050. For the same stabilization level, studies since TAR that take into account induced technological change lower these price ranges to 5 to 65 US\$/tCO<sub>2</sub>-eq in 2030 and 15 to 130 US\$/tCO<sub>2</sub>-eq in 2050 [3.3, 11.4, 11.5].
- Most top-down, as well as some 2050 bottom-up assessments, suggest that real or implicit carbon prices of 20 to 50 US\$/tCO<sub>2</sub>-eq, sustained or increased over decades, could lead to a power generation sector with low-GHG emissions by 2050 and make many mitigation options in the end-use sectors economically attractive. [4.4, 11.6]
- Barriers to the implementation of mitigation options are manifold and vary by country and sector. They can be related to financial, technological, institutional, informational and behavioural aspects [4.5, 5.5, 6.7, 7.6, 8.6, 9.6, 10.5].

**Table SPM.7:** Selected sectoral policies, measures and instruments that have shown to be environmentally effective in the respective sector in at least a number of national cases.

Sector	Policies <sup>a)</sup> , measures and instruments shown to be environmentally effective	Key constraints or opportunities
Energy supply [4.5]	Reduction of fossil fuel subsidies Taxes or carbon charges on fossil fuels	Resistance by vested interests may make them difficult to implement
	Feed-in tariffs for renewable energy technologies Renewable energy obligations Producer subsidies	May be appropriate to create markets for low emissions technologies
Transport [5.5]	Mandatory fuel economy, biofuel blending and CO <sub>2</sub> standards for road transport	Partial coverage of vehicle fleet may limit effectiveness
	Taxes on vehicle purchase, registration, use and motor fuels, road and parking pricing	Effectiveness may drop with higher incomes
	Influence mobility needs through land use regulations, and infrastructure planning Investment in attractive public transport facilities and non-motorised forms of transport	Particularly appropriate for countries that are building up their transportation systems
Buildings [6.8]	Appliance standards and labelling	Periodic revision of standards needed
	Building codes and certification	Attractive for new buildings. Enforcement can be difficult
	Demand-side management programmes Public sector leadership programmes, including procurement	Need for regulations so that utilities may profit Government purchasing can expand demand for energy-efficient products
	Incentives for energy service companies (ESCOs)	Success factor: Access to third party financing
Industry [7.9]	Provision of benchmark information Performance standards Subsidies, tax credits	May be appropriate to stimulate technology uptake. Stability of national policy important in view of international competitiveness
	Tradable permits	Predictable allocation mechanisms and stable price signals important for investments
	Voluntary agreements	Success factors include: clear targets, a baseline scenario, third party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry
Agriculture [8.6, 8.7, 8.8]	Financial incentives and regulations for improved land management, maintaining soil carbon content, efficient use of fertilizers and irrigation	May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation
Forestry/ forests [9.6]	Financial incentives (national and international) to increase forest area, to reduce deforestation, and to maintain and manage forests	Constraints include lack of investment capital and land tenure issues. Can help poverty alleviation
	Land use regulation and enforcement	
Waste management [10.5]	Financial incentives for improved waste and wastewater management	May stimulate technology diffusion
	Renewable energy incentives or obligations	Local availability of low-cost fuel
	Waste management regulations	Most effectively applied at national level with enforcement strategies

Note:

a) Public RD &amp; D investment in low emissions technologies have proven to be effective in all sectors

**24. Government support through financial contributions, tax credits, standard setting and market creation is important for effective technology development, innovation and deployment. Transfer of technology to developing countries depends on enabling conditions and financing (high agreement, much evidence).**

- Public benefits of RD&D investments are bigger than

the benefits captured by the private sector, justifying government support of RD&D.

- Government funding in real absolute terms for most energy research programmes has been flat or declining for nearly two decades (even after the UNFCCC came into force) and is now about half of the 1980 level [2.7, 3.4, 4.5, 11.5, 13.2].

- Governments have a crucial supportive role in providing appropriate enabling environment, such as, institutional, policy, legal and regulatory frameworks<sup>31</sup>, to sustain investment flows and for effective technology transfer – without which it may be difficult to achieve emission reductions at a significant scale. Mobilizing financing of incremental costs of low-carbon technologies is important. International technology agreements could strengthen the knowledge infrastructure [13.3].
- The potential beneficial effect of technology transfer to developing countries brought about by Annex I countries action may be substantial, but no reliable estimates are available [11.7].
- Financial flows to developing countries through Clean Development Mechanism (CDM) projects have the potential to reach levels of the order of several billions US\$ per year<sup>32</sup>, which is higher than the flows through the Global Environment Facility (GEF), comparable to the energy oriented development assistance flows, but at least an order of magnitude lower than total foreign direct investment flows. The financial flows through CDM, GEF and development assistance for technology transfer have so far been limited and geographically unequally distributed [12.3, 13.3].

**25. Notable achievements of the UNFCCC and its Kyoto Protocol are the establishment of a global response to the climate problem, stimulation of an array of national policies, the creation of an international carbon market and the establishment of new institutional mechanisms that may provide the foundation for future mitigation efforts (*high agreement, much evidence*).**

- The impact of the Protocol's first commitment period relative to global emissions is projected to be limited. Its economic impacts on participating Annex-B countries are projected to be smaller than presented in TAR, that showed 0.2-2% lower GDP in 2012 without emissions trading, and 0.1-1.1% lower GDP with emissions trading among Annex-B countries [1.4, 11.4, 13.3].

**26. The literature identifies many options for achieving reductions of global GHG emissions at the international level through cooperation. It also suggests that successful agreements are environmentally effective, cost-effective, incorporate distributional considerations and equity, and are institutionally feasible (*high agreement, much evidence*).**

- Greater cooperative efforts to reduce emissions will help to reduce global costs for achieving a given level of mitigation, or will improve environmental effectiveness [13.3].
- Improving, and expanding the scope of, market mechanisms (such as emission trading, Joint

Implementation and CDM) could reduce overall mitigation costs [13.3].

- Efforts to address climate change can include diverse elements such as emissions targets; sectoral, local, sub-national and regional actions; RD&D programmes; adopting common policies; implementing development oriented actions; or expanding financing instruments. These elements can be implemented in an integrated fashion, but comparing the efforts made by different countries quantitatively would be complex and resource intensive [13.3].
- Actions that could be taken by participating countries can be differentiated both in terms of when such action is undertaken, who participates and what the action will be. Actions can be binding or non-binding, include fixed or dynamic targets, and participation can be static or vary over time [13.3].

## F. Sustainable development and climate change mitigation

**27. Making development more sustainable by changing development paths can make a major contribution to climate change mitigation, but implementation may require resources to overcome multiple barriers. There is a growing understanding of the possibilities to choose and implement mitigation options in several sectors to realize synergies and avoid conflicts with other dimensions of sustainable development (*high agreement, much evidence*).**

- Irrespective of the scale of mitigation measures, adaptation measures are necessary [1.2].
- Addressing climate change can be considered an integral element of sustainable development policies. National circumstances and the strengths of institutions determine how development policies impact GHG emissions. Changes in development paths emerge from the interactions of public and private decision processes involving government, business and civil society, many of which are not traditionally considered as climate policy. This process is most effective when actors participate equitably and decentralized decision making processes are coordinated [2.2, 3.3, 12.2].
- Climate change and other sustainable development policies are often but not always synergistic. There is growing evidence that decisions about macroeconomic policy, agricultural policy, multilateral development bank lending, insurance practices, electricity market reform, energy security and forest conservation, for example, which are often treated as being apart from

<sup>31</sup> See the IPCC Special Report on Methodological and Technological Issues in Technology Transfer.

<sup>32</sup> Depends strongly on the market price that has fluctuated between 4 and 26 US\$/tCO<sub>2</sub>-eq and based on approximately 1000 CDM proposed plus registered projects likely to generate more than 1.3 billion emission reduction credits before 2012.

climate policy, can significantly reduce emissions. On the other hand, decisions about improving rural access to modern energy sources for example may not have much influence on global GHG emissions [12.2].

- Climate change policies related to energy efficiency and renewable energy are often economically beneficial, improve energy security and reduce local pollutant emissions. Other energy supply mitigation options can be designed to also achieve sustainable development benefits such as avoided displacement of local populations, job creation, and health benefits [4.5,12.3].
- Reducing both loss of natural habitat and deforestation can have significant biodiversity, soil and water conservation benefits, and can be implemented in a socially and economically sustainable manner. Forestation and bioenergy plantations can lead to restoration of degraded land, manage water runoff, retain soil carbon and benefit rural economies, but could compete with land for food production and may be negative for biodiversity, if not properly designed [9.7, 12.3].
- There are also good possibilities for reinforcing sustainable development through mitigation actions in the waste management, transportation and buildings sectors [5.4, 6.6, 10.5, 12.3].
- Making development more sustainable can enhance both mitigative and adaptive capacity, and reduce emissions and vulnerability to climate change. Synergies between mitigation and adaptation can exist, for example properly designed biomass production, formation of protected areas, land management, energy use in buildings and forestry. In other situations, there may be trade-offs, such as increased GHG emissions due to increased consumption of energy related to adaptive responses [2.5, 3.5, 4.5, 6.9, 7.8, 8.5, 9.5, 11.9, 12.1].

## G. Gaps in knowledge

- 28. There are still relevant gaps in currently available knowledge regarding some aspects of mitigation of climate change, especially in developing countries. Additional research addressing those gaps would further reduce uncertainties and thus facilitate decision-making related to mitigation of climate change [TS.14].**



### Endbox 1: Uncertainty representation

Uncertainty is an inherent feature of any assessment. The fourth assessment report clarifies the uncertainties associated with essential statements.

Fundamental differences between the underlying disciplinary sciences of the three Working Group reports make a common approach impractical. The “likelihood” approach applied in “Climate change 2007, the physical science basis” and the “confidence” and “likelihood” approaches used in “Climate change 2007, impacts, adaptation, and vulnerability” were judged to be inadequate to deal with the specific uncertainties involved in this mitigation report, as here human choices are considered.

In this report a two-dimensional scale is used for the treatment of uncertainty. The scale is based on the expert judgment of the authors of WGIII on the level of concurrence in the literature on a particular finding (level of agreement), and the number and quality of independent sources qualifying under the IPCC rules upon which the finding is based (amount of evidence<sup>33</sup>) (see Table SPM.E.1). This is not a quantitative approach, from which probabilities relating to uncertainty can be derived.

**Table SPM.E.1:** *Qualitative definition of uncertainty*

 Level of agreement (on a particular finding)	<b>High agreement,            limited evidence</b>	<b>High agreement,            medium evidence</b>	<b>High agreement,            much evidence</b>
	<b>Medium agreement,            limited evidence</b>	<b>Medium agreement,            medium evidence</b>	<b>Medium agreement,            much evidence</b>
	<b>Low agreement,            limited evidence</b>	<b>Low agreement,            medium evidence</b>	<b>Low agreement,            much evidence</b>
	Amount of evidence <sup>33</sup> (number and quality of independent sources) 		

Because the future is inherently uncertain, scenarios i.e. internally consistent images of different futures - not predictions of the future - have been used extensively in this report.

<sup>33</sup> “Evidence” in this report is defined as: Information or signs indicating whether a belief or proposition is true or valid. See Glossary.

**Contribution of Working Group III to the  
Fourth Assessment Report of the  
Intergovernmental Panel on Climate Change**

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## **Technical Summary**

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**Authors:**

Terry Barker (UK), Igor Bashmakov (Russia), Lenny Bernstein (USA), Jean E. Bogner (USA), Peter Bosch (The Netherlands), Rutu Dave (The Netherlands), Ogunlade Davidson (Sierra Leone), Brian S. Fisher (Australia), Sujata Gupta (India), Kirsten Halsnæs (Denmark), BertJan Heij (The Netherlands), Suzana Kahn Ribeiro (Brazil), Shigeki Kobayashi (Japan), Mark D. Levine (USA), Daniel L. Martino (Uruguay), Omar Masera (Mexico), Bert Metz (The Netherlands), Leo Meyer (The Netherlands), Gert-Jan Nabuurs (The Netherlands), Adil Najam (Pakistan), Nebojsa Nakicenovic (Austria/Montenegro), Hans-Holger Rogner (Germany), Joyashree Roy (India), Jayant Sathaye (USA), Robert Schock (USA), Priyadarshi Shukla (India), Ralph E. H. Sims (New Zealand), Pete Smith (UK), Dennis A. Tirpak (USA), Diana Urge-Vorsatz (Hungary), Dadi Zhou (PR China)

**Review Editor:**

Mukiri wa Githendu (Kenya)

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## 1 Introduction

### Structure of the report, the rationale behind it, the role of cross-cutting themes and framing issues

The main aim of this report is to assess options for mitigating climate change. Several aspects link climate change with development issues. This report explores these links in detail, and illustrates where climate change and sustainable development are mutually reinforcing.

Economic development needs, resource endowments and mitigative and adaptive capacities differ across regions. There is no one-size-fits-all approach to the climate change problem, and solutions need to be regionally differentiated to reflect different socio-economic conditions and, to a lesser extent, geographical differences. Although this report has a global focus, an attempt is made to differentiate the assessment of scientific and technical findings for the various regions.

Given that mitigation options vary significantly between economic sectors, it was decided to use the economic sectors to organize the material on short- to medium-term mitigation options. Contrary to what was done in the Third Assessment Report, all relevant aspects of sectoral mitigation options, such as technology, cost, policies etc., are discussed together, to provide the user with a comprehensive discussion of the sectoral mitigation options.

Consequently, the report has four parts. Part A (Chapters 1 and 2) includes the introduction and sets out the frameworks to describe mitigation of climate change in the context of other policies and decision-making. It introduces important concepts (e.g., risk and uncertainty, mitigation and adaptation relationships, distributional and equity aspects and regional integration) and defines important terms used throughout the report. Part B (Chapter 3) assesses long-term stabilization targets, how to get there and what the associated costs are, by examining mitigation scenarios for ranges of stability targets. The relation between adaptation, mitigation and climate change damage avoided is also discussed, in the light of decision-making regarding stabilization (Art. 2 UNFCCC). Part C (Chapters 4–10) focuses on the detailed description of the various sectors responsible for greenhouse gas (GHG) emissions, the short- to medium-term mitigation options and costs in these sectors, the policies for achieving mitigation, the barriers to getting there and the relationship with adaptation and other policies that affect GHG emissions. Part D (Chapters 11–13) assesses cross-sectoral issues, sustainable development and national and international aspects. Chapter 11 covers the aggregated mitigation potential, macro-economic impacts, technology development and transfer, synergies, and trade-offs with other policies and cross-border influences (or spill-over effects). Chapter 12 links climate mitigation with sustainable development. Chapter 13 assesses domestic climate policies and various forms of international cooperation. This Technical Summary has an additional Chapter 14, which deals with gaps in knowledge.

### Past, present and future: emission trends

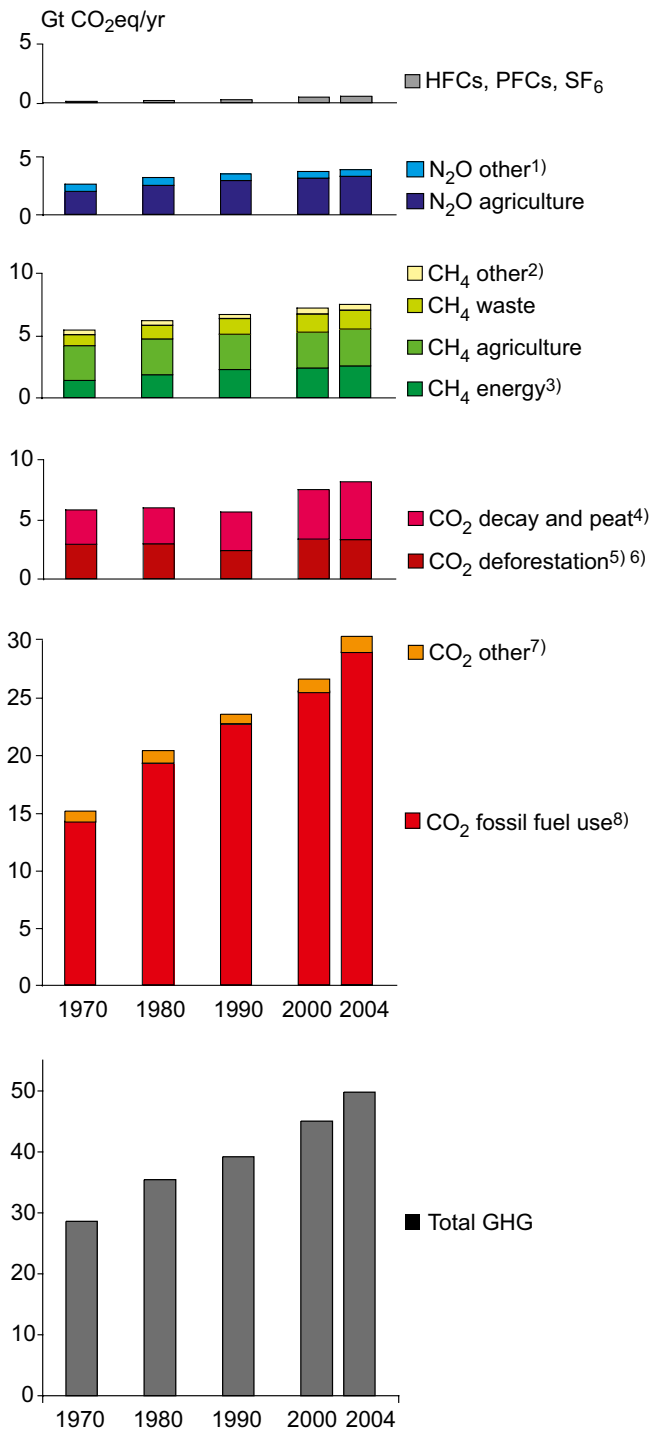
Emissions of the GHGs covered by the Kyoto Protocol increased by about 70% (from 28.7 to 49.0 GtCO<sub>2</sub>-eq) from 1970–2004 (by 24% from 1990–2004), with carbon dioxide (CO<sub>2</sub>) being the largest source, having grown by about 80% (see Figure TS.1). The largest growth in CO<sub>2</sub> emissions has come from power generation and road transport. Methane (CH<sub>4</sub>) emissions rose by about 40% from 1970, with an 85% increase from the combustion and use of fossil fuels. Agriculture, however, is the largest source of CH<sub>4</sub> emissions. Nitrous oxide (N<sub>2</sub>O) emissions grew by about 50%, due mainly to increased use of fertilizer and the growth of agriculture. Industrial emission of N<sub>2</sub>O fell during this period (*high agreement, much evidence*) [1.3].

Emissions of ozone-depleting substances (ODS) controlled under the Montreal Protocol (which includes GHGs chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs)), increased from a low level in 1970 to about 7.5 GtCO<sub>2</sub>-eq in 1990 (about 20% of total GHG emissions, not shown in the Figure TS.1), but then decreased to about 1.5 GtCO<sub>2</sub>-eq in 2004, and are projected to decrease further due to the phase-out of CFCs in developing countries. Emissions of the fluorinated gases (F-gases) (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and SF<sub>6</sub>) controlled under the Kyoto Protocol grew rapidly (primarily HFCs) during the 1990s as they replaced ODS to a substantial extent and were estimated at about 0.5 GtCO<sub>2</sub>-eq in 2004 (about 1.1% of total emissions on a 100-year global warming potential (GWP) basis) (*high agreement, much evidence*) [1.3].

Atmospheric CO<sub>2</sub> concentrations have increased by almost 100 ppm since their pre-industrial level, reaching 379 ppm in 2005, with mean annual growth rates in the 2000–2005 period higher than in the 1990s. The total CO<sub>2</sub>-equivalent (CO<sub>2</sub>-eq) concentration of all long-lived GHGs is now about 455 ppm CO<sub>2</sub>-eq. Incorporating the cooling effect of aerosols, other air pollutants and gases released from land-use change into the equivalent concentration, leads to an effective 311–435 ppm CO<sub>2</sub>-eq concentration (*high agreement, much evidence*).

Considerable uncertainties still surround the estimates of anthropogenic aerosol emissions. As regards global sulphur emissions, these appear to have declined from 75 ± 10 MtS in 1990 to 55–62 MtS in 2000. Data on non-sulphur aerosols are sparse and highly speculative. (*medium agreement, medium evidence*).

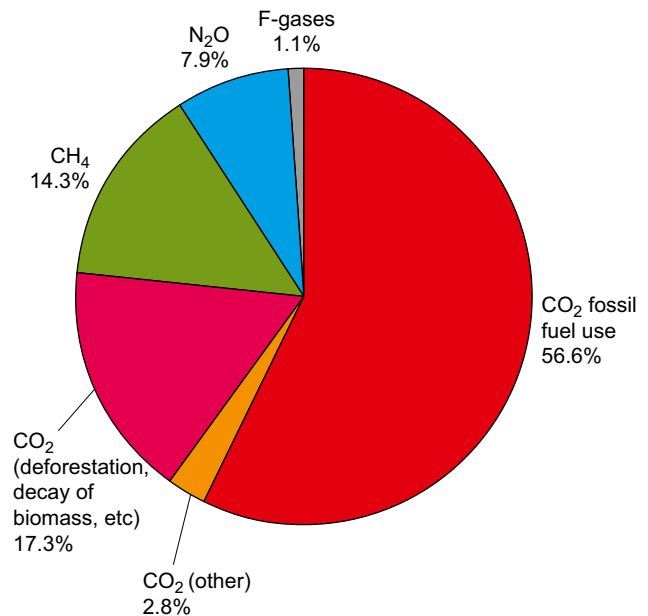
In 2004, energy supply accounted for about 26% of GHG emissions, industry 19%, gases released from land-use change and forestry 17%, agriculture 14%, transport 13%, residential, commercial and service sectors 8% and waste 3% (see Figure TS.2). These figures should be seen as indicative, as some uncertainty remains, particularly with regards to CH<sub>4</sub> and N<sub>2</sub>O emissions (error margin estimated to be in the order of 30–50%) and CO<sub>2</sub> emissions from agriculture and forestry with an even higher error margin (*high agreement, medium evidence*) [1.3].



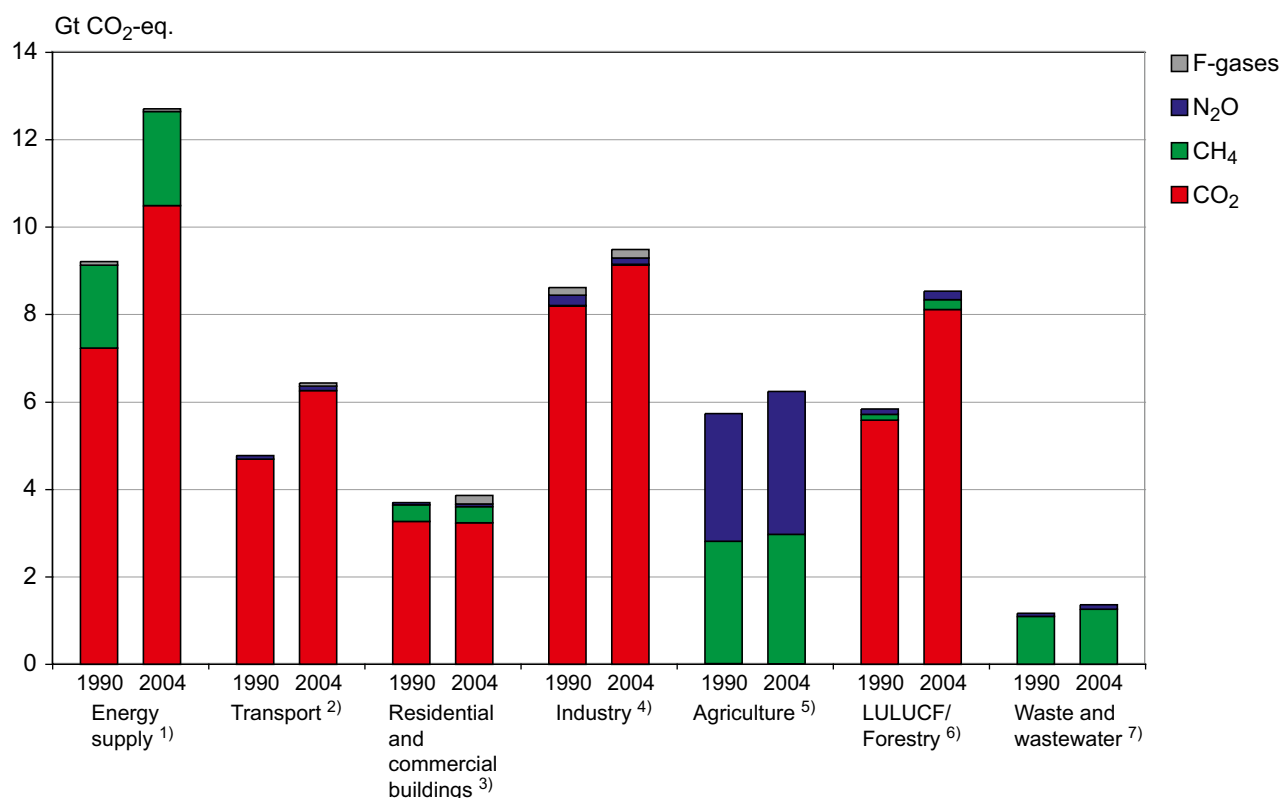
**Figure TS.1a:** Global anthropogenic greenhouse gas emissions, 1970–2004. One hundred year global warming potentials (GWPs) from IPCC 1996 (SAR) were used to convert emissions to CO<sub>2</sub>-eq. (see the UNFCCC reporting guidelines). Gases are those reported under UNFCCC reporting guidelines. The uncertainty in the graph is quite large for CH<sub>4</sub> and N<sub>2</sub>O (in the order of 30-50%) and even larger for CO<sub>2</sub> from agriculture and forestry. [Figure 1.1a].

Notes:

- 1) Other N<sub>2</sub>O includes industrial processes, deforestation/ savannah burning, waste water and waste incineration.
- 2) Other is CH<sub>4</sub> from industrial processes and savannah burning.
- 3) Including emissions from bioenergy production and use
- 4) CO<sub>2</sub> emissions from decay (decomposition) of above ground biomass that remains after logging and deforestation and CO<sub>2</sub> from peat fires and decay of drained peat soils.
- 5) As well as traditional biomass use at 10% of total, assuming 90% is from sustainable biomass production. Corrected for the 10% of carbon in biomass that is assumed to remain as charcoal after combustion.
- 6) For large-scale forest and scrubland biomass burning averaged data for 1997-2002 based on Global Fire Emissions Data base satellite data.
- 7) Cement production and natural gas flaring.
- 8) Fossil fuel use includes emissions from feedstocks.



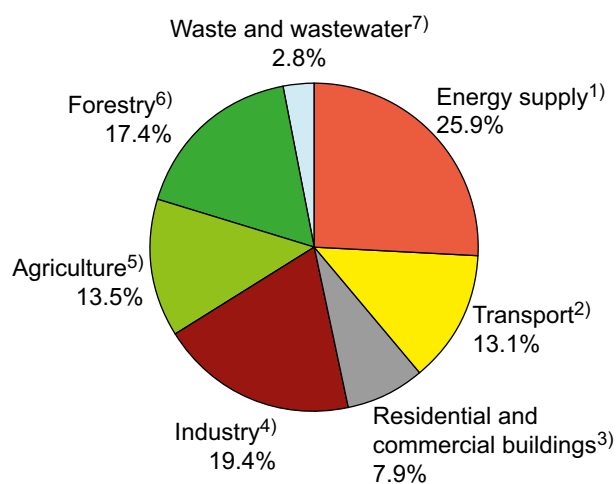
**Figure TS.1b:** Global anthropogenic greenhouse gas emissions in 2004 [Figure 1.1b].



**Figure TS.2a:** GHG emissions by sector in 1990 and 2004 100-year GWPs from IPCC 1996 (Second Assessment Report (SAR)) were used to convert emissions to CO<sub>2</sub>-eq. The uncertainty in the graph is quite large for CH<sub>4</sub> and N<sub>2</sub>O (in the order of 30–50%) and even larger for CO<sub>2</sub> from agriculture and forestry. For large-scale biomass burning, averaged activity data for 1997–2002 were used from Global Fire Emissions Database based on satellite data. Peat (fire and decay) emissions are based on recent data from WL/Delft Hydraulics. [Figure 1.3a]

Notes to Figure TS.2a and 2b:

- 1) Excluding refineries, coke ovens etc., which are included in industry.
- 2) Including international transport (bunkers), excluding fisheries. Excluding off-road agricultural and forestry vehicles and machinery.
- 3) Including traditional biomass use. Emissions in Chapter 6 are also reported on the basis of end-use allocation (including the sector's share in emissions caused by centralized electricity generation) so that any mitigation achievements in the sector resulting from lower electricity use are credited to the sector.
- 4) Including refineries, coke ovens etc. Emissions reported in Chapter 7 are also reported on the basis of end-use allocation (including the sector's share in emissions caused by centralized electricity generation) so that any mitigation achievements in the sector resulting from lower electricity use are credited to the sector.
- 5) Including agricultural waste burning and savannah burning (non-CO<sub>2</sub>). CO<sub>2</sub> emissions and/or removals from agricultural soils are not estimated in this database.
- 6) Data include CO<sub>2</sub> emissions from deforestation, CO<sub>2</sub> emissions from decay (decomposition) of above-ground biomass that remains after logging and deforestation, and CO<sub>2</sub> from peat fires and decay of drained peat soils. Chapter 9 reports emissions from deforestation only.
- 7) Includes landfill CH<sub>4</sub>, wastewater CH<sub>4</sub> and N<sub>2</sub>O, and CO<sub>2</sub> from waste incineration (fossil carbon only).



**Figure TS.2b:** GHG emissions by sector in 2004 [Figure 1.3b].

Figure TS.3 identifies the individual contributions to energy-related CO<sub>2</sub> emissions from changes in population, income per capita (gross domestic product (GDP) expressed in terms of purchasing-power parity per person - GDP<sub>ppp</sub>/cap<sup>1</sup>), energy intensity (Total Primary Energy Supply (TPES)/GDP<sub>ppp</sub>), and carbon intensity (CO<sub>2</sub>/TPES). Some of these factors boost CO<sub>2</sub> emissions (bars above the zero line), while others lower them (bar below the zero line). The actual change in emissions per decade is shown by the dashed black lines. According to Figure TS.3, the increase in population and GDP-<sub>ppp</sub>/cap (and therefore energy use per capita) have outweighed and are projected to continue to outweigh the decrease in energy intensities (TPES/GDP<sub>ppp</sub>) and conceal the fact that CO<sub>2</sub> emissions per unit of GDP<sub>ppp</sub> are 40% lower today than during the early 1970s and have declined faster than primary energy per unit of GDP<sub>ppp</sub> or CO<sub>2</sub> per unit of primary energy. The carbon intensity of energy supply (CO<sub>2</sub>/TPES) had an offsetting effect on CO<sub>2</sub> emissions between the mid 1980s and 2000, but has since been increasing and is projected to have no such effect after 2010 (*high agreement, much evidence*) [1.3].

In 2004, Annex I countries had 20% of the world’s population, but accounted for 46% of global GHG emissions, and the 80% in Non-Annex I countries for only 54%. The contrast between the region with the highest per capita GHG emissions (North America) and the lowest (Non-Annex I South Asia) is even more pronounced (see Figure TS.4a): 5% of the world’s population (North America) emits 19.4%,

while 30.3% (Non-Annex I South Asia) emits 13.1%. A different picture emerges if the metric GHG emissions per unit of GDP<sub>ppp</sub> is used (see Figure TS.4b). In these terms, Annex I countries generated 57% of gross world product with a GHG intensity of production of 0.68 kg CO<sub>2</sub>-eq/US\$ GDP<sub>ppp</sub> (non-Annex I countries 1.06 kg CO<sub>2</sub>-eq/US\$ GDP<sub>ppp</sub>) (*high agreement, much evidence*) [1.3].

Global energy use and supply – the main drivers of GHG emissions – is projected to continue to grow, especially as developing countries pursue industrialization. Should there be no change in energy policies, the energy mix supplied to run the global economy in the 2025–30 timeframe will essentially remain unchanged, with more than 80% of energy supply based on fossil fuels with consequent implications for GHG emissions. On this basis, the projected emissions of energy-related CO<sub>2</sub> in 2030 are 40–110% higher than in 2000, with two thirds to three quarters of this increase originating in non-Annex I countries, though per capita emissions in developed countries will remain substantially higher, that is 9.6 tCO<sub>2</sub>/cap to 15.1 tCO<sub>2</sub>/cap in Annex I regions versus 2.8 tCO<sub>2</sub>/cap to 5.1 tCO<sub>2</sub>/cap in non-Annex I regions (*high agreement, much evidence*) [1.3].

For 2030, projections of total GHG emissions (Kyoto gases) consistently show an increase of 25–90% compared with 2000, with more recent projections higher than earlier ones (*high agreement, much evidence*).

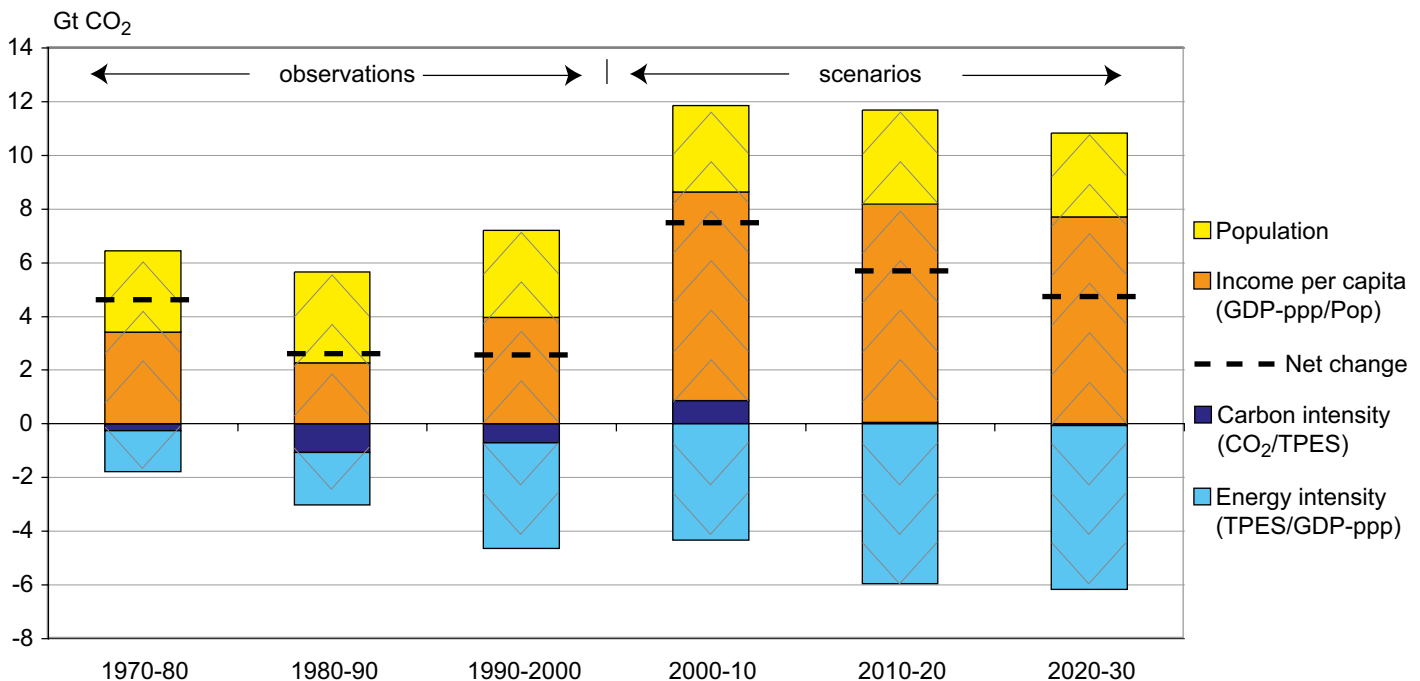
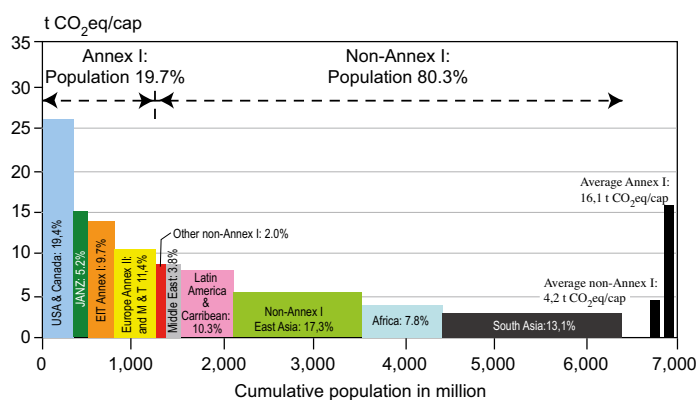


Figure TS.3: Decomposition of global energy-related CO<sub>2</sub> emission changes at the global scale for three past and three future decades [Figure 1.6].

1 The GDP<sub>ppp</sub> metric is used for illustrative purposes only for this report.

For 2100, the SRES<sup>2</sup> range (a 40% decline to 250% increase compared with 2000) is still valid. More recent projections tend to be higher: increase of 90% to 250% compared with 2000 (see Figure TS.5). Scenarios that account for climate policies, whose implementation is currently under discussion, also show global emissions rising for many decades.

Developing countries (e.g., Brazil, China, India and Mexico) that have undertaken efforts for reasons other than climate change have reduced their emissions growth over the past three decades by approximately 500 million tonnes CO<sub>2</sub> per year; that is, more than the reductions required from Annex I countries by the Kyoto Protocol. Many of these efforts are motivated by economic development and poverty alleviation, energy security and local environmental protection. The most promising policy approaches, therefore, seem to be those that capitalize on natural synergies between climate protection and development priorities to advance both simultaneously (*high agreement, medium evidence*) [1.3].

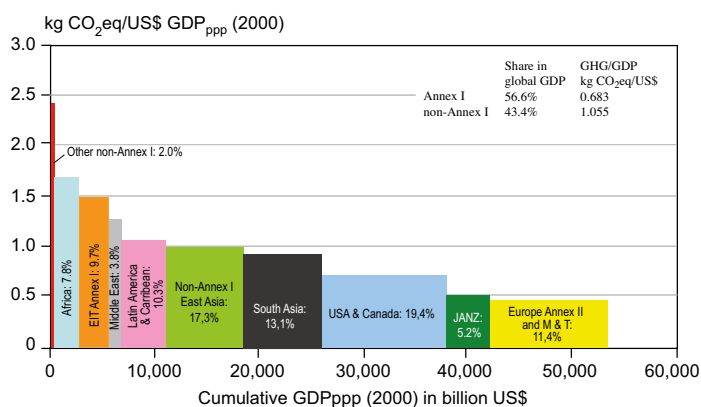


**Figure TS.4a:** Distribution of regional per capita GHG emissions (all Kyoto gases including those from land-use) over the population of different country groupings in 2004. The percentages in the bars indicate a region's share in global GHG emissions [Figure 1.4a].

## International response

The United Nations Framework Convention on Climate Change (UNFCCC) is the main vehicle for promoting international responses to climate change. It entered into force in March 1994 and has achieved near universal ratification – 189 of the 194 UN member states (December 2006). A Dialogue on Long-Term Cooperation Action to Address Climate Change by Enhancing Implementation of the Convention was set up at CMP1<sup>3</sup> in 2005, taking the form of an open and non-binding exchange of views and information in support of enhanced implementation of the Convention.

The first addition to the treaty, the Kyoto Protocol, was adopted in 1997 and entered into force in February 2005. As of February 2007, 168 states and the European Economic Community have ratified the Protocol. Under Article 3.1 of the Kyoto Protocol, Annex I Parties in aggregate agreed to reduce



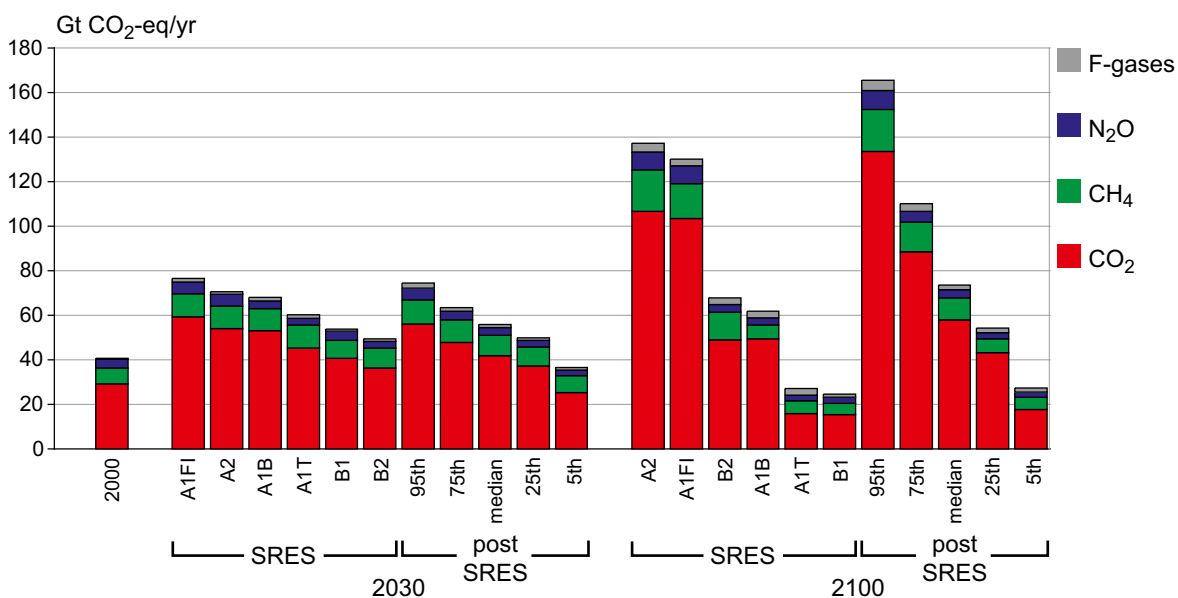
**Figure TS.4b:** Distribution of regional GHG emissions (all Kyoto gases including those from land-use) per US\$ of GDP over the GDP of different country groupings in 2004. The percentages in the bars indicate a region's share in global GHG emissions [Figure 1.4b].

Note: Countries are grouped according to the classification of the UNFCCC and its Kyoto Protocol; this means that countries that have joined the European Union since then are still listed under EIT Annex I. A full set of data for all countries for 2004 was not available. The countries in each of the regional groupings include:

- **EIT Annex I:** Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Russian Federation, Slovakia, Slovenia, Ukraine
- **Europe Annex II & M&T:** Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom; Monaco and Turkey
- **JANZ:** Japan, Australia, New Zealand.
- **Middle East:** Bahrain, Islamic Republic of Iran, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen
- **Latin America & the Caribbean:** Antigua & Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Saint Lucia, St. Kitts-Nevis-Anguilla, St. Vincent-Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela
- **Non-Annex I East Asia:** Cambodia, China, Korea (DPR), Laos (PDR), Mongolia, Republic of Korea, Viet Nam.
- **South Asia:** Afghanistan, Bangladesh, Bhutan, Comoros, Cook Islands, Fiji, India, Indonesia, Kiribati, Malaysia, Maldives, Marshall Islands, Micronesia, (Federated States of), Myanmar, Nauru, Niue, Nepal, Pakistan, Palau, Papua New Guinea, Philippine, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Timor-Leste, Tonga, Tuvalu, Vanuatu
- **North America:** Canada, United States of America.
- **Other non-Annex I:** Albania, Armenia, Azerbaijan, Bosnia Herzegovina, Cyprus, Georgia, Kazakhstan, Kyrgyzstan, Malta, Moldova, San Marino, Serbia, Tajikistan, Turkmenistan, Uzbekistan, Republic of Macedonia
- **Africa:** Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Democratic Republic of Congo, Côte d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Swaziland, Togo, Tunisia, Uganda, United Republic of Tanzania, Zambia, Zimbabwe.

2 SRES refers to scenarios described in the IPCC Special Report on Emission Scenarios (IPCC, 2000b). The A1 family of scenarios describes a future with very rapid economic growth, low population growth and rapid introduction of new and more efficient technologies. B1 describes a convergent world, with the same global population that peaks in mid century and declines thereafter, with rapid changes in economic structures. B2 describes a world 'in which emphasis is on local solutions to economic, social, and environmental sustainability'. It features moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than the A1B scenario.

3 The Conference of the Parties (COP) is the supreme body of the Convention also serves as the Meeting of the Parties (MOP) for the Protocol. CMP1 is the first meeting of the Conference of the Parties acting as the Meeting of the Parties of the Kyoto Protocol.



**Figure TS.5:** Global GHG emissions for 2000 and projected baseline emissions for 2030 and 2100 from IPCC SRES and the post-SRES literature. The figure provides the emissions from the six illustrative SRES scenarios. It also provides the frequency distribution of the emissions in the post-SRES scenarios (5th, 25th, median, 75th, 95th percentile), as covered in Chapter 3. F-gases cover HFCs, PFCs and SF<sub>6</sub> [Figure 1.7].

their overall GHG emissions to at least 5% below 1990 levels. The entry into force of the Kyoto Protocol marks a first, though modest, step towards achieving the ultimate objective of the UNFCCC to avoid dangerous anthropogenic interference with the climate system. Its full implementation by all the Protocol signatories, however, would still be far from reversing overall global GHG-emission trends. The strengths of the Kyoto Protocol are its provision for market mechanisms such as GHG-emission trading and its institutional architecture. One weakness of the Protocol, however, is its non-ratification by some significant GHG emitters. A new Ad Hoc Working Group (AWG) on the Commitments of Annex I Countries under the Kyoto Protocol beyond 2012 was set up at CMP1, and agreed at CMP2 that the second review of Article 9 of the Kyoto Protocol will take place in 2008.

There are also voluntary international initiatives to develop and implement new technologies to reduce GHG emissions. These include: the Carbon Sequestration Leadership Forum (promoting CO<sub>2</sub> capture and storage); the Hydrogen partnership; the Methane to Markets Partnership, and the Asia-Pacific Partnership for Clean Development and Climate (2005), which includes Australia, USA, Japan, China, India and South-Korea. Climate change has also become an important growing concern of the G8 since its meeting in Gleneagles, Scotland in 2005. At that meeting, a plan of action was developed which tasked the International Energy Agency, the World Bank and the Renewable Energy and Energy Efficiency Partnership with supporting their efforts. Additionally, Gleneagles created a Clean Energy, Climate Change and Sustainable Development Dialogue process for the largest emitters. The International Energy Agency (IEA) and the World Bank were charged with advising that dialogue process [1.4].

## Article 2 of the Convention and mitigation

Article 2 of the UNFCCC requires that dangerous interference with the climate system be prevented and hence the stabilization of atmospheric GHG concentrations at levels and within a time frame that would achieve this objective. The criteria in Article 2 that specify (risks of) dangerous anthropogenic climate change include: food security, protection of ecosystems and sustainable economic development. Implementing Article 2 implies dealing with a number of complex issues:

### What level of climate change is dangerous?

Decisions made in relation to Article 2 would determine the level of climate change that is set as the goal for policy, and have fundamental implications for emission-reduction pathways as well as the scale of adaptation required. Choosing a stabilization level implies balancing the risks of climate change (from gradual change and extreme events, and irreversible change of the climate, including those to food security, ecosystems and sustainable development) against the risks of response measures that may threaten economic sustainability. Although any judgment on ‘dangerous interference’ is necessarily a social and political one, depending on the level of risk deemed acceptable, large emission reductions are unavoidable if stabilization is to be achieved. The lower the stabilization level, the earlier these large reductions have to be realized (*high agreement, much evidence*) [1.2].

### Sustainable development:

Projected anthropogenic climate change appears likely to adversely affect sustainable development, with the effects tending to increase with higher GHG concentrations (WGII AR4, Chapter 19). Properly designed climate change responses

can be an integral part of sustainable development and the two can be mutually reinforcing. Mitigation of climate change can conserve or enhance natural capital (ecosystems, the environment as sources and sinks for economic activities) and prevent or avoid damage to human systems and, thereby contribute to the overall productivity of capital needed for socio-economic development, including mitigative and adaptive capacity. In turn, sustainable development paths can reduce vulnerability to climate change and reduce GHG emissions (*medium agreement, much evidence*) [1.2].

#### **Distributional issues:**

Climate change is subject to a very asymmetric distribution of present emissions and future impacts and vulnerabilities. Equity can be elaborated in terms of distributing the costs of mitigation or adaptation, distributing future emission rights and ensuring institutional and procedural fairness. Because the industrialized nations are the source of most past and current GHG emissions and have the technical and financial capability to act, the Convention places the heaviest burden for the first steps in mitigating climate change on them. This is enshrined in the principle of ‘common but differentiated responsibilities’ (*high agreement, much evidence*) [1.2].

#### **Timing:**

Due to the inertia of both climate and socio-economic systems, the benefits of mitigation actions initiated now may result in significant avoided climate change only after several decades. This means that mitigation actions need to start in the short term in order to have medium- and longer-term benefits and to avoid lock-in of carbon-intensive technologies (*high agreement, much evidence*) [1.2].

#### **Mitigation and adaptation:**

Adaptation and mitigation are two types of policy response to climate change, which can be complementary, substitutable or independent of each other. Irrespective of the scale of mitigation measures, adaptation measures will be required anyway, due to the inertia in the climate system. Over the next 20 years or so, even the most aggressive climate policy can do little to avoid warming already ‘loaded’ into the climate system. The benefits of avoided climate change will only accrue beyond that time. Over longer time frames, beyond the next few decades, mitigation investments have a greater potential to avoid climate change damage and this potential is larger than the adaptation options that can currently be envisaged (*medium agreement, medium evidence*) [1.2].

#### **Risk and uncertainty:**

An important aspect in the implementation of Article 2 is the uncertainty involved in assessing the risk and severity of climate change impacts and evaluating the level of mitigation action (and its costs) needed to reduce the risk. Given this uncertainty, decision-making on the implementation of Article 2 would benefit from the incorporation of risk-management principles. A precautionary and anticipatory risk-management approach would incorporate adaptation and

preventive mitigation measures based on the costs and benefits of avoided climate change damage, taking into account the (small) chance of worst-case outcomes (*medium agreement, medium evidence*) [1.2].

## 2 Framing issues

### **Climate change mitigation and sustainable development**

There is a two-way relationship between climate change and development. On the one hand vulnerability to climate change is framed and strongly influenced by development patterns and income levels. Decisions about technology, investment, trade, poverty, community rights, social policies or governance, which may seem unrelated to climate policy, may have profound impacts on emissions, the extent of mitigation required, and the cost and benefits that result [2.2.3].

On the other hand, climate change itself, and adaptation and mitigation policies could have significant positive impacts on development in the sense that development can be made more sustainable. This leads to the notion that climate change policies can be considered 1) in their own right (‘climate first’); or 2) as an integral element of sustainable-development policies (‘development first’). Framing the debate as a sustainable development problem rather than a solely environmental one may better address the needs of countries, while acknowledging that the driving forces for emissions are linked to the underlying development path [2.2.3].

Development paths evolve as a result of economic and social transactions, which are influenced by government policies, private sector initiatives and by the preferences and choices of consumers. These include a broad number of policies related to nature conservation, legal frameworks, property rights, rule of law, taxes and regulation, production, security and safety of food, consumption patterns, human and institutional capacity building efforts, R&D, financial schemes, technology transfer, energy efficiency and energy options. These policies do not usually emerge and become implemented as part of a general development-policy package, but are normally targeted towards more specific policy goals like air-pollution standards, food security and health issues, GHG-emission reduction, income generation by specific groups, or development of industries for green technologies. However, significant impacts can arise from such policies on sustainability and greenhouse mitigation and the outcomes of adaptation. The strong relationship between mitigation of climate change and development applies in both developed and developing countries. Chapter 12 and to some extent Chapters 4–11 address these issues in more detail [2.2.5; 2.2.7].

Emerging literature has identified methodological approaches to identify, characterize and analyze the interactions between sustainable development and climate change responses. Several



authors have suggested that sustainable development can be addressed as a framework for jointly assessing social, human, environmental and economic dimensions. One way to address these dimensions is to use a number of economic, environmental, human and social indicators to assess the impacts of policies on sustainable development, including both quantitative and qualitative measurement standards (*high agreement, limited evidence*) [2.2.4].

### Decision-making, risk and uncertainty

Mitigation policies are developed in response to concerns about the risk of climate change impacts. However, deciding on a proper reaction to these concerns means dealing with uncertainties. Risk refers to cases for which the probability of outcomes and its consequences can be ascertained through well-established theories with reliable, complete data, while uncertainty refers to situations in which the appropriate data may be fragmentary or unavailable. Causes of uncertainty include insufficient or contradictory evidence as well as human behaviour. The human dimensions of uncertainty, especially coordination and strategic behaviour issues, constitute a major part of the uncertainties related to climate change mitigation (*high agreement, much evidence*) [2.3.3; 2.3.4].

Decision-support analysis can assist decision makers, especially if there is no optimum policy that everybody can agree on. For this, a number of analytical approaches are available, each with their own strengths and weaknesses, which help to keep the information content of the climate change problem within the cognitive limits of the large number of decision makers and support a more informed and effective dialogue among the many parties involved. There are, however,

significant problems in identifying, measuring and quantifying the many variables that are important inputs to any decision-support analysis framework – particularly impacts on natural systems and human health that do not have a market value, and for which all approaches are simplifications of the reality (*high agreement, much evidence*) [2.3.7].

When many decision makers with different value systems are involved in a decision, it is helpful to be as clear as possible about the value judgments underpinning any analytic outcomes they are expected to draw on. This can be particularly difficult and subtle where analysis aims to illuminate choices associated with high levels of uncertainty and risk (*medium agreement, medium evidence*) [2.3.2; 2.3.7].

Integrated assessments can inform decision makers of the relationship between geophysical climate change, climate-impact predictions, adaptation potentials and the costs of emission reductions and the benefits of avoided climate change damage. These assessments have frameworks to deal with incomplete or imprecise data.

To communicate the uncertainties involved, this report uses the terms in Table TS.1 to describe the relative levels of expert agreement on the respective statements in the light of the underlying literature (in rows) and the number and quality of independent sources qualifying under IPCC rules<sup>4</sup> upon which a finding is based (in columns). The other approaches of ‘likelihood’ and ‘confidence’ are not used in this report as human choices are concerned, and none of the other approaches used provides sufficient characterization of the uncertainties involved in mitigation (*high agreement, much evidence*) [2.4].

**Table TS.1:** Qualitative definition of uncertainty [Table 2.2].

	High agreement, limited evidence	High agreement, medium evidence	High agreement, much evidence
	Medium agreement, limited evidence	Medium agreement, medium evidence	Medium agreement, much evidence
	Low agreement, limited evidence	Low agreement, medium evidence	Low agreement, much evidence
Level of agreement (on a particular finding) ↑			
	Amount of evidence (number and quality of independent sources) →		

Note: This table is based on two dimensions of uncertainty: the amount of evidence<sup>5</sup> and the level of agreement. The amount of evidence available about a given technology is assessed by examining the number and quality of independent sources of information. The level of agreement expresses the subjective probability of the results being in a certain realm.

<sup>4</sup> IPCC rules permit the use of both peer-reviewed literature and non-peer-reviewed literature that the authors deem to be of equivalent quality.

<sup>5</sup> ‘Evidence’ in this report is defined as: Information or signs indicating whether a belief or proposition is true or valid. See Glossary.

## Costs, benefits, concepts including private and social cost perspectives and relationships with other decision-making frameworks

There are different ways of defining the potential for mitigation and it is therefore important to specify what potential is meant. ‘Potential’ is used to express the degree of GHG reduction that can be achieved by a mitigation option with a given cost per tonne of carbon avoided over a given period, compared with a baseline or reference case. The measure is usually expressed as million tonnes carbon- or CO<sub>2</sub>-equivalent emissions avoided compared with baseline emissions [2.4.3].

**Market potential** is the mitigation potential based on private costs and private discount rates<sup>6</sup>, which might be expected to occur under forecast market conditions, including policies and measures currently in place, noting that barriers limit actual uptake.

**Economic potential** is the amount of GHG mitigation, which takes into account social costs and benefits and social discount rates<sup>7</sup> assuming that market efficiency is improved by policies and measures and barriers are removed. However, current bottom-up and top-down studies of economic potential have limitations in considering life-style choices and in including all externalities such as local air pollution.

**Technical potential** is the amount by which it is possible to reduce GHG emissions by implementing a technology or practice that has already been demonstrated. There is no specific reference to costs here, only to ‘practical constraints’, although implicit economic considerations are taken into account in some cases. (*high agreement, much evidence*) [2.4.3].

Studies of market potential can be used to inform policy makers about mitigation potential with existing policies and barriers, while studies of economic potentials show what might be achieved if appropriate new and additional policies were put into place to remove barriers and include social costs and benefits. The economic potential is therefore generally greater than the market potential.

Mitigation potential is estimated using different types of approaches. There are two broad classes – “bottom-up” and “top-down” approaches, which primarily have been used to assess the economic potential:

- **Bottom-up studies** are based on assessment of mitigation options, emphasizing specific technologies and regulations. They are typically sectoral studies taking the macro-economy as unchanged. Sector estimates have been aggregated, as in the TAR, to provide an estimate of global mitigation potential for this assessment.
- **Top-down studies** assess the economy-wide potential of mitigation options. They use globally consistent frameworks

and aggregated information about mitigation options and capture macro-economic and market feedbacks.

Bottom-up studies in particular are useful for the assessment of specific policy options at sectoral level, e.g. options for improving energy efficiency, while top-down studies are useful for assessing cross-sectoral and economy-wide climate change policies, such as carbon taxes and stabilization policies. Bottom-up and top-down models have become more similar since the TAR as top-down models have incorporated more technological mitigation options (see Chapter 11) and bottom-up models have incorporated more macroeconomic and market feedbacks as well as adopting barrier analysis into their model structures.

## Mitigation and adaptation relationships; capacities and policies

Climate change mitigation and adaptation have some common elements, they may be complementary, substitutable, independent or competitive in dealing with climate change, and also have very different characteristics and timescales [2.5].

Both adaptation and mitigation make demands on the capacity of societies, which are intimately connected to social and economic development. The responses to climate change depend on exposure to climate risk, society’s natural and man-made capital assets, human capital and institutions as well as income. Together these will define a society’s adaptive and mitigative capacities. Policies that support development and those that enhance its adaptive and mitigative capacities may, but need not, have much in common. Policies may be chosen to have synergetic impacts on the natural system and the socio-economic system but difficult trade-offs may sometimes have to be made. Key factors that determine the capacity of individual stakeholders and societies to implement climate change mitigation and adaptation include: access to resources; markets; finance; information, and a number of governance issues (*medium agreement, limited evidence*) [2.5.2].

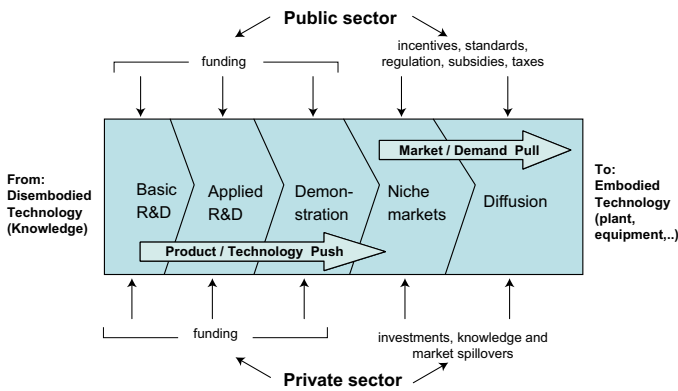
## Distributional and equity aspects

Decisions on climate change have large implications for local, national, inter-regional and intergenerational equity, and the application of different equity approaches has major implications for policy recommendations as well as for the distribution of the costs and benefits of climate policies [2.6].

Different approaches to social justice can be applied to the evaluation of the equity consequences of climate change policies. As the IPCC Third Assessment Report (TAR) suggested, given strong subjective preferences for certain equity principles among different stakeholders, it is more effective to look for practical approaches that combine equity principles. Equity approaches vary from traditional economic approaches to rights-

<sup>6</sup> Private costs and discount rates reflect the perspective of private consumers and companies; see Glossary for a fuller description.

<sup>7</sup> Social costs and discount rates reflect the perspective of society. Social discount rates are lower than those used by private investors; see Glossary for a fuller description.



**Figure TS.6:** The technology development cycle and its main driving forces [Figure 2.3].

Note: important overlaps and feedbacks exist between the stylized technology life-cycle phases illustrated here. The figure therefore does not suggest a 'linear' model of innovation. It is important to recognize the need for finer terminological distinction of 'technology', particularly when discussing different mitigation and adaptation options.

based approaches. An economic approach would be to assess welfare losses and gains to different groups and the society at large, while a rights-based approach would focus on rights, for example, in terms of emissions per capita or GDP allowed for all countries, irrespective of the costs of mitigation or the mitigative capacity. The literature also includes a capability approach that puts the emphasis on opportunities and freedom, which in terms of climate policy can be interpreted as the capacity to mitigate or to adapt or to avoid being vulnerable to climate change (*medium agreement, medium evidence*) [2.6.3].

### Technology research, development, deployment, diffusion and transfer

The pace and cost of any response to climate change concerns will also depend critically on the cost, performance, and availability of technologies that can lower emissions in the future, although other factors such as growth in wealth and population are also highly important [2.7].

Technology simultaneously influences the size of the climate change problem and the cost of its solution. Technology is the broad set of competences and tools covering know-how, experience and equipment, used by humans to produce services and transform resources. The principal role of technology in mitigating GHG emissions is in controlling the social cost of limiting the emissions. Many studies show the significant economic value of the improvements in emission-mitigating technologies that are currently in use and the development and deployment of advanced emission-mitigation technologies (*high agreement, much evidence*) [2.7.1].

A broad portfolio of technologies can be expected to play a role in meeting the goal of the UNFCCC and managing the risk of climate change, because of the need for large emission reductions, the large variation in national circumstances and

the uncertainty about the performance of individual options. Climate policies are not the only determinant of technological change. However, a review of future scenarios (see Chapter 3) indicates that the overall rate of change of technologies in the absence of climate policies might be as large as, if not larger than, the influence of the climate policies themselves (*high agreement, much evidence*) [2.7.1].

Technological change is particularly important over the long-term time scales characteristic of climate change. Decade- or century-long time scales are typical for the lags involved between technological innovation and widespread diffusion and of the capital turnover rates characteristic of long-lived energy capital stock and infrastructures.

Many approaches are used to split up the process of technological change into distinct phases. One is to consider technological change as roughly a two-part process: 1) conceiving, creating and developing new technologies or enhancing existing technologies – advancing the 'technological frontier'; 2) the diffusion or deployment of these technologies. Our understanding of technology and its role in addressing climate change is improving continuously. The processes by which technologies are created, developed, deployed and eventually replaced, however, are complex (see Figure TS.6) and no simple descriptions of these processes exist. Technology development and deployment is characterized by two public goods problems. First, the level of R&D is sub-optimal because private decision-makers cannot capture the full value of private investments. Second, there is a classical environmental externality problem, in that private markets do not reflect the full costs of climate change (*high agreement, much evidence*) [2.7.2].

Three important sources of technological change are R&D, learning and spill-overs.

- R&D encompasses a broad set of activities in which firms, governments or other entities expend resources specifically to gain new knowledge that can be embodied in new or improved technology.
- Learning is the aggregate outcome of complex underlying sources of technology advance that frequently include important contributions from R&D, spill-overs and economies of scale.
- Spill-overs refer to the transfer of the knowledge or the economic benefits of innovation from one individual, firm, industry or other entity, or from one technology to another.

On the whole, empirical and theoretical evidence strongly suggest that all three of these play important roles in technological advance, and there is no compelling reason to believe that one is broadly more important than the others. As spill-overs from other sectors have had an enormous effect on innovation in the energy sector, a robust and broad technological base may be as important for the development of technologies pertinent to climate change as explicit climate change or energy research. A broad portfolio of research is needed, because it is not possible to identify winners and losers ex-ante. The sources of

technological change are frequently subsumed under the general drivers ‘supply push’ (e.g., via R&D) or ‘demand pull’ (e.g., via learning). These are, however, not simply substitutes, but may have highly complementary interactions (*high agreement, much evidence*) [2.7.2].

On technology transfer, the main findings of the IPCC Special Report on Methodological and Technological Issues of Technology Transfer (2000) remain valid: that a suitable enabling environment needs to be created in host and recipient countries (*high agreement, much evidence*) [2.7.3].

### Regional Dimensions

Climate change studies have used various different regional definitions, depending on the character of the problem considered and differences in methodological approaches. The multitude of possible regional representations hinders the comparability and transfer of information between the various types of studies done for specific regions and scales. This report largely has chosen a pragmatic ways of analysing regional information and presenting findings [2.8].

## 3 Issues related to mitigation in the long-term context

### Baseline scenario drivers

Population projections are now generally lower than in the IPCC Special Report on Emission Scenarios (SRES), based on new data indicating that birth rates in many parts of the world have fallen sharply. So far, these new population projections have not been implemented in many of the new emissions scenarios in the literature. The studies that have incorporated them result in more or less the same overall emissions levels, due to changes in other driving factors such as economic growth (*high agreement, much evidence*) [3.2.1].

Economic growth perspectives have not changed much. There is a considerable overlap in the GDP numbers published, with a slight downwards shift of the median of the new scenarios by about 7% compared with the median in the pre-SRES scenario literature. The data suggest no appreciable change in the distribution of GDP projections. Economic growth projections for Africa, Latin America and the Middle East are lower than in the SRES scenarios (*high agreement, much evidence*) [3.2.1].

### Baseline scenario emissions (all gases and sectors)

The resulting span of energy-related and industrial CO<sub>2</sub> emissions in 2100 across baseline scenarios in the post-SRES

literature is very large, ranging from 17 to around 135 GtCO<sub>2</sub>-eq (4.6-36.8 GtC)<sup>8</sup>, about the same as the SRES range (Figure TS.7). Different reasons may contribute to the fact that emissions have not declined despite somewhat lower projections for population and GDP. All other factors being equal, lower population projections would result in lower emissions. In the scenarios that use lower projections, however, changes in other drivers of emissions have partly offset the consequences of lower populations. Few studies incorporated lower population projections, but where they did, they showed that lower population is offset by higher rates of economic growth, and/or a shift toward a more carbon-intensive energy system, such as a shift to coal because of increasing oil and gas prices. The majority of scenarios indicate an increase in emissions during most of the century. However, there are some baseline (reference) scenarios both in the new and older literature where emissions peak and then decline (*high agreement, much evidence*) [3.2.2].

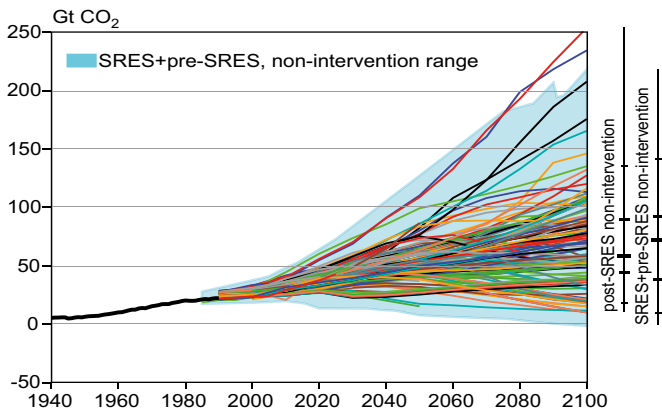
Baseline land-related GHG emissions are projected to increase with growing cropland requirements, but at a slower rate than energy-related emissions. As far as CO<sub>2</sub> emissions from land-use change (mostly deforestation) are concerned, post-SRES scenarios show a similar trend to SRES scenarios: a slow decline, possibly leading to zero net emissions by the end of the century.

Emissions of non-CO<sub>2</sub> GHGs as a group (mostly from agriculture) are projected to increase, but somewhat less rapidly than CO<sub>2</sub> emissions, because the most important sources of CH<sub>4</sub> and N<sub>2</sub>O are agricultural activities, and agriculture is growing less than energy use. Emission projections from the recent literature are similar to SRES. Recent non-CO<sub>2</sub> GHG emission baseline scenarios suggest that agricultural CH<sub>4</sub> and N<sub>2</sub>O emissions will increase until the end of this century, potentially doubling in some baselines. While the emissions of some fluorinated compounds are projected to decrease, many are expected to grow substantially because of the rapid growth rate of some emitting industries and the replacement of ODS with HFCs (*high agreement, medium evidence*) [3.2.2].

Noticeable changes have occurred in projections of the emissions of the aerosol precursors SO<sub>2</sub> and NO<sub>x</sub> since SRES. Recent literature shows a slower short-term growth of these emissions than SRES. As a consequence also the long-term ranges of both emissions sources are lower in the recent literature. Recent scenarios project sulphur emissions to peak earlier and at lower levels than in SRES. A small number of new scenarios have begun to explore emission pathways for black and organic carbon (*high agreement, medium evidence*) [3.2.2].

In general, the comparison of SRES and new scenarios in the literature shows that the ranges of the main driving forces and emissions have not changed very much.

8 This is the 5<sup>th</sup> to 95<sup>th</sup> percentile of the full distribution



**Figure TS.7:** Comparison of the SRES and pre-SRES energy-related and industrial CO<sub>2</sub> emission scenarios in the literature with the post-SRES scenarios [Figure 3.8].

Note: Two vertical bars on the right extend from the minimum to maximum of the distribution of scenarios and indicate the 5<sup>th</sup>, 25<sup>th</sup>, 50<sup>th</sup>, 75<sup>th</sup> and the 95<sup>th</sup> percentiles of the distributions by 2100.

### GDP metrics

For long-term scenarios, economic growth is usually reported in the form of growth in GDP or gross national product (GNP). To get a meaningful comparison of the real size of economic activities over time and between countries, GDP is reported in constant prices taken from a base year.

The choice of the conversion factor, Market Exchange Rate (MER) or Purchasing Power Parity (PPP), depends on the type of analysis being undertaken. However, when it comes to calculating emissions (or other physical measures like energy), the choice between MER and PPP-based representations of GDP should not matter, since emission intensity will change (in a compensating manner) when the GDP numbers change. Thus, if a consistent set of metrics is employed, the choice of metric should not appreciably affect the final emission level. A number of new studies in the literature concur that the actual choice of exchange rates does not itself have an appreciable effect on long-term emission projections. In the case of SRES, the emissions trajectories are the same whether economic activities in the four scenario families are measured in MER or PPP.

There are studies that find some differences in emission levels between PPP and MER-based estimates. These results depend critically on convergence assumptions, among other things. In some of the short-term scenarios (with a horizon to 2030) a bottom-up approach is taken where assumptions about productivity growth and investment/saving decisions are the main drivers of growth in the models. In long-term scenarios, a top-down approach is more commonly used where the actual growth rates are more directly prescribed on the basis of convergence or other assumptions about long-term growth potentials. Different results can also be due to inconsistencies in adjusting the metrics of energy efficiency improvement when moving from MER to PPP-based calculations.

Evidence from the limited number of new PPP-based studies indicates that the choice of metric for GDP (MER or PPP) does not appreciably affect the projected emissions, when the metrics are used consistently. The differences, if any, are small compared with the uncertainties caused by assumptions on other parameters, for example, technological change. The debate clearly shows, however, the need for modellers to be more transparent in explaining conversion factors as well as taking care in making assumptions on exogenous factors (*high agreement, much evidence*) [3.2.1].

### Stabilization scenarios

A commonly used target in the literature is stabilization of CO<sub>2</sub> concentrations in the atmosphere. If more than one GHG is studied, a useful alternative is to formulate a GHG-concentration target in terms of CO<sub>2</sub>-equivalent concentration or radiative forcing, thereby weighting the concentrations of the different gases by their radiative properties. Another option is to stabilize or target global mean temperature. The advantage of radiative-forcing targets over temperature targets is that the calculation of radiative forcing does not depend on climate sensitivity. The disadvantage is that a wide range of temperature impacts is possible for each radiative-forcing level. Temperature targets, on the other hand, have the important advantage of being more directly linked to climate change impacts. Another approach is to calculate the risks or the probability of exceeding particular values of global annual mean temperature rise since pre-industrial times for specific stabilization or radiative-forcing targets.

There is a clear and strong correlation between the CO<sub>2</sub>-equivalent concentrations (or radiative forcing) and the CO<sub>2</sub>-only concentrations by 2100 in the published studies, because CO<sub>2</sub> is the most important contributor to radiative forcing. Based on this relationship, to facilitate scenario comparison and assessment, stabilization scenarios (both multi-gas and CO<sub>2</sub>-only studies) have been grouped into different categories that vary in the stringency of the targets (Table TS.2).

Essentially, any specific concentration or radiative-forcing target requires emissions to fall to very low levels as the removal processes of the ocean and terrestrial systems saturate. Higher stabilization targets do push back the timing of this ultimate result beyond 2100. However, to reach a given stabilization target, emissions must ultimately be reduced well below current levels. For achievement of the stabilization categories I and II, negative net emissions are required towards the end of the century in many scenarios considered (Figure TS. 8) (*high agreement, much evidence*) [3.3.5].

The timing of emission reductions depends on the stringency of the stabilization target. Stringent targets require an earlier peak in CO<sub>2</sub> emissions (see Figure TS.8). In the majority of the scenarios in the most stringent stabilization category (I), emissions are required to decline before 2015 and be further reduced to less

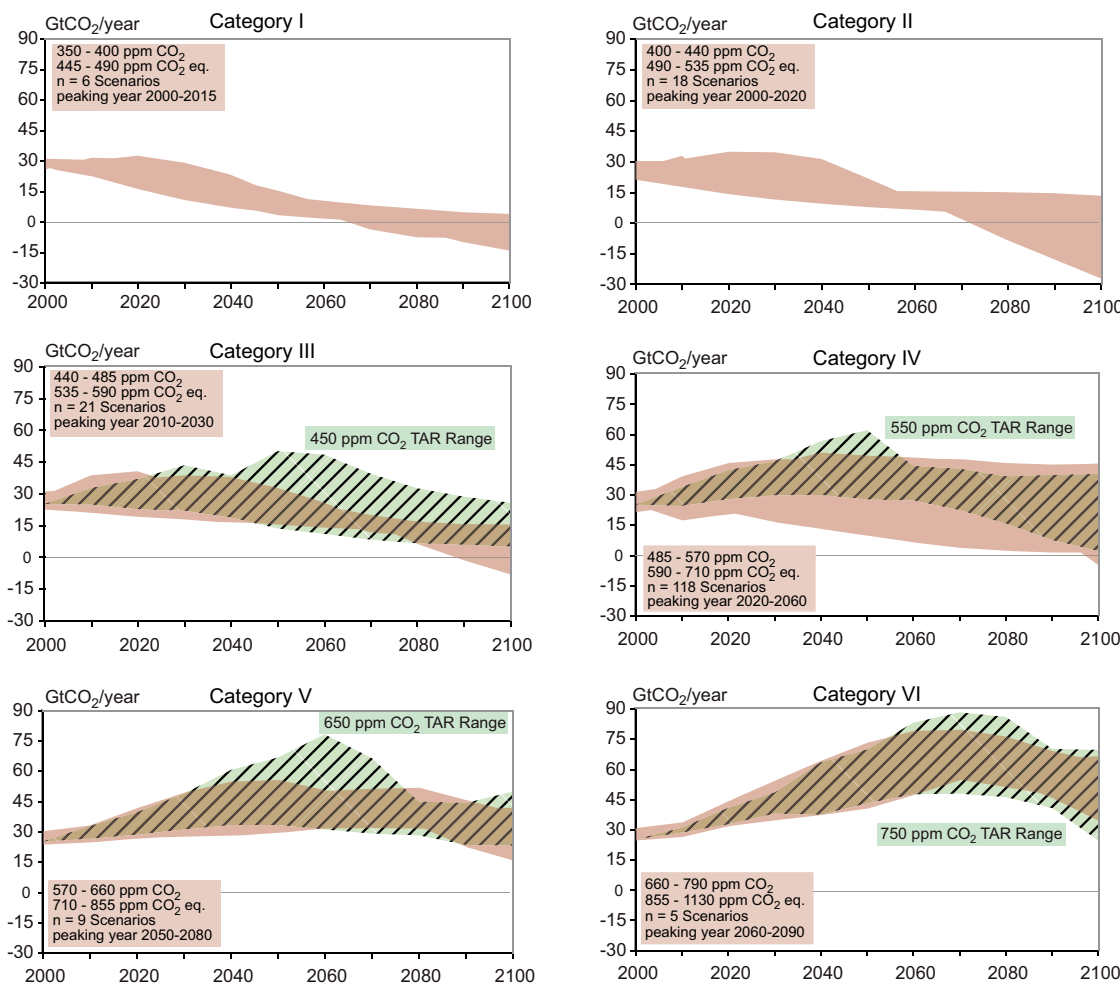
**Table TS.2:** Classification of recent (Post-Third Assessment Report) stabilization scenarios according to different stabilization targets and alternative stabilization metrics [Table 3.5].

Category	Additional radiative forcing (W/m <sup>2</sup> )	CO <sub>2</sub> concentration (ppm)	CO <sub>2</sub> -eq concentration (ppm)	Global mean temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity <sup>a), b)</sup> (°C)	Peaking year for CO <sub>2</sub> emissions <sup>c)</sup>	Change in global CO <sub>2</sub> emissions in 2050 (% of 2000 emissions) <sup>c)</sup>	No. of assessed scenarios
I	2.5-3.0	350-400	445-490	2.0-2.4	2000 - 2015	-85 to -50	6
II	3.0-3.5	400-440	490-535	2.4-2.8	2000 - 2020	-60 to -30	18
III	3.5-4.0	440-485	535-590	2.8-3.2	2010 - 2030	-30 to +5	21
IV	4.0-5.0	485-570	590-710	3.2-4.0	2020 - 2060	+10 to +60	118
V	5.0-6.0	570-660	710-855	4.0-4.9	2050 - 2080	+25 to +85	9
VI	6.0-7.5	660-790	855-1130	4.9-6.1	2060 - 2090	+90 to +140	5
Total							177

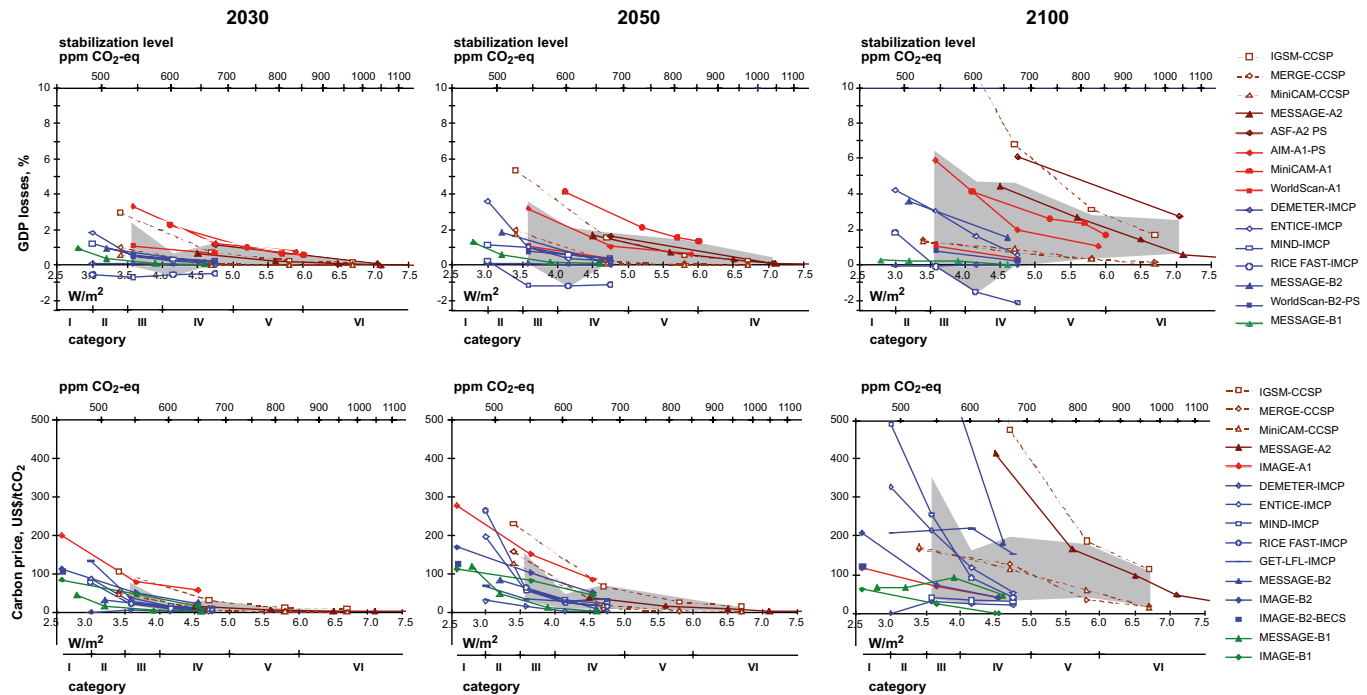
**Notes:**

- a) Note that global mean temperature at equilibrium is different from expected global mean temperatures in 2100 due to the inertia of the climate system.
- b) The simple relationships  $T_{eq} = T_{2\times CO_2} \times \ln([CO_2]/278)/\ln(2)$  and  $\Delta Q = 5.35 \times \ln([CO_2]/278)$  are used. Non-linearities in the feedbacks (including e.g., ice cover and carbon cycle) may cause time dependence of the effective climate sensitivity, as well as leading to greater uncertainties for greater warming levels. The best-estimate climate sensitivity (3 °C) refers to the most likely value, that is, the mode of the climate sensitivity PDF consistent with the WGI assessment of climate sensitivity and drawn from additional consideration of Box 10.2, Figure 2, in the WGI AR4.
- c) Ranges correspond to the 15<sup>th</sup> to 85<sup>th</sup> percentile of the Post-Third Assessment Report (TAR) scenario distribution. CO<sub>2</sub> emissions are shown, so multi-gas scenarios can be compared with CO<sub>2</sub>-only scenarios.

Note that the classification needs to be used with care. Each category includes a range of studies going from the upper to the lower boundary. The classification of studies was done on the basis of the reported targets (thus including modelling uncertainties). In addition, the relationship that was used to relate different stabilization metrics is also subject to uncertainty (see Figure 3.16).



**Figure TS.8:** Emission pathways of mitigation scenarios for alternative categories of stabilization targets (Category I to VI as defined in the box in each panel). Lightbrown shaded areas give the CO<sub>2</sub> emissions for the recent mitigation scenarios developed post-TAR. Green shaded and hatched areas depict the range of more than 80 TAR stabilization scenarios (Morita et al., 2001). Category I and II scenarios explore stabilization targets below the lowest of TAR. Base year emissions may differ between models due to differences in sector and industry coverage. To reach the lower stabilization levels some scenarios deploy removal of CO<sub>2</sub> from the atmosphere (negative emissions) using technologies such as biomass energy production utilizing carbon capture and storage [Figure 3.17].



**Figure TS.9:** Relationship between the cost of mitigation and long-term stabilization targets (radiative forcing compared with pre-industrial level,  $W/m^2$  and  $CO_2$ -eq concentrations) [Figure 3.25].

Notes: Panels give costs measured as percentage loss of GDP (top), and carbon price (bottom). Left-hand panels for 2030, middle panels for 2050 and right-hand panels for 2100. Individual coloured lines denote selected studies with representative cost dynamics from very high to very low cost estimates. Scenarios from models sharing similar baseline assumptions are shown in the same colour. The grey shaded range represents the 80th percentile of TAR and post-TAR scenarios. Solid lines show representative scenarios considering all radiatively active gases. Dashed lines represent multi-gas scenarios where the target is defined by the six Kyoto gases (other multi-gas scenarios consider all radiatively active gases).  $CO_2$  stabilization scenarios are added based on the relationship between  $CO_2$  concentration and the radiative-forcing targets given in Figure 3.16.

than 50% of today’s emissions by 2050. For category III, global emissions in the scenarios generally peak around 2010–2030, followed by a return to 2000 levels on average around 2040. For category IV, the median emissions peak around 2040 (Figure TS.9) (*high agreement, much evidence*).

The costs of stabilization depend on the stabilization target and level, the baseline and the portfolio of technologies considered, as well as the rate of technological change. Global mitigation costs<sup>9</sup> rise with lower stabilization levels and with higher baseline emissions. Costs in 2050 for multi-gas stabilization at 650 ppm  $CO_2$ -eq (cat IV) are between a 2% loss or a one percent increase<sup>10</sup> of GDP in 2050. For 550 ppm  $CO_2$ -eq (cat III) these costs are a range of a very small increase to 4% loss of GDP<sup>11</sup>. For stabilization levels between 445 and 535 ppm  $CO_2$ -eq. costs are lower than 5.5% loss of GDP, but the number of studies is limited and they generally use low baselines.

A multi-gas approach and inclusion of carbon sinks generally reduces costs substantially compared with  $CO_2$  emission abatement only. Global average costs of stabilization are uncertain, because assumptions on baselines and mitigation options in models vary a lot and have a major impact. For some countries, sectors or shorter time periods, costs could vary considerably from the global and long-term average (*high agreement, much evidence*) [3.3.5].

Recent stabilization studies have found that land-use mitigation options (both non- $CO_2$  and  $CO_2$ ) provide cost-effective abatement flexibility in achieving 2100 stabilization targets. In some scenarios, increased commercial biomass energy (solid and liquid fuel) is significant in stabilization, providing 5–30% of cumulative abatement and potentially 10–25% of total primary energy over the century, especially as a net negative emissions strategy that combines biomass energy with  $CO_2$  capture and storage.

<sup>9</sup> Studies on mitigation portfolios and macro-economic costs assessed in this report are based on a global least-cost approach, with optimal mitigation portfolios and without allocation of emission allowances to regions. If regions are excluded or non-optimal portfolios are chosen, global costs will go up. The variation in mitigation portfolios and their costs for a given stabilization level is caused by different assumptions, such as on baselines (lower baselines give lower costs), GHGs and mitigation options considered (more gases and mitigation options give lower costs), cost curves for mitigation options and rate of technological change.

<sup>10</sup> The median and the 10<sup>th</sup>–90<sup>th</sup> percentile range of the analysed data are given.

<sup>11</sup> Loss of GDP of 4% in 2050 is equivalent to a reduction of the annual GDP growth rate of about 0.1 percentage points.

The baseline choice is crucial in determining the nature and cost of stabilization. This influence is due mainly to different assumptions about technological change in the baseline scenarios.

### The role of technologies

Virtually all scenarios assume that technological and structural changes occur during this century, leading to relative reduction of emissions compared with the hypothetical case of attempting to ‘keep’ the emission intensities of GDP and economic structures the same as today (see Chapter 2, Section 2.9.1.3).

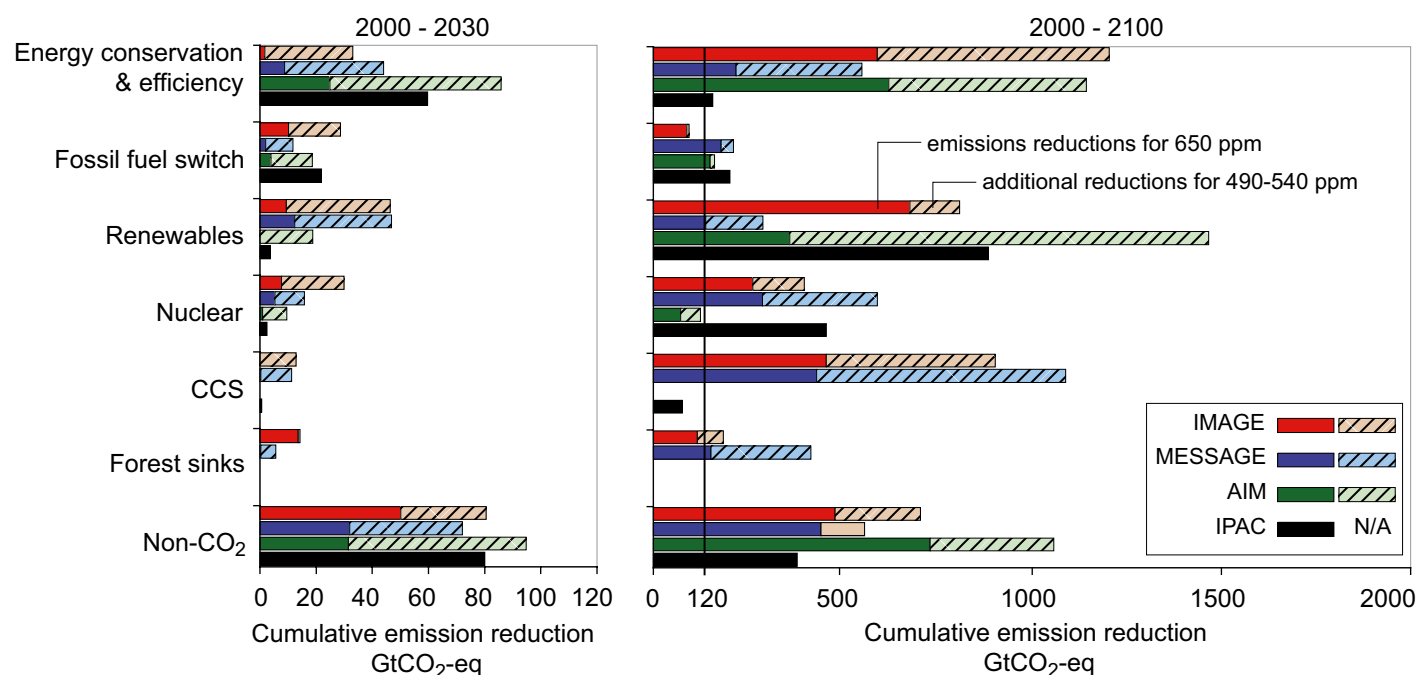
Baseline scenarios usually assume significant technological change and diffusion of new and advanced technologies. In mitigation scenarios there is additional technological change ‘induced’ through various policies and measures. Long-term stabilization scenarios highlight the importance of technology improvements, advanced technologies, learning by doing and endogenous technology change both for achieving the stabilization targets and for cost reduction. While the technology improvement and use of advanced technologies have been introduced in scenarios largely exogenously in most of the literature, new literature covers learning-by-doing and endogenous technological change. These newer scenarios show higher benefits of early action, as models assume that early

deployment of technologies leads to benefits of learning and cost reductions (*high agreement, much evidence*) [3.4].

The different scenario categories also reflect different contributions of mitigation measures. However, all stabilization scenarios concur that 60–80% of all reductions would come from the energy and industry sectors. Non-CO<sub>2</sub> gases and land-use would contribute the remaining 30–40% (see for illustrative examples Figure TS. 10). New studies exploring more stringent stabilization levels indicate that a wider portfolio of technologies is needed. Those could include nuclear, carbon capture and storage (CCS) and bio-energy with carbon capture and geologic storage (BECS) (*high agreement, much evidence*) [3.3.5].

### Mitigation and adaptation in the light of climate change impacts and decision-making under uncertainties

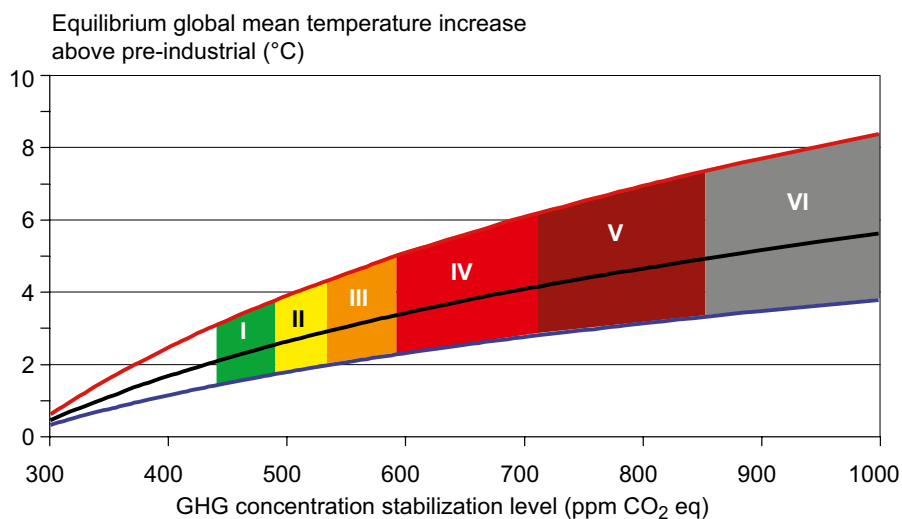
Concern about key vulnerabilities and notions of what is dangerous climate change will affect decisions about long-term climate change objectives and hence mitigation pathways. Key vulnerabilities traverse different human and natural systems and exist at different levels of temperature change. More stringent stabilization scenarios achieve more stringent climate targets and lower the risk of triggering key vulnerabilities related to climate change. Using the ‘best estimate’ of climate sensitivity<sup>12</sup>,



**Figure TS.10:** Cumulative emission reductions for alternative mitigation measures for 2000–2030 (left-hand panel) and for 2000–2100 (right-hand panel). The figure shows illustrative scenarios from four models (AIM, IMAGE, IPAC and MESSAGE) aiming at the stabilization at low (490–540 ppm CO<sub>2</sub>-eq) and intermediate levels (650 ppm CO<sub>2</sub>-eq) respectively. Dark bars denote reductions for a target of 650 ppm CO<sub>2</sub>-eq and light bars the additional reductions to achieve 490–540 ppm CO<sub>2</sub>-eq. Note that some models do not consider mitigation through forest sink enhancement (AIM and IPAC) or CCS (AIM) and that the share of low-carbon energy options in total energy supply is also determined by inclusion of these options in the baseline. CCS includes carbon capture and storage from biomass. Forest sinks include reducing emissions from deforestation [Figure 3.23].

<sup>12</sup> The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is not a projection but is defined as the global average surface warming following a doubling of carbon dioxide concentrations [AR4 WGI SPM].





**Figure TS.11:** Stabilization scenario categories as reported in Figure TS.8 (coloured bands) and their relationship to equilibrium global mean temperature change above pre-industrial temperatures [Figure 3.38].

Notes: Middle (black) line – ‘best estimate’ climate sensitivity of 3°C; upper (red) line – upper bound of likely range of climate sensitivity of 4.5°C; lower (blue) line – lower bound of likely range of climate sensitivity of 2°C. Coloured shading shows the concentration bands for stabilization of GHGs in the atmosphere corresponding to the stabilization scenario categories I to VI as indicated in Table TS.2.

the most stringent scenarios (stabilizing at 445–490 ppm CO<sub>2</sub>-eq) could limit global mean temperature increases to 2-2.4°C above pre-industrial, at equilibrium, requiring emissions to peak within 10 years and to be around 50% of current levels by 2050. Scenarios stabilizing at 535-590 ppm CO<sub>2</sub>-eq could limit the increase to 2.8-3.2°C above pre-industrial and those at 590-710 CO<sub>2</sub>-eq to 3.2-4°C, requiring emissions to peak within the next 25 and 55 years respectively (see Figure TS.11) [3.3, 3.5].

The risk of higher climate sensitivities increases the probability of exceeding any threshold for specific key vulnerabilities. Emission scenarios that lead to temporary overshooting of concentration ceilings can lead to higher rates of climate change over the century and increase the probability of exceeding key vulnerability thresholds. Results from studies exploring the effect of carbon cycle and climate feedbacks indicate that the above-mentioned concentration levels and the associated warming of a given emissions scenario might be an underestimate. With higher climate sensitivity, earlier and more stringent mitigation measures are necessary to reach the same concentration level.

Decision-making about the appropriate level of mitigation is an iterative risk-management process considering investment in mitigation and adaptation, co-benefits of undertaking climate change decisions and the damages due to climate change. It is intertwined with decisions on sustainability, equity and development pathways. Cost-benefit analysis, as one of the available tools, tries to quantify climate change damage in monetary terms (as social cost of carbon (SCC) or time-discounted damage). Due to large uncertainties and difficulties in quantifying non-market damage, it is still difficult to estimate SCC with confidence. Results depend on a large number of

normative and empirical assumptions that are not known with any certainty. Limited and early analytical results from integrated analyses of the costs and benefits of mitigation indicate that these are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilization level where benefits exceed costs. Integrated assessment of the economic costs and benefits of different mitigation pathways shows that the economically optimal timing and level of mitigation depends upon the uncertain shape and character of the assumed climate change damage cost curve.

To illustrate this dependency:

- if the climate change damage cost curve grows slowly and regularly, and there is good foresight (which increases the potential for timely adaptation), later and less stringent mitigation is economically justified;
- alternatively if the damage cost curve increases steeply, or contains non-linearities (e.g. vulnerability thresholds or even small probabilities of catastrophic events), earlier and more stringent mitigation is economically justified (*high agreement, much evidence*) [3.6.1].

### Linkages between short term and long term

For any chosen GHG-stabilization target, near-term decisions can be made regarding mitigation opportunities to help maintain a consistent emissions trajectory within a range of long-term stabilization targets. Economy-wide modelling of long-term global stabilization targets can help inform near-term mitigation choices. A compilation of results from short-and long-term models using scenarios with stabilization targets in the 3–5 W/m<sup>2</sup> range (category II to III), reveals that in 2030, for carbon prices of less than 20 US\$/tCO<sub>2</sub>-eq, emission reductions of in the

range of 9-18 GtCO<sub>2</sub>-eq/yr across all GHGs can be expected. For carbon prices less than 50 US\$/tCO<sub>2</sub>-eq this range is 14–23 GtCO<sub>2</sub>-eq/yr and for carbon prices less than US\$100/tCO<sub>2</sub>-eq it is 17-26 GtCO<sub>2</sub>-eq/yr. (*high agreement, much evidence*).

Three important considerations need to be remembered with regard to the reported marginal costs. First, these mitigation scenarios assume complete ‘what’ and ‘where’ flexibility; that is, there is full substitution among GHGs, and reductions take place anywhere in the world as soon as the models begin their analyses. Second, the marginal costs of realizing these levels of mitigation increase in the time horizon beyond 2030. Third, at the economic-sector level, emission-reduction potential for all GHGs varies significantly across the different model scenarios (*high agreement, much evidence*) [3.6.2].

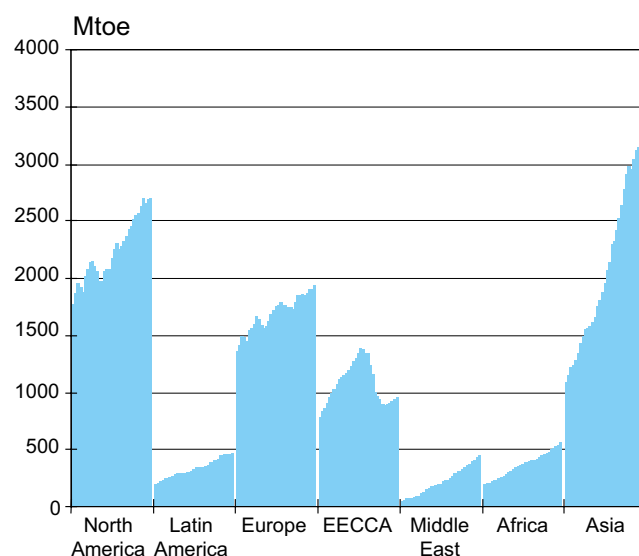
A risk management or ‘hedging’ approach can assist policy-makers to advance mitigation decisions in the absence of a long-term target and in the face of large uncertainties related to the cost of mitigation, the efficacy of adaptation and the negative impacts of climate change. The extent and the timing of the desirable hedging strategy will depend on the stakes, the odds and societies’ attitudes to risks, for example, with respect to risks of abrupt change in geophysical systems and other key vulnerabilities. A variety of integrated assessment approaches exist to assess mitigation benefits in the context of policy decisions related to such long-term climate goals. There will be ample opportunity for learning and mid-course corrections as new information becomes available. However, actions in the short term will largely determine long-term global mean temperatures and thus what corresponding climate change impacts can be avoided. Delayed emission reductions lead to investments that lock in more emission-intensive infrastructure and development pathways. This significantly constrains the opportunities to achieve lower stabilization levels and increases the risk of more severe climate change impacts. Hence, analysis of near-term decisions should not be decoupled from analysis that considers long-term climate change outcomes (*high agreement, much evidence*) [3.6; 3.5.2].

## 4 Energy supply

### Status of the sector and development until 2030

Global energy demand continues to grow, but with regional differences. The annual average growth of global primary energy consumption was 1.4 % per year in the 1990–2004 period. This was lower than in the previous two decades due to the economic transition in Eastern Europe, the Caucasus and Central Asia, but energy consumption in that region is now moving upwards again (Figure TS.12) (*high agreement, much evidence*) [4.2.1].

Rapid growth in energy consumption per capita is occurring in many developing countries. Africa is the region with the lowest per capita consumption. Increasing prices of oil and gas

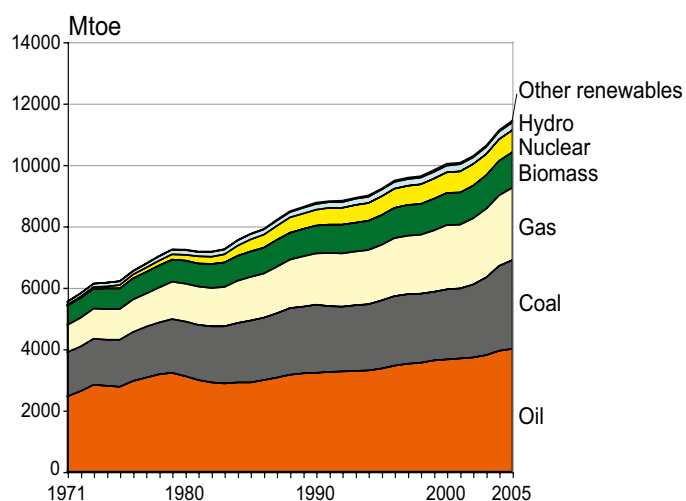


**Figure TS.12:** Annual primary energy consumption, including traditional biomass, 1971 to 2003 [Figure 4.2].

Note: EECCA = countries of Eastern Europe, the Caucasus and Central Asia. 1000 Mtoe = 42 EJ.

compromise energy access, equity and sustainable development of the poorest countries and interfere with reaching poverty-reduction targets that, in turn, imply improved access to electricity, modern cooking and heating fuels and transportation (*high agreement, much evidence*) [4.2.4].

Total fossil fuel consumption has increased steadily during the past three decades. Consumption of nuclear energy has continued to grow, though at a slower rate than in the 1980s. Large hydro and geothermal energy are relatively static. Between 1970 and 2004, the share of fossil fuels dropped from 86% to 81%. Wind and solar are growing most rapidly, but from a very low base (Figure TS.13) (*high agreement, much evidence*) [4.2].



**Figure TS.13:** World primary energy consumption by fuel type. [Figure 4.5].

Most business-as-usual (BAU) scenarios point to continued growth of world population (although at lower rates than predicted decades ago) and GDP, leading to a significant growth in energy demand. High energy-demand growth rates in Asia (3.2% per year 1990–2004) are projected to continue and to be met mainly by fossil fuels (*high agreement, much evidence*) [4.2].

Absolute fossil fuel scarcity at the global level is not a significant factor in considering climate change mitigation. Conventional oil production will eventually peak, but it is uncertain exactly when and what the repercussions will be. The energy in conventional natural gas is more abundant than in conventional oil but, like oil, is not distributed evenly around the globe. In the future, lack of security of oil and gas supplies for consuming nations may drive a shift to coal, nuclear power and/or renewable energy. There is also a trend towards more efficient and convenient energy carriers (electricity, and liquid and gaseous fuels) instead of solids (*high agreement, much evidence*) [4.3.1].

In all regions of the world, emphasis on security of supply has grown since the Third Assessment Report (TAR). This is coupled with reduced investments in infrastructure, increased global demand, political instability in key areas and the threats of conflict, terrorism and extreme weather events. New energy infrastructure investments in developing countries and upgrades of capacity in developed countries opens a window of opportunity for exploiting the co-benefits of choices in the energy mix in order to lower GHG emissions from what they otherwise would be (*high agreement, much evidence*) [4.2.4; 4.1].

The conundrum for many governments has become how best to meet the ever growing demand for reliable energy services while limiting the economic costs to their constituents, ensuring energy security, reducing dependence on imported energy sources and minimizing emissions of the associated GHGs and other pollutants. Selection of energy-supply systems for each region of the world will depend on their development, existing infrastructure and the local comparative costs of the available energy resources (*high agreement, much evidence*) [4.1].

If fossil fuel prices remain high, demand may decrease temporarily until other hydrocarbon reserves in the form of oil sands, oil shales, coal-to-liquids, gas-to-liquids etc. become commercially viable. Should this happen, emissions will increase further as the carbon intensity increases, unless carbon dioxide capture and storage (CCS) is applied. Due to increased energy security concerns and recent increases in gas prices, there is growing interest in new, more efficient, coal-based power plants. A critical issue for future GHG emissions is how quickly new coal plants are going to be equipped with CCS technology, which will increase the costs of electricity. Whether building ‘capture ready’ plants is more cost-effective than retrofitting plants or building a new plant integrated with CCS

depends on economic and technical assumptions. Continuing high fossil fuel prices may also trigger more nuclear and/or renewable energy, although price volatility will be a disincentive for investors. Concerns about safety, weapons proliferation and waste remain as constraints for nuclear power. Hydrogen may also eventually contribute as an energy carrier with low carbon emissions, dependent on the source of the hydrogen and the successful uptake of CCS for hydrogen production from coal or gas. Renewable energy must either be used in a distributed manner or will need to be concentrated to meet the intensive energy demands of cities and industries, because, unlike fossil fuel sources, the sources of renewable energy are widely distributed with low energy returns per exploited area (*medium agreement, medium evidence*) [4.3].

If energy demand continues to grow along the current trajectory, an improved infrastructure and conversion system will, by 2030, require a total cumulative investment of over US\$<sub>2005</sub> 20 trillion ( $20 \times 10^{12}$ ). For comparison, the total capital investment by the global energy industry is currently around 300 billion US\$ per year ( $300 \times 10^9$ ) (*medium agreement, medium evidence*) [4.1].

## Global and regional emission trends

With the exception of the countries in Eastern Europe, the Caucasus and Central Asia (where emissions declined post-1990 but are now rising again) and Europe (currently stable), carbon emissions have continued to rise. Business-as-usual emissions to 2030 will increase significantly. Without effective policy actions, global CO<sub>2</sub> emissions from fossil fuel combustion are predicted to rise at a minimum of more than 40%, from around 25 GtCO<sub>2</sub>-eq/yr (6.6 GtC-eq) in 2000 to 37-53 GtCO<sub>2</sub>-eq/yr (10-14 GtC-eq) by 2030 [4.2.3].

In 2004, emissions from power generation and heat supply alone were 12.7 GtCO<sub>2</sub>-eq (26% of total emissions) including 2.2 GtCO<sub>2</sub>-eq from CH<sub>4</sub>. In 2030, according to the World Energy Outlook 2006 baseline, these will have increased to 17.7 GtCO<sub>2</sub>-eq. (*high agreement, much evidence*) [4.2.2].

## Description and assessment of mitigation technologies and practices, options, potentials and costs in the electricity generation sector

The electricity sector has a significant mitigation potential using a range of technologies (Table TS.3). The economic potential for mitigation of each individual technology is based on what might be a realistic deployment expectation of the various technologies using all efforts, but given practical constraints on rate of uptake, public acceptance, capacity building and commercialization. Competition between options and the influence of end-use energy conservation and efficiency improvement is not included [4.4].

A wide range of energy-supply mitigation options are available and cost effective at carbon prices of <20US\$/tCO<sub>2</sub>

**Table TS.3:** Potential GHG emissions avoided by 2030 for selected electricity generation mitigation technologies (in excess of the IEA World Energy Outlook (2004) Reference baseline) employed in isolation with estimated mitigation potential shares spread across each cost range (2006 US\$/tCO<sub>2</sub>-eq) [Table 4.19].

	Regional groupings	Mitigation potential; total emissions saved in 2030 (GtCO <sub>2</sub> -eq)	Mitigation potential (%) for specific carbon price ranges (US\$/tCO <sub>2</sub> -eq avoided)				
			<0	0-20	20-50	50-100	>100
<b>Fuel switch and plant efficiency</b>	OECD <sup>a</sup>	0.39		100			
	EIT <sup>b</sup>	0.04		100			
	Non-OECD	0.64		100			
	World	1.07					
<b>Nuclear</b>	OECD	0.93	50	50			
	EIT	0.23	50	50			
	Non-OECD	0.72	50	50			
	World	1.88					
<b>Hydro</b>	OECD	0.39	85	15			
	EIT	0.00					
	Non-OECD	0.48	25	35	40		
	World	0.87					
<b>Wind</b>	OECD	0.45	35	40	25		
	EIT	0.06	35	45	20		
	Non-OECD	0.42	35	50	15		
	World	0.93					
<b>Bio-energy</b>	OECD	0.20	20	25	40	15	
	EIT	0.07	20	25	40	15	
	Non-OECD	0.95	20	30	45	5	
	World	1.22					
<b>Geothermal</b>	OECD	0.09	35	40	25		
	EIT	0.03	35	45	20		
	Non-OECD	0.31	35	50	15		
	World	0.43					
<b>Solar PV and concentrated solar power</b>	OECD	0.03				20	80
	EIT	0.01				20	80
	Non-OECD	0.21				25	75
	World	0.25					
<b>CCS + coal</b>	OECD	0.28			100		
	EIT	0.01			100		
	Non-OECD	0.20			100		
	World	0.49					
<b>CCS + gas</b>	OECD	0.09				100	
	EIT	0.04				70	
	Non-OECD	0.19			30	100	
	World	0.32					

Notes:

a) Organization for Economic Cooperation and Development

b) Economies in Transition

including fuel switching and power-plant efficiency improvements, nuclear power and renewable energy systems. CCS will become cost effective at higher carbon prices. Other options still under development include advanced nuclear power, advanced renewables, second-generation biofuels and, in the longer term, the possible use of hydrogen as an energy carrier (*high agreement, much evidence*) [4.3, 4.4].

Since the estimates in Table TS.3 are for the mitigation potentials of individual options without considering the actual supply mix, they cannot be added. An additional analysis of the supply mix to avoid double counting was therefore carried out.

For this analysis, it was assumed that the capacity of thermal electricity generation capacity would be substituted gradually and new power plants would be built to comply with demand, under the following conditions:

- 1) Switching from coal to gas was assumed for 20% of the coal plants, as this is the cheapest option.
- 2) The replacement of existing fossil fuel plants and the building of new plants up to 2030 to meet increasing power demand was shared between efficient fossil fuel plants, renewables, nuclear and coal and gas-fired plants with CCS. No early retirement of plants or stranded assets was assumed.
- 3) Low- or zero-carbon technologies are employed proportional

**Table TS.4:** Projected power demand increase from 2010 to 2030 as met by new, more efficient additional and replacement plants and the resulting mitigation potential above the World Energy Outlook 2004 baseline [Table 4.20].

	Power plant efficiencies by 2030 (based on IEA 2004a) <sup>a</sup> (%)	Existing mix of power generation in 2010 (TWh)	Generation from additional new plant by 2030 (TWh)	Generation from new plant replacing old, existing 2010 plant by 2030 (TWh)	Share of mix of generation of total new and replacement plant built by 2030 including CCS at various carbon prices (US\$/tCO <sub>2</sub> -eq) <sup>b</sup>			Total GtCO <sub>2</sub> -eq avoided by fuel switching, CCS and displacing some fossil fuel generation with low-carbon options of wind, solar, geothermal, hydro, nuclear and biomass		
					<20 US\$/TWh	<50 US\$/TWh	<100 US\$/TWh	<20 US\$/t	<50 US\$/t	<100 US\$/t
<b>OECD</b>		<b>11,302</b>	<b>2942</b>	<b>4521</b>	<b>7463</b>			<b>1.58</b>	<b>2.58</b>	<b>2.66</b>
Coal	41	4079	657	1632	899	121	0			
Oil	40	472	-163C	189	13	2	0			
Gas	48	2374	1771	950	1793	637	458			
Nuclear	33	2462	-325	985	2084	2084	1777			
Hydro	100	1402	127	561	1295	1295	1111			
Biomass	28	237	168	95	263	499	509			
Other renewables	63	276	707	110	1116	1544	1526			
CCS					0	1282	2082			
<b>Economies In Transition (EIT)</b>		<b>1746</b>	<b>722</b>	<b>698</b>	<b>1420</b>			<b>0.32</b>	<b>0.42</b>	<b>0.49</b>
Coal	32	381	13	152	72	46	29			
Oil	29	69	-8	28	11	7	4			
Gas	39	652	672	261	537	357	240			
Nuclear	33	292	-20	117	442	442	442			
Hydro	100	338	35	135	170	170	170			
Biomass	48	4	7	2	47	109	121			
Other renewables	36	10	23	4	142	167	191			
CCS					0	123	222			

**Notes:**

- <sup>a</sup>) Implied efficiencies calculated from WEO 2004 (IEA, 2004b) = Power output (EJ)/Estimated power input (EJ). See Appendix 1, Chapter 11.
- <sup>b</sup>) At higher carbon prices, more coal, oil and gas power generation is displaced by low- and zero-carbon options. Since nuclear and hydro are cost competitive at <20US\$/tCO<sub>2</sub>-eq in most regions (Chapter 4, Table 4.4.4), their share remains constant.
- <sup>c</sup>) Negative data depicts a decline in generation, which was included in the analysis.

to their estimated maximum shares in electricity generation in 2030. These shares are based on the literature, taking into account resource availability, relative costs and variability of supply related to intermittency issues in the power grid, and were differentiated according to carbon cost levels.

The resulting economic mitigation potential for the energy-supply sector by 2030 from improved thermal power-plant efficiency, fuel switching and the implementation of more nuclear, renewables, fuel switching and CCS to meet growing demand is around 7.2 GtCO<sub>2</sub>-eq at carbon prices <100 US\$/tCO<sub>2</sub>-eq. At costs <20 US\$/tCO<sub>2</sub>-eq the reduction potential is estimated at 3.9 GtCO<sub>2</sub>-eq (Table TS.4). At this carbon price level, the share of renewable energy in electricity generation would increase from 20% in 2010 to about 30% in 2030. At carbon prices <50 US\$/tCO<sub>2</sub>-eq, the share would increase to 35% of total electricity generation. The share of nuclear energy would be about 18% in 2030 at carbon prices <50 US\$/tCO<sub>2</sub>-eq, and would not change much at higher prices as other technologies would be competitive.

For assessment of the economic potential, maximum technical shares for the employment of low- or zero-carbon technologies were assumed and the estimate is therefore at the high end of the wide range found in the literature. If, for instance, only 70% of the assumed shares is reached, the mitigation potential at carbon prices <100 US\$/tCO<sub>2</sub>-eq would be almost halved. Potential savings in electricity demand in end-use sectors reduce the need for mitigation measures in the power sector. When the impact of mitigation measures in the building and industry sectors on electricity demand (outlined in Chapter 11) is taken into account, a lower mitigation potential for the energy-supply sector results than the stand-alone figure reported here (*medium agreement, limited evidence*) [4.4].

### Interactions of mitigation options with vulnerability and adaptation

Many energy systems are themselves vulnerable to climate change. Fossil fuel based offshore and coastal oil and gas extraction systems are vulnerable to extreme weather events.

Cooling of conventional and nuclear power plants may become problematic if river waters are warmer. Renewable energy resources can also be affected adversely by climate change (such as solar systems impacted by changes in cloud cover; hydropower generation influenced by changes in river discharge, glaciers and snow melt; windpower influenced by changing wind velocity; and energy crop yields reduced by drought and higher temperatures). Some adaptation measures to climate change, like air-conditioning and water pumps use energy and may contribute to even higher CO<sub>2</sub> emissions, and thus necessitate even more mitigation (*high agreement, limited evidence*) [4.5.5].

### **Effectiveness of and experience with climate policies, potentials, barriers, opportunities and implementation issues**

The need for immediate short-term action in order to make any significant impact in the longer term has become apparent, as has the need to apply the whole spectrum of policy instruments, since no single instrument will enable a large-scale transition in energy-supply systems on a global basis. Large-scale energy conversion technologies have a life of several decades and hence a turnover of only 1–3% per year. That means that policy decisions taken today will affect the rate of deployment of carbon-emitting technologies for several decades. They will have profound consequences on development paths, especially in a rapidly developing world [4.1].

Economic and regulatory instruments have been employed. Approaches to encourage the greater uptake of low-carbon energy-supply systems include reducing fossil fuel subsidies and stimulating front-runners in specific technologies through active government involvement in market creation (such as in Denmark for wind energy and Japan with solar photovoltaic (PV)). Reducing fossil fuel subsidies has been difficult, as it meets resistance by vested interests. In terms of support for renewable-electricity projects, feed-in-tariffs have been more effective than green certificate trading systems based on quotas. However, with increasing shares of renewables in the power mix, the adjustment of such tariffs becomes an issue. Tradable permit systems and the use of the Kyoto flexible mechanisms are expected to contribute substantially to emission reductions (*medium agreement, medium evidence*) [4.5].

### **Integrated and non-climate policies and co-benefits of mitigation policies**

Co-benefits of GHG mitigation in the energy supply sector can be substantial. When applying cost-effective energy-efficiency measures, there is an immediate economic benefit to consumers from lower energy costs. Other co-benefits in terms of energy supply security, technological innovation, air-pollution abatement and employment also typically result at the local scale. This is especially true for renewables which can reduce import dependency and in many cases minimize transmission

losses and costs. Electricity, transport fuels and heat supplied by renewable energy are less prone to price fluctuations, but in many cases have higher costs. As renewable energy technologies can be more labour-intensive than conventional technologies per unit of energy output, more employment will result. High investment costs of new energy system infrastructures can, however, be a major barrier to their implementation.

Developing countries that continue to experience high economic growth will require significant increases in energy services that are currently being met mainly by fossil fuels. Increasing access to modern energy services can have multiple benefits. Their use can help improve air quality, particularly in large urban areas, and lead to a decrease in GHG emissions. An estimated 2400 GW of new power plants plus the related infrastructure will need to be built in developing countries by 2030 to meet increased consumer demand, requiring an investment of around 5 trillion US\$ ( $5 \times 10^{12}$ ). If well directed, such large investments provide opportunities for sustainable development. The integration of development policies with GHG mitigation objectives can deliver the advantages mentioned above and contribute to development goals pertaining to employment, poverty and equity. Analysis of possible policies should take into account these co-benefits. However, it should be noted again that, in specific circumstances, pursuing air-pollution abatement or energy security aims can lead to more energy use and related GHG emissions.

Liberalization and privatization policies to develop free energy markets aim to provide greater competition and lower consumer prices but have not always been successful in this regard, often resulting in a lack of capital investment and scant regard for environmental impacts (*high agreement, much evidence*) [4.2.4; 4.5.2; 4.5.3; 4.5.4].

### **Technology research, development, diffusion and transfer**

Investment in energy technology R&D has declined overall since the levels achieved in the late 1970s that resulted from the oil crisis. Between 1980 and 2002, public energy-related R&D investment declined by 50% in real terms. Current levels have risen, but may still be inadequate to develop the technologies needed to reduce GHG emissions and meet growing energy demand. Greater public and private investment will be required for rapid deployment of low-carbon energy technologies. Improved energy conversion technologies, energy transport and storage methods, load management, co-generation and community-based services will have to be developed (*high agreement, limited evidence*) [4.5.6].

### **Long-term outlook**

Outlooks from both the IEA and World Energy Council project increases in primary energy demand of between 40 and 150% by 2050 over today's demand, depending on the scenarios for popu-

lation and economic growth and the rate of technology development. Electricity use is expected to grow by between 110 and 260%. Both organizations realize that business-as-usual scenarios are not sustainable. It is well accepted that even with good decision-making and co-operation between the public and private sectors, the necessary transition will take time and the sooner it is begun the lower the costs will be (*high agreement, much evidence*) [4.2.3].

## 5 Transport and its infrastructure

### Status and development of the sector

Transport activity is increasing around the world as economies grow. This is especially true in many areas of the developing world where globalization is expanding trade flows, and rising personal incomes are amplifying demand for motorized mobility. Current transportation activity is mainly driven by internal combustion engines powered by petroleum fuels (95% of the 83 EJ of world transport energy use in 2004). As a consequence, petroleum use closely follows the growth in transportation activity. In 2004, transport energy amounted to 26% of total world energy use. In the developed world, transport energy use continues to increase at slightly more than 1% per year;

passenger transport currently consumes 60–75% of total transport energy there. In developing countries, transport energy use is rising faster (3 to 5% per year) and is projected to grow from 31% in 2002 to 43% of world transport energy use by 2025 [5.2.1, 5.2.2].

Transport activity is expected to grow robustly over the next several decades. Unless there is a major shift away from current patterns of energy use, projections foresee a continued growth in world transportation energy use of 2% per year, with energy use and carbon emissions about 80% above 2002 levels by 2030 [5.2.2]. In developed economies, motor vehicle ownership approaches five to eight cars for every ten inhabitants (Figure TS.14). In the developing world, levels of vehicle ownership are much lower; non-motorized transport plays a significant role, and there is a greater reliance on two- and three-wheeled motorized vehicles and public transport. The motorization of transport in the developing world is, however, expected to grow rapidly in the coming decades. As incomes grow and the value of travellers' time increases, travellers are expected to choose faster modes of transport, shifting from non-motorized to automotive, to air and high-speed rail. Increasing speed has generally led to greater energy intensity and higher GHG emissions.

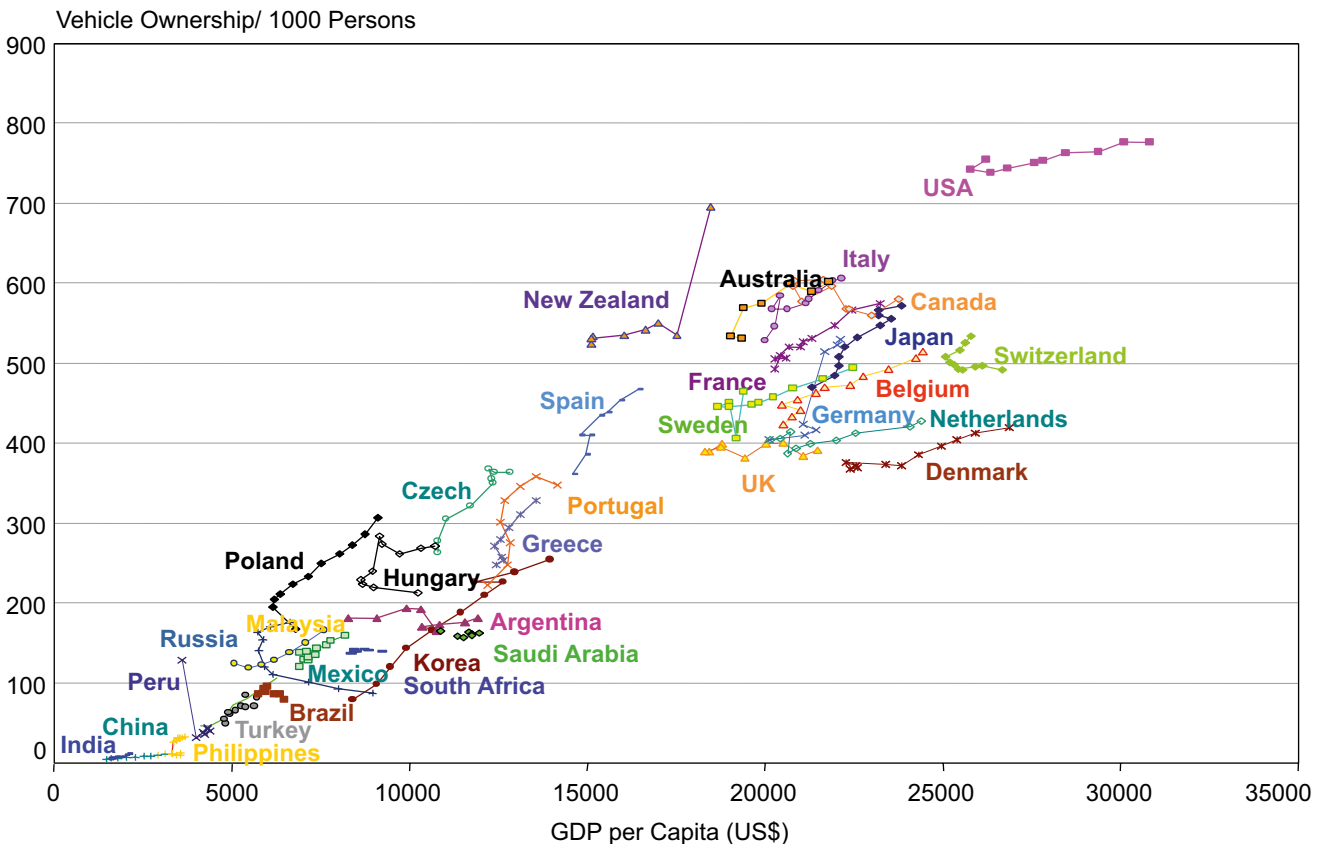


Figure TS.14: Vehicle ownership and income per capita as a time line per country [Figure 5.2].

Note: data are for 1900–2002, but the years plotted vary by country, depending on data availability.

In addition to GHG emissions, the motorization of transport has created congestion and air-pollution problems in large cities all around the world (*high agreement, much evidence*) [5.2.1; 5.2.2; 5.5.4].

### Emission trends

In 2004, the contribution of transport to total energy-related GHG emissions was about 23%, with emissions of CO<sub>2</sub> and N<sub>2</sub>O amounting to about 6.3-6.4 GtCO<sub>2</sub>-eq. Transport sector CO<sub>2</sub> emissions (6.2 GtCO<sub>2</sub>-eq. in 2004) have increased by around 27% since 1990 and its growth rate is the highest among the end-user sectors. Road transport currently accounts for 74% of total transport CO<sub>2</sub> emissions. The share of non-OECD countries is 36% now and will increase rapidly to 46% by 2030 if current trends continue (*high agreement, medium evidence*) [5.2.2].

The transport sector also contributes small amounts of CH<sub>4</sub> and N<sub>2</sub>O emissions from fuel combustion and F-gases from vehicle air-conditioning. CH<sub>4</sub> emissions are between 0.1–0.3% of total transport GHG emissions, N<sub>2</sub>O between 2.0 and 2.8% (all figures based on US, Japan and EU data only). Emissions of F gases (CFC-12 + HFC-134a + HCFC-22) worldwide in 2003 were 4.9% of total transport CO<sub>2</sub> emissions (*medium agreement, limited evidence*) [5.2.1].

Estimates of CO<sub>2</sub> emissions from global aviation increased by a factor of about 1.5, from 330 MtCO<sub>2</sub>/yr in 1990 to 480 MtCO<sub>2</sub>/yr in 2000, and accounted for about 2% of total anthropogenic CO<sub>2</sub> emissions. Aviation CO<sub>2</sub> emissions are projected to continue to grow strongly. In the absence of additional measures, projected annual improvements in aircraft fuel efficiency of the order of 1–2% will be largely surpassed by traffic growth of around 5% each year, leading to a projected increase in emissions of 3–4% per year (*high agreement, medium evidence*). Moreover, the overall climate impact of aviation is much greater than the impact of CO<sub>2</sub> alone. As well as emitting CO<sub>2</sub>, aircraft contribute to climate change through the emission of nitrogen oxides (NO<sub>x</sub>), which are particularly effective in forming the GHG ozone when emitted at cruise altitudes. Aircraft also trigger the formation of condensation trails, or contrails, which are suspected of enhancing the formation of cirrus clouds, which add to the overall global warming effect. These effects are estimated to be about two to four times greater than those of aviation's CO<sub>2</sub> alone, even without considering the potential impact of cirrus cloud enhancement. The environmental effectiveness of future mitigation policies for aviation will depend on the extent to which these non-CO<sub>2</sub> effects are also addressed (*high agreement, medium evidence*) [5.2.1; 5.2.2].

All of the projections discussed above assume that world oil supplies will be more than adequate to support the expected growth in transport activity. There is ongoing debate, however, about whether the world is nearing a peak in conventional oil

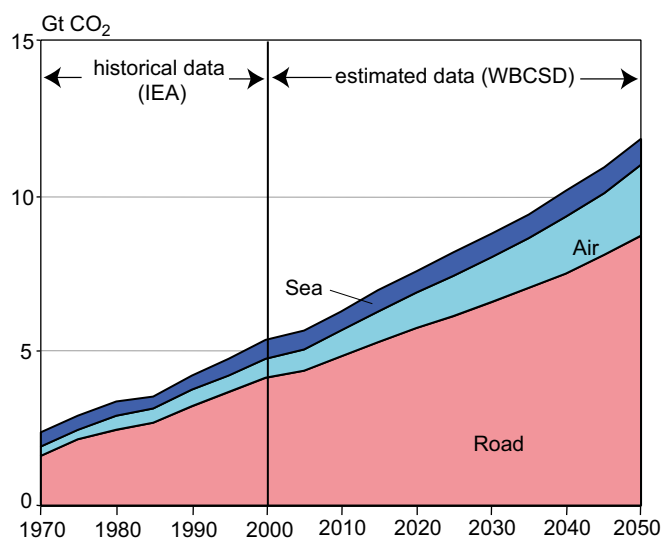


Figure TS.15: Historical and projected CO<sub>2</sub> emissions from transport [Figure 5.4].

production that would require a significant and rapid transition to alternative energy sources. There is no shortage of alternative energy sources, including oil sands and oil shales, coal-to-liquids, biofuels, electricity and hydrogen. Among these alternatives, unconventional fossil carbon resources would produce the least expensive fuels most compatible with the existing transportation infrastructure. Unfortunately, tapping into these fossil resources to power transportation would increase upstream carbon emissions and greatly increase the input of carbon into the atmosphere [5.2.2; 5.3].

### Description and assessment of mitigation technologies and practices, options, potentials and costs

Transport is distinguished from other energy-using sectors by its predominant reliance on a single fossil resource and by the infeasibility of capturing carbon emissions from transport vehicles with any known technologies. It is also important to view GHG-emission reductions in conjunction with air pollution, congestion and energy security (oil import) problems. Solutions therefore have to try to optimize improvement of transportation problems as a whole, not just GHG emissions [5.5.4].

There have been significant developments in mitigation technologies since the Third Assessment Report (TAR), and significant research, development and demonstration programmes on hydrogen-powered fuel-cell vehicles have been launched around the globe. In addition, there are still many opportunities for improvement of conventional technologies. Biofuels continue to be important in certain markets and have much greater potential for the future. With regard to non-CO<sub>2</sub> emissions, vehicle air-conditioning systems based on low GWP refrigerants have been developed [5.3].



**Road traffic: efficient technologies and alternative fuels**

Since the TAR, the energy efficiency of road vehicles has improved by the market success of cleaner directed-injection turbocharged (TDI) diesels and the continued market penetration of many incremental efficiency technologies; hybrid vehicles have also played a role, though their market penetration is currently small. Further technological advances are expected for hybrid vehicles and TDI diesel engines. A combination of these with other technologies, including materials substitution, reduced aerodynamic drag, reduced rolling resistance, reduced engine friction and pumping losses, has the potential to approximately double the fuel economy of ‘new’ light-duty vehicles by 2030, thereby roughly halving carbon emissions per vehicle mile travelled (note that this is only for a new car and not the fleet average) (*medium agreement, medium evidence*) [5.3.1].

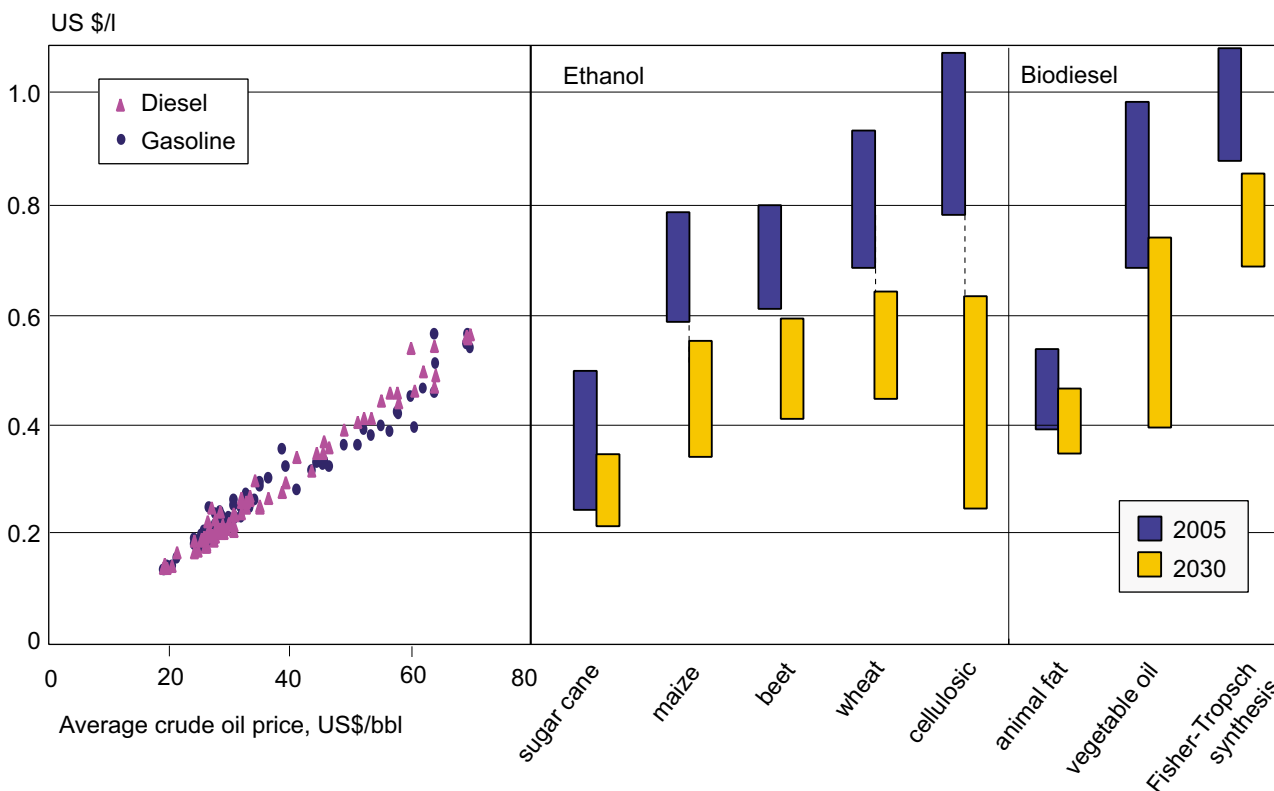
Biofuels have the potential to replace a substantial part, but not all, petroleum use by transport. A recent IEA report estimated that the share of biofuels could increase to about 10% by 2030 at costs of 25 US\$/tCO<sub>2</sub>-eq, which includes a small contribution from biofuels from cellulosic biomass. The potential strongly depends on production efficiency, the development of advanced techniques such as conversion of cellulose by enzymatic processes or by gasification and synthesis, costs, and competition with other uses of land. Currently the cost and performance of ethanol in terms of CO<sub>2</sub> emissions avoided is unfavourable, except for production from sugarcane in low-

wage countries (Figure TS.16) (*medium agreement, medium evidence*) [5.3.1].

The economic and market potential of hydrogen vehicles remains uncertain. Electric vehicles with high efficiency (more than 90%), but low driving range and short battery life have a limited market penetration. For both options, the emissions are determined by the production of hydrogen and electricity. If hydrogen is produced from coal or gas with CCS (currently the cheapest way) or from biomass, solar, nuclear or wind energy, well-to-wheel carbon emissions could be nearly eliminated. Further technological advances and/or cost reductions would be required in fuel-cells, hydrogen storage, hydrogen or electricity production with low- or zero-carbon emissions, and batteries (*high agreement, medium evidence*) [5.3.1].

The total mitigation potential in 2030 of the energy-efficiency options applied to light duty vehicles would be around 0.7–0.8 GtCO<sub>2</sub>-eq in 2030 at costs lower than 100 US\$/tCO<sub>2</sub>. Data are not sufficient to provide a similar estimate for heavy-duty vehicles. The use of current and advanced biofuels, as mentioned above, would give an additional reduction potential of another 600–1500 MtCO<sub>2</sub>-eq in 2030 at costs lower than 25 US\$/tCO<sub>2</sub> (*low agreement, limited evidence*) [5.4.2].

A critical threat to the potential for future reduction of CO<sub>2</sub> emissions from use of fuel economy technologies is that



**Figure TS.16:** Comparison between current and future biofuel production costs versus gasoline and diesel ex-refinery (FOB) prices for a range of crude oil prices [Figure 5.9]. Note: prices exclude taxes.

they can be used to increase vehicle power and size rather than to improve the overall fuel economy and reduce carbon emissions. The preference of the market for power and size has consumed much of the potential for GHG mitigation reduction achieved over the past two decades. If this trend continues, it will significantly diminish the GHG mitigation potential of the advanced technologies described above (*high agreement, much evidence*) [5.2; 5.3].

#### **Air traffic**

The fuel efficiency of civil aviation can be improved by a variety of means including technology, operation and management of air traffic. Technology developments might offer a 20% improvement in fuel efficiency over 1997 levels by 2015, with a 40–50% improvement likely by 2050. As civil aviation continues to grow at around 5% each year, such improvements are unlikely to keep carbon emissions from global air travel from increasing. The introduction of biofuels could mitigate some of aviation's carbon emissions, if biofuels can be developed to meet the demanding specifications of the aviation industry, although both the costs of such fuels and the emissions from their production process are uncertain at this time (*medium agreement, medium evidence*) [5.3.3].

Aircraft operations can be optimized for energy use (with minimum CO<sub>2</sub> emissions) by minimizing taxiing time, flying at optimal cruise altitudes, flying minimum-distance great-circle routes, and minimizing holding and stacking around airports. The GHG-reduction potential of such strategies has been estimated at 6–12%. More recently, researchers have begun to address the potential for minimizing the total climate impact of aircraft operations, including ozone impacts, contrails and nitrogen oxides emissions. The mitigation potential in 2030 for aviation is 280 MtCO<sub>2</sub>/yr at costs <100 US\$/tCO<sub>2</sub> (*medium agreement, medium evidence*) [5.4.2].

#### **Marine transport**

Since the TAR, an International Maritime Organization (IMO) assessment found that a combination of technical measures could reduce carbon emissions by 4–20% in older ships and 5–30% in new ships by applying state-of-the-art knowledge, such as hull and propeller design and maintenance. However, due to the long lifetime of engines, it will take decades before measures on existing ships are implemented on a significant scale. The short-term potential for operational measures, including route-planning and speed reduction, ranged from 1–40%. The study estimated a maximum reduction of emissions of the world fleet of about 18% by 2010 and 28% by 2020, when all measures were to be implemented. The data do not allow an estimate of an absolute mitigation potential figure and the mitigation potential is not expected to be sufficient to offset the growth in shipping activity over the same period (*medium agreement, medium evidence*) [5.3.4].

#### **Rail transport**

The main opportunities for mitigating GHG emissions associated with rail transport are improving aerodynamics, reduction of train weight, introducing regenerative braking and on-board energy storage and, of course, mitigating the GHG emissions from electricity generation. There are no estimates available of total mitigation potential and costs [5.3.2].

#### **Modal shifts and public transport**

Providing public transports systems and their related infrastructure and promoting non-motorized transport can contribute to GHG mitigation. However, local conditions determine how much transport can be shifted to less energy-intensive modes. Occupancy rates and the primary energy sources of the transport modes further determine the mitigation potential [5.3.1].

The energy requirements of urban transport are strongly influenced by the density and spatial structure of the built environment, as well as by the location, extent and nature of the transport infrastructure. Large-capacity buses, light-rail transit and metro or suburban rail are increasingly being used for the expansion of public transport. Bus Rapid Transit systems have relatively low capital and operational costs, but it is uncertain if they can be implemented in developing countries with the same success as in South America. If the share of buses in passenger transport were to increase by 5–10%, then CO<sub>2</sub> emissions would fall by 4–9% at costs in the order of US\$ 60–70/tCO<sub>2</sub> [5.3.1].

More than 30% of the trips made by cars in Europe are for less than 3 km and 50% for less than 5 km. Although the figures may differ for other continents, there is potential for mitigation by shifting from cars to non-motorized transport (walking and cycling), or preventing a growth of car transport at the expense of non-motorized transport. Mitigation potentials are highly dependent on local conditions, but there are substantial co-benefits in terms of air quality, congestion and road safety (*high agreement, much evidence*) [5.3.1].

#### **Overall mitigation potential in the transport sector**

The overall potential and cost for CO<sub>2</sub> mitigation can only be partially estimated due to lack of data for heavy-duty vehicles, rail transport, shipping and modal split change/ public transport promotion. The total economic potential for improved efficiency of light-duty vehicles and aeroplanes and substituting biofuels for conventional fossil fuels, for a carbon price up to 100 US\$/tCO<sub>2</sub>-eq, is estimated to be about 1600–2550 MtCO<sub>2</sub>. This is an underestimate of potential for mitigation in the transport sector (*high agreement, medium evidence*) [5.4.2].

## Effectiveness of and experience with climate policies, potentials, barriers and opportunities/ implementation issues

### *Policies and measures for surface transport*

Given the positive effects of higher population densities on public transport use, walking, cycling and CO<sub>2</sub> emissions, better integrated spatial planning is an important policy element in the transportation sector. There are some good examples for large cities in several countries. Transportation Demand Management (TDM) can be effective in reducing private vehicle travel if rigorously implemented and supported. Soft measures, such as the provision of information and the use of communication strategies and educational techniques have encouraged a change in personal behaviour leading to a reduction in the use of the car by 14% in an Australian city, 12% in a German city and 13% in a Swedish city (*medium agreement, medium evidence*) [5.5.1].

Fuel-economy standards or CO<sub>2</sub> standards have been effective in reducing GHG emissions, but so far, transport growth has overwhelmed their impact. Most industrialized and some developing countries have set fuel-economy standards for new light-duty vehicles. The forms and stringency of standards vary widely, from uniform, mandatory corporate average standards, through graduated standards by vehicle weight class or size, to voluntary industry-wide standards. Fuel economy standards have been universally effective, depending on their stringency, in improving vehicle fuel economy, increasing on-road fleet-average fuel economy and reducing fuel use and carbon emissions. In some countries, fuel-economy standards have been strongly opposed by segments of the automotive industry on a variety of grounds, ranging from economic efficiency to safety. The overall effectiveness of standards can be significantly enhanced if combined with fiscal incentives and consumer information (*high agreement, much evidence*) [5.5.1].

Taxes on vehicle purchase, registration, use and motor fuels, as well as road and parking pricing policies are important determinants of vehicle-energy use and GHG emissions. They are employed by different countries to raise general revenue, to partially internalize the external costs of vehicle use or to control congestion of public roads. An important reason for fuel or CO<sub>2</sub> tax having limited effects is that price elasticities tend to be substantially smaller than the income elasticities of demand. In the long run, the income elasticity of demand is a factor 1.5–3 higher than the price elasticity of total transport demand, meaning that price signals become less effective with increasing incomes. Rebates on vehicle purchase and registration taxes for fuel-efficient vehicles have been shown to be effective. Road and parking pricing policies are applied in several cities, with marked effects on passenger car traffic (*high agreement, much evidence*) [5.5.1].

Many governments have introduced or are intending to implement policies to promote biofuels in national emission

abatement strategies. Since the benefit of biofuels for CO<sub>2</sub> mitigation comes mainly from the well-to-tank part, incentives for biofuels are more effective climate policies if they are tied to entire well-to-wheels CO<sub>2</sub> efficiencies. Thus preferential tax rates, subsidies and quotas for fuel blending should be calibrated to the benefits in terms of net CO<sub>2</sub> savings over the entire well-to-wheel cycle associated with each fuel. In order to avoid the negative effects of biofuel production on sustainable development (e.g., biodiversity impacts), additional conditions could be tied to incentives for biofuels.

### *Policies and measures for aviation and marine transport*

In order to reduce emissions from air and marine transport resulting from the combustion of bunker fuels, new policy frameworks need to be developed. Both the International Civil Aviation Organization (ICAO) and IMO have studied options for limiting GHG emissions. However, neither has yet been able to devise a suitable framework for implementing policies. ICAO, however, has endorsed the concept of an open, international emission-trading system implemented through a voluntary scheme, or the incorporation of international aviation into existing emission-trading systems.

For aviation, both fuel or emission charges and trading would have the potential to reduce emissions considerably. The geographical scope (routes and operators covered), the amount of allowances to be allocated to the aviation sector and the coverage of non-CO<sub>2</sub> climate impacts will be key design elements in determining the effectiveness of emissions trading for reducing the impacts of aviation on climate. Emission charges or trading would lead to an increase in fuel costs that will have a positive impact on engine efficiency [5.5.2].

Current policy initiatives in the shipping sector are mostly based on voluntary schemes, using indexes for the fuel efficiency of ships. Environmentally differentiated port dues are being used in a few places. Other policies to limit shipping emissions would be the inclusion of international shipping in international emissions-trading schemes, fuel taxes and regulatory instruments (*high agreement, medium evidence*) [5.5.2].

### *Integrated and non-climate policies affecting emissions of GHGs and co-benefits of GHG mitigation policies*

Transport planning and policy have recently placed more weight on sustainable development aspects. This includes reducing oil imports, improved air quality, reducing noise pollution, increasing safety, reducing congestion and improving access to transport facilities. Such policies can have important synergies with reducing GHG emissions (*high agreement, medium evidence*) [5.5.4; 5.5.5].

## 6 Residential and commercial buildings

### Status of the sector and emission trends

In 2004, direct GHG emissions from the buildings sector (excluding emissions from electricity use) were about 5 GtCO<sub>2</sub>-eq/yr (3 GtCO<sub>2</sub>-eq/yr CO<sub>2</sub>; 0.1 GtCO<sub>2</sub>-eq/yr N<sub>2</sub>O; 0.4 GtCO<sub>2</sub>-eq/yr CH<sub>4</sub> and 1.5 GtCO<sub>2</sub>-eq/yr halocarbons). The last figure includes F-gases covered by the Montreal protocol and about 0.1–0.2 GtCO<sub>2</sub>-eq/yr of HFCs. As mitigation in this sector includes many measures aimed at saving electricity, the mitigation potential is generally calculated including electricity saving measures. For comparison, emission figures of the building sector are often presented including emissions from electricity use in the sector. When including the emissions from electricity use, energy-related CO<sub>2</sub> emissions from the buildings sector were 8.6 Gt/yr, or 33% of the global total in 2004. Total GHG emissions, including the emissions from electricity use, are then estimated at 10.6 Gt CO<sub>2</sub>eq/yr (*high agreement, medium evidence*) [6.2].

### Future carbon emissions from energy use in buildings

The literature for the buildings sector uses a mixture of baselines. Therefore, for this chapter, a building sector baseline was defined, somewhere between SRES B2 and A1B<sup>2</sup>, with 14.3 GtCO<sub>2</sub>-eq GHG emissions (including emissions from electricity use) in 2030. The corresponding emissions in the SRES B2 and A1B scenarios are 11.4 and 15.6 GtCO<sub>2</sub>. In the SRES B2 scenario (Figure TS.17), which is based on relatively lower economic growth, North America and Non-Annex I East Asia account for the largest portion of the increase in emissions. In the SRES A1B scenario, which shows rapid economic growth, all the CO<sub>2</sub> emissions increase is in the developing world: Asia, Middle East and North Africa, Latin America, and Sub-Saharan Africa, in that order. Overall, average annual CO<sub>2</sub> emission growth between 2004 and 2030 is 1.5% in Scenario B2 and

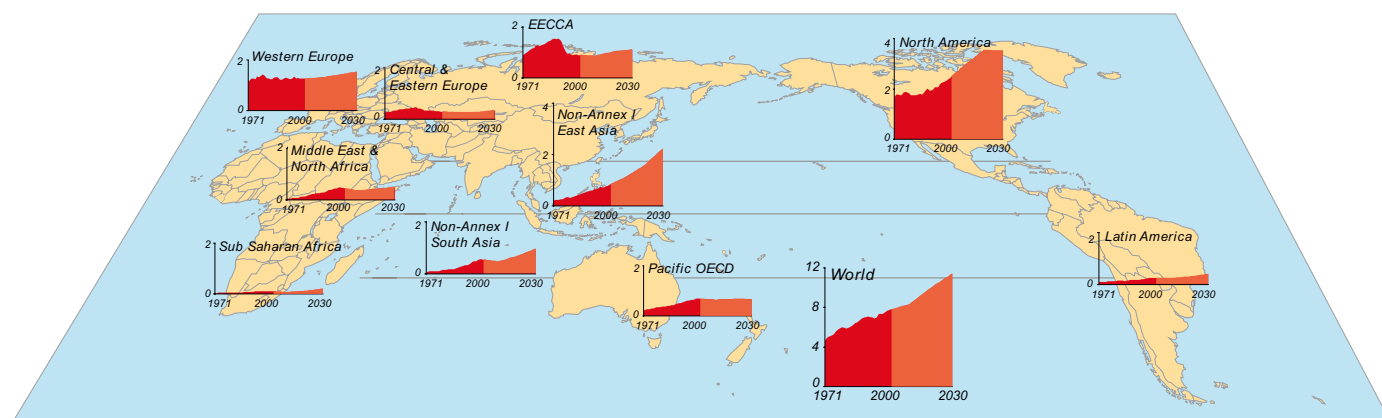
2.4% in Scenario A1B (*high agreement, medium evidence*) [6.2, 6.3].

### Mitigation technologies and practices

Measures to reduce GHG emissions from buildings fall into one of three categories: 1) reducing energy consumption<sup>13</sup> and embodied energy in buildings; 2) switching to low-carbon fuels, including a higher share of renewable energy; 3) controlling emissions of non-CO<sub>2</sub> GHG gases. Many current technologies allow building energy consumption to be reduced through better thermal envelopes<sup>14</sup>, improved design methods and building operations, more efficient equipment, and reductions in demand for energy services. The relative importance of heating and cooling depends on climate and thus varies regionally, while the effectiveness of passive design techniques also depends on climate, with important distinctions between hot-humid and hot-arid regions. Occupant behaviour, including avoiding unnecessary operation of equipment and adaptive rather than invariant temperature standards for heating and cooling, is also a significant factor in limiting building energy use (*high agreement, much evidence*) [6.4].

### Mitigation potential of the building sector

Substantial CO<sub>2</sub> emission reduction from energy use in buildings can be achieved over the coming years compared with projected emissions. The considerable experience in a wide variety of technologies, practices and systems for energy efficiency and an equally rich experience with policies and programmes that promote energy efficiency in buildings lend considerable confidence to this view. A significant portion of these savings can be achieved in ways that reduce life-cycle costs, thus providing reductions in CO<sub>2</sub> emissions that have a net negative cost (generally higher investment cost but lower operating cost) (*high agreement, much evidence*) [6.4; 6.5].



**Figure TS.17:** CO<sub>2</sub> emissions (GtCO<sub>2</sub>) from buildings including emissions from the use of electricity, 1971–2030 [Figure 6.2].

Note: Dark red – historic emissions; light red – projection according to SRES B2 scenario. EECCA=Countries of Eastern Europe, the Caucasus and Central Asia.

<sup>13</sup> This counts all forms of energy use in buildings, including electricity.

<sup>14</sup> The term 'thermal envelope' refers to the shell of a building as a barrier to unwanted heat or mass transfer between the interior of the building and outside.

**Table TS.5: GHG emissions reduction potential for the buildings stock in 2020<sup>a</sup> [Table 6.2].**

Economic region	Countries/country groups reviewed for region	Potential as % of national baseline for buildings <sup>b</sup>	Measures covering the largest potential	Measures providing the cheapest mitigation options
<b>Developed countries</b>	USA, EU-15, Canada, Greece, Australia, Republic of Korea, United Kingdom, Germany, Japan	<u>Technical:</u> 21%-54% <sup>c</sup> <u>Economic (&lt;US\$ 0/tCO<sub>2</sub>-eq):</u> 12%-25% <sup>d</sup> <u>Market:</u> 15%-37%	1. Shell retrofit, inc. insulation, esp. windows and walls; 2. Space heating systems; 3. Efficient lights, especially shift to compact fluorescent lamps (CFL) and efficient ballasts.	1. Appliances such as efficient TVs and peripherals (both on-mode and standby), refrigerators and freezers, ventilators and air-conditioners; 2. Water heating equipment; 3. Lighting best practices.
<b>Economies in Transition</b>	Hungary, Russia, Poland, Croatia, as a group: Latvia, Lithuania, Estonia, Slovakia, Slovenia, Hungary, Malta, Cyprus, Poland, the Czech Republic	<u>Technical:</u> 26%-47% <sup>e</sup> <u>Economic (&lt;US\$ 0/tCO<sub>2</sub>-eq):</u> 13%-37% <sup>f</sup> <u>Market:</u> 14%	1. Pre- and post- insulation and replacement of building components, esp. windows; 2. Efficient lighting, esp. shift to CFLs; 3. Efficient appliances such as refrigerators and water heaters.	1. Efficient lighting and its controls; 2. Water and space heating control systems; 3. Retrofit and replacement of building components, esp. windows.
<b>Developing countries</b>	Myanmar, India, Indonesia, Argentine, Brazil, China, Ecuador, Thailand, Pakistan, South Africa	<u>Technical:</u> 18%-41% <u>Economic (&lt;US\$ 0/tCO<sub>2</sub>-eq):</u> 13%-52% <sup>g</sup> <u>Market:</u> 23%	1. Efficient lights, esp. shift to CFLs, light retrofit, and kerosene lamps; 2. Various types of improved cooking stoves, esp. biomass stoves, followed by LPG and kerosene stoves; 3. Efficient appliances such as air-conditioners and refrigerators.	1. Improved lights, esp. shift to CFLs light retrofit, and efficient kerosene lamps; 2. Various types of improved cooking stoves, esp. biomass based, followed by kerosene stoves; 3. Efficient electric appliances such as refrigerators and air-conditioners.

**Notes:**

- a) Except for EU-15, Greece, Canada, India, and Russia, for which the target year was 2010, and Hungary, Ecuador and South Africa, for which the target was 2030.
- b) The fact that the market potential is higher than the economic potential for developed countries is explained by limitation of studies considering only one type of potential, so information for some studies likely having higher economic potential is missing.
- c) Both for 2010, if the approximate formula of  $Potential_{2020} = 1 - (1 - Potential_{2010})^{20/10}$  is used to extrapolate the potential as percentage of the baseline into the future (the year 2000 is assumed as a start year), this interval would be 38%–79%.
- d) Both for 2010, if suggested extrapolation formula is used, this interval would be 22%–44%.
- e) The last figure is for 2010, corresponds to 72% in 2020 if the extrapolation formula is used.
- f) The first figure is for 2010, corresponds to 24% in 2020 if the extrapolation formula is used.
- g) The last figure is for 2030, corresponds to 38% in 2020 if the suggested extrapolation formula is applied to derive the intermediate potential.

These conclusions are supported by a survey of 80 studies (Table TS.5), which show that efficient lighting technologies are among the most promising GHG-abatement measures in buildings in almost all countries, in terms of both cost-effectiveness and potential savings. By 2020, approximately 760 Mt of CO<sub>2</sub> emissions can be abated by the adoption of least life-cycle cost lighting systems globally, at an average cost of -160 US\$/tCO<sub>2</sub> (i.e., at a net economic benefit). In terms of the size of savings, improved insulation and district heating in the colder climates and efficiency measures related to space cooling and ventilation in the warmer climates come first in almost all studies, along with cooking stoves in developing countries. Other measures that rank high in terms of savings potential are solar water heating, efficient appliances and energy-management systems.

As far as cost effectiveness is concerned, efficient cooking stoves rank second after lighting in developing countries, while the measures in second place in the industrialized countries

differ according to climatic and geographic region. Almost all the studies examining economies in transition (typically in cooler climates) found heating-related measures to be the most cost effective, including insulation of walls, roofs, windows and floors, as well as improved heating controls for district heating. In developed countries, appliance-related measures are typically identified as the most cost-effective, with upgrades of cooling-related equipment ranking high in warmer climates. Air-conditioning savings can be more expensive than other efficiency measures but can still be cost-effective, because they tend to displace more expensive peak power.

In individual new buildings, it is possible to achieve 75% or more energy savings compared with recent current practice, generally at little or no extra cost. Realizing these savings requires an integrated design process involving architects, engineers, contractors and clients, with full consideration of opportunities for passively reducing the energy demands of buildings [6.4.1].

**Table TS.6:** Global CO<sub>2</sub> mitigation potential projections for 2020, as a function of costs [Table 6.3].

World regions	Baseline emissions in 2020 GtCO <sub>2</sub> -eq	CO <sub>2</sub> mitigation potentials as share of the baseline CO <sub>2</sub> emission projections in cost categories in 2020 (costs in US\$/tCO <sub>2</sub> -eq)				CO <sub>2</sub> mitigation potentials in absolute values in cost categories in 2020, GtCO <sub>2</sub> -eq (costs in US\$/tCO <sub>2</sub> -eq)			
		<0	0-20	20-100	<100	<0	0-20	20-100	<100
<b>Globe</b>	11.1	29%	3%	4%	36%	3.2	0.35	0.45	4.0
<b>OECD (-EIT)</b>	4.8	27%	3%	2%	32%	1.3	0.10	0.10	1.6
<b>EIT</b>	1.3	29%	12%	23%	64%	0.4	0.15	0.30	0.85
<b>Non-OECD</b>	5.0	30%	2%	1%	32%	1.5	0.10	0.05	1.6

Note: The aggregated global potential as a function of cost and region is based on 17 studies that reported potentials in detail as a function of costs.

Addressing GHG mitigation in buildings in developing countries is of particular importance. Cooking stoves can be made to burn more efficiently and combust particles more completely, thus benefiting village dwellers through improved indoor-air quality, while reducing GHG emissions. Local sources of improved, low GHG materials can be identified. In urban areas, and increasingly in rural ones, there is a need for all the modern technologies used in industrialized countries to reduce GHG emissions [6.4.3].

Emerging areas for energy savings in commercial buildings include the application of controls and information technology to continuously monitor, diagnose and communicate faults in commercial buildings ('intelligent control'); and systems approaches to reduce the need for ventilation, cooling, and dehumidification. Advanced windows, passive solar design, techniques for eliminating leaks in buildings and ducts, energy-efficient appliances, and controlling standby and idle power consumption as well as solid-state lighting are also important in both residential and commercial sectors (*high agreement, much evidence*) [6.5].

Occupant behaviour, culture and consumer choice and use of technologies are major determinants of energy use in buildings and play a fundamental role in determining CO<sub>2</sub> emissions. However, the potential reduction through non-technological options is rarely assessed and the potential leverage of policies over these is poorly understood (*high agreement, medium evidence*).

There are opportunities to reduce direct emissions of fluorinated gases in the buildings sector significantly through the global application of best practices and recovery methods, with mitigation potential for all F-gases of 0.7 GtCO<sub>2</sub>-eq in 2015. Mitigation of halocarbon refrigerants mainly involves avoiding leakage from air conditioners and refrigeration equipment (e.g., during normal use, maintenance and at end of life) and reducing the use of halocarbons in new equipment. A key factor determining whether this potential will be realized is the costs associated with implementation of the measures to achieve the

emission reduction. These vary considerably, from a net benefit to 300 US\$/tCO<sub>2</sub>-eq. (*high agreement, much evidence*) [6.5].

#### *Mitigation potential of the building sector*

There is a global potential to reduce approximately 30% of the projected baseline emissions from the residential and commercial sectors cost effectively by 2020 (Table TS.6). At least a further 3% of baseline emissions can be avoided at costs up to 20 US\$/tCO<sub>2</sub>-eq and 4% more if costs up to 100 US\$/tCO<sub>2</sub>-eq are considered. However, due to the large opportunities at low costs, the high-cost potential has only been assessed to a limited extent, and thus this figure is an underestimate. Using the global baseline emission projections for buildings<sup>15</sup>, these estimates represent a reduction of about 3.2, 3.6, and 4.0 Gtons of CO<sub>2</sub>-eq in 2020, at zero, 20 US\$/tCO<sub>2</sub>-eq, and 100 US\$/tCO<sub>2</sub>-eq, respectively (*high agreement, much evidence*) [6.5].

The real potential is likely to be higher, because not all end-use efficiency options were considered by the studies; non-technological options and their often significant co-benefits were omitted as were advanced integrated high-efficiency buildings. However, the market potential is much smaller than the economic potential.

Given limited information for 2030, the 2020 findings for the economic potential to 2030 have been extrapolated to enable comparisons with other sectors. The estimates are given in Table TS.7. Extrapolation of the potentials to 2030 suggests that, globally, about 4.5, 5.0 and 5.6 GtCO<sub>2</sub>-eq/yr could be reduced at costs of <0, <20 and <100 US\$/tCO<sub>2</sub>-eq respectively. This is equivalent to 30, 35, and 40% of the projected baseline emissions. These figures are associated with significantly lower levels of certainty than the 2020 ones due to very limited research available for 2030 (*medium agreement, low evidence*).

The outlook for the long-term future, assuming options in the building sector with a cost up to US\$ 25/tCO<sub>2</sub>-eq, identifies a potential of about 7.7 GtCO<sub>2</sub>-eq reductions in 2050.

<sup>15</sup> The baseline CO<sub>2</sub> emission projections were calculated on the basis of the 17 studies used for deriving the global potential (if a study did not contain a baseline, projections from another national mitigation report were used).

**Table TS.7: Global CO<sub>2</sub> mitigation potential projections for 2030, as a function of cost, based on extrapolation from the 2020 numbers, in GtCO<sub>2</sub> [Table 6.4].**

Mitigation option	Region	Baseline projections in 2030	Potential costs at below 100 US\$/tCO <sub>2</sub> -eq		Potential in different cost categories		
			Low	High	<0 US\$/tCO <sub>2</sub>	0-20 US\$/tCO <sub>2</sub>	20-100 US\$/tCO <sub>2</sub>
					<0 US\$/tC	0-73 US\$/tC	73-367 US\$/tC
<b>Electricity savings<sup>a)</sup></b>	OECD	3.4	0.75	0.95	0.85	0.0	0.0
	EIT	0.40	0.15	0.20	0.20	0.0	0.0
	Non-OECD/EIT	4.5	1.7	2.4	1.9	0.1	0.1
<b>Fuel savings</b>	OECD	2.0	1.0	1.2	0.85	0.2	0.1
	EIT	1.0	0.55	0.85	0.20	0.2	0.3
	Non-OECD/EIT	3.0	0.70	0.80	0.65	0.1	0.0
<b>Total</b>	OECD	5.4	1.8	2.2	1.7	0.2	0.1
	EIT	1.4	0.70	1.1	0.40	0.2	0.3
	Non-OECD/EIT	7.5	2.4	3.2	2.5	0.1	0.0
	Global	14.3	4.8	6.4	4.5	0.5	0.7

Note:

<sup>a)</sup> The absolute values of the potentials resulting from electricity savings in Table TS.8 and Chapter 11, Table 11.3 do not coincide due to application of different baselines; however, the potential estimates as percentage of the baseline are the same in both cases. Also Table 11.3 excludes the share of emission reductions which is already taken into account by the energy supply sector, while Table TS.7 does not separate this potential.

## Interactions of mitigation options with vulnerability and adaptation

If the world experiences warming, energy use for heating in temperate climates will decline (e.g., Europe, parts of Asia and North America), and for cooling will increase in most world regions. Several studies indicate that, in countries with moderate climates, the increase in electricity for additional cooling will outweigh the decrease for heating, and in Southern Europe a significant increase in summer peak demand is expected. Depending on the generation mix in particular countries, the net effect of warming on CO<sub>2</sub> emissions may be an increase even where overall demand for final energy declines. This causes a positive feedback loop: more mechanical cooling emits more GHGs, thereby exacerbating warming (*medium agreement, medium evidence*).

Investments in the buildings sector may reduce the overall cost of climate change by simultaneously addressing mitigation and adaptation. The most important of these synergies includes reduced cooling needs or energy use through measures such as application of integrated building design, passive solar construction, heat pumps with high efficiency for heating and cooling, adaptive window glazing, high-efficiency appliances emitting less waste heat, and retrofits including increased insulation, optimized for specific climates, and storm-proofing. Appropriate urban planning, including increasing green areas as well as cool roofs in cities, has proved to be an efficient way of limiting the ‘heat island’ effect, thereby reducing cooling needs and the likelihood of urban fires. Adaptive comfort, where occupants accept higher indoor (comfort) temperatures when the outside temperature is high, is now often incorporated in design considerations (*high agreement, medium evidence*) [6.9].

## Effectiveness of and experience with policies for reducing CO<sub>2</sub> emissions from energy use in buildings

Realizing such emissions reductions up to 2020 requires the rapid design, implementation and enforcement of strong policies promoting energy efficiency for buildings and equipment, renewable energy (where cost-effective), and advanced design techniques for new buildings (*high agreement, much evidence*) [6.5].

There are, however, substantial barriers that need to be overcome to achieve the high indicated negative and low cost mitigation potential. These include hidden costs, mismatches between incentives and benefits (e.g., between landlords and tenants), limitations in access to financing, subsidies on energy prices, as well as fragmentation of the industry and the design process. These barriers are especially strong and diverse in the residential and commercial sectors; overcoming them is therefore only possible through a diverse portfolio of policy instruments combined with good enforcement (*high agreement, medium evidence*).

A wide range of policies has been shown in many countries to be successful in cutting GHG emissions from buildings. Table TS.8 summarizes the key policy tools applied and compares them according to the effectiveness of the policy instrument, based on selected best practices. Most instruments reviewed can achieve significant energy and CO<sub>2</sub> savings. In an evaluation of 60 policy evaluations from about 30 countries, the highest CO<sub>2</sub> emission reductions were achieved through building codes, appliance standards and tax-exemption policies. Appliance standards, energy-efficiency obligations and quotas, demand-side management programmes and mandatory labelling were found to be among the most cost-effective policy tools. Subsidies and energy or carbon taxes were the least cost-effective instrument. Information programmes are also cost

**Table TS.8: The impact and effectiveness of selected policy instruments aimed at mitigating GHG emissions in the buildings sector using best practices [Table 6.6].**

Policy instrument	Emission reduction effectiveness <sup>a</sup>	Cost-effectiveness <sup>b</sup>	Special conditions for success, major strengths and limitations, co-benefits
<b>Appliance standards</b>	High	High	Factors for success: periodic update of standards, independent control, information, communication and education.
<b>Building codes</b>	High	Medium	No incentive to improve beyond target. Only effective if enforced.
<b>Public leadership programmes, inc. procurement regulations</b>	High	High/Medium	Can be used effectively to demonstrate new technologies and practices. Mandatory programmes have higher potential than voluntary ones. Factor for success: ambitious energy efficiency labelling and testing.
<b>Energy efficiency obligations and quotas</b>	High	High	Continuous improvements necessary: new EE measures, short term incentives to transform markets, etc.
<b>Demand-side management programmes</b>	High	High	Tend to be more cost-effective for commercial sector than for residences.
<b>Energy performance contracting/ESCO supportC</b>	High	Medium	Strength: no need for public spending or market intervention, co-benefit of improved competitiveness.
<b>Energy efficiency certificate schemes</b>	Medium	Medium	No long-term experience. Transaction costs can be high. Institutional structures needed. Profound interactions with existing policies. Benefits for employment.
<b>Kyoto Protocol flexible mechanisms<sup>d</sup></b>	Low	Low	So far limited number of CDM &JI projects in buildings.
<b>Taxation (on CO<sub>2</sub> or fuels)</b>	Low	Low	Effect depends on price elasticity. Revenues can be earmarked for further efficiency. More effective when combined with other tools.
<b>Tax exemptions/ reductions</b>	High	High	If properly structured, stimulate introduction of highly efficient equipment and new buildings.
<b>Capital subsidies, grants, subsidised loans</b>	High	Low	Positive for low-income households, risk of free-riders, may induce pioneering investments.
<b>Labelling and certification programmes</b>	Medium/High	High	Mandatory programmes more effective than voluntary ones. Effectiveness can be boosted by combination with other instruments and regular updates.
<b>Voluntary and negotiated agreements</b>	Medium/High	Medium	Can be effective when regulations are difficult to enforce. Effective if combined with financial incentives, and threat of regulation.
<b>Education and information programmes</b>	Low/Medium	High	More applicable in residential sector than commercial. Success condition: best applied in combination with other measures.
<b>Mandatory audit and energy management requirement</b>	High, but variable	Medium	Most effective if combined with other measures such as financial incentives.
<b>Detailed billing and disclosure programmes</b>	Medium	Medium	Success conditions: combination with other measures and periodic evaluation.

Notes:

- a) includes ease of implementation; feasibility and simplicity of enforcement; applicability in many locations; and other factors contributing to overall magnitude of realized savings.
- b) Cost-effectiveness is related to specific societal cost per carbon emissions avoided.
- c) Energy service companies.
- d) Joint Implementation, Clean Development Mechanism, International Emissions Trading (includes the Green Investment Scheme).

effective, particularly when they accompany most other policy measures (*medium agreement, medium evidence*) [6.8].

Policies and measures that aim at reducing leakage or discourage the use of refrigerants containing fluorine may reduce emissions of F-gases substantially in future years (*high agreement, medium evidence*) [6.8.4].

The limited overall impact of policies so far is due to several factors: 1) slow implementation processes; 2) the lack of regular

updating of building codes (requirements of many policies are often close to common practices, despite the fact that CO<sub>2</sub>-neutral construction without major financial sacrifices is already possible) and appliance standards and labelling; 3) inadequate funding; 4) insufficient enforcement. In developing countries and economies in transition, implementation of energy-efficiency policies is compromised by a lack of concrete implementation combined with poor or non-existent enforcement mechanisms. Another challenge is to promote GHG-abatement measures for the building shell of existing buildings due to the long time



periods between regular building retrofits and the slow turnover of buildings in developed countries (*high agreement, much evidence*) [6.8].

### Co-benefits and links to sustainable development

Energy efficiency and utilization of renewable energy in buildings offer synergies between sustainable development and GHG abatement. The most relevant of these for the least developed countries are safe and efficient cooking stoves that, while cutting GHG emissions, significantly reduce mortality and morbidity by reducing indoor air pollution. Safe and efficient cooking stoves also reduce the workload for women and children who typically gather the fuel for traditional stoves and decrease the demands on scarce natural resources. Reduction in outdoor air pollution is another significant co-benefit.

In general, in developed and developing countries, improved energy efficiency in buildings and the clean and efficient use of locally available renewable energy resources results in:

- substantial savings in energy-related investment, since efficiency is less costly than new supply;
- funds freed up for other purposes, such as infrastructure investments;
- improved system reliability and energy security;
- increased access to energy services;
- reduced fuel poverty;
- improvement of local environmental quality;
- positive effects on employment, by creating new business opportunities and through the multiplier effects of spending money saved on energy costs in another way.

There is increasing evidence that well-designed energy-efficient buildings often promote occupant productivity and health (*high agreement, medium evidence*) [6.9].

Support from industrialized countries for the development and implementation of policies to increase energy efficiency of buildings and equipment in developing countries and economies in transition could contribute substantially to reductions in the growth of CO<sub>2</sub> emissions and improve the welfare of the population. Devoting international aid or other public and private funds aimed at sustainable development to energy efficiency and renewable energy initiatives in buildings can achieve a multitude of development objectives and result in long-lasting impacts. The transfer of knowledge, expertise and know-how from developed to developing countries can facilitate the adoption of photovoltaics (PV), including PV-powered light emitting diode-based (LED) lighting, high-insulation building materials, efficient appliances and lighting, integrated design, building energy-management systems, and solar cooling. However, capital financing will also be needed [6.8.3].

### Technology research, development, deployment, diffusion and transfer

Although many practical and cost-effective technologies and practices are available today, research and development is needed in such areas as: high-performance control systems<sup>16</sup>; advanced window glazing; new materials for insulated panels; various systems to utilize passive and other renewable energy sources; phase-change materials to increase thermal storage; high-performance ground-source reversible heat pumps; integrated appliances and other equipment to use waste heat; novel cooling technologies, and the use of community-wide networks to supply heating, cooling and electricity to buildings. Demonstrations of these technologies and systems, and training of professionals, are necessary steps toward bringing those new technologies to market [6.8.3].

### Long-term-outlook

Long-term GHG reduction in buildings needs to start soon because of the slow turnover of the building stock. To achieve large-scale savings in new buildings in the longer term, new approaches to integrated design and operation of buildings need to be taught, spread, and put into large-scale practice as soon as possible. Such training is currently not available for the majority of professionals in the building industry. Because of the important role of non-technological opportunities in buildings, ambitious GHG reductions may require a cultural shift towards a society that embraces climate protection and sustainable development among its fundamental values, leading to social pressure for building construction and use with much reduced environmental footprints (*high agreement, medium evidence*) [6.4.1; 6.8.1].

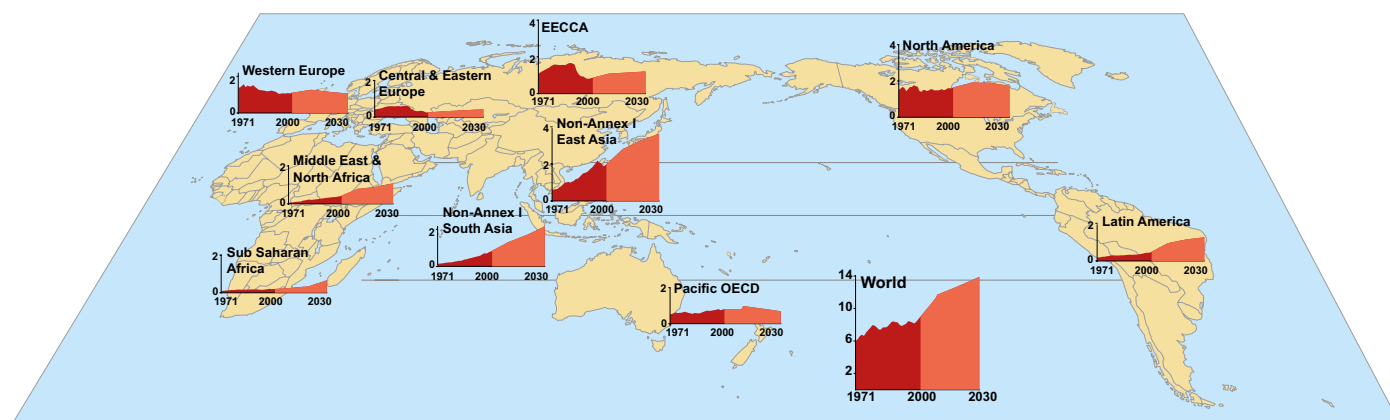
## 7 Industry

### Status of the sector, development trends and implications

Energy-intensive industries, iron and steel, non-ferrous metals, chemicals and fertilizer, petroleum-refining, cement, and pulp and paper, account for about 85% of the industry sector's energy consumption in most countries. Since energy use in other sectors grew faster, the sector's share in global primary energy use declined from 40% in 1971 to 37% in 2004 [7.1.3].

Much of this energy-intensive industry is now located in developing countries. Overall, in 2003, developing countries accounted for 42% of global steel production, 57% of global nitrogen fertilizer production, 78% of global cement manufacture, and about 50% of global aluminium production. In 2004, developing countries accounted for 46% of final energy

<sup>16</sup> Advanced control systems need to be created that permit the integration of all energy service functions in the design and subsequent operation of commercial buildings ('intelligent control').



**Figure TS.18:** Industrial sector energy-related CO<sub>2</sub> emissions (GtCO<sub>2</sub>; including electricity use), 1971–2030. [Table 7.1, 7.2].

Note: Dark red – historic emissions; light red – projections according to SRES B2 scenario. Data extracted from Price et al. (2006). EECCA = Countries of Eastern Europe, the Caucasus and Central Asia.

use by industry, developed country for 43% and economies in transition for 11%. Many facilities (for aluminium, cement and fertilizer industries) in developing nations are new and include the latest technology with lowest specific energy use. However, as in industrialized countries, many older, inefficient facilities remain. This creates a huge demand for investment in developing countries to improve energy efficiency and achieve emission reductions. The strong growth of energy-intensive industries during the 20th century is expected to continue as population and GDP increase [7.1.2; 7.1.3].

Though large-scale production dominates these energy-intensive industries globally, small- and medium-sized enterprises (SMEs) have significant shares in many developing countries. While regulations and international competition are moving large industrial enterprises towards the use of environmentally sound technology, SMEs may not have the economic or technical capacity to install the necessary control equipment or are slower to innovate. These SME limitations create special challenges for efforts to mitigate GHG emissions (*high agreement, much evidence*) [7.1.1].

### Emission trends (global and regional)

Direct GHG emissions from industry are currently about 7.2 GtCO<sub>2</sub>-eq. As the mitigation options discussed in this chapter include measures aimed at reducing the industrial use of electricity, emissions including those from electricity use are important for comparison. Total industrial sector GHG emissions were about 12 GtCO<sub>2</sub>-eq in 2004, about 25% of the global total. CO<sub>2</sub> emissions (including electricity use) from the industrial sector grew from 6.0 GtCO<sub>2</sub> in 1971 to 9.9 GtCO<sub>2</sub> in 2004. In 2004, developed nations accounted for 35% of total energy-related CO<sub>2</sub> emissions, economies in transition for 11% and developing nations for 53% (see Figure TS.18). Industry also emits CO<sub>2</sub> from non-energy uses of fossil fuels and from non-fossil fuel sources. In 2000,

these were estimated to total 1.7 GtCO<sub>2</sub> (*high agreement, much evidence*) [7.1.3].

Industrial processes also emit other GHGs, including HFC-23 from the manufacture of HCFC-22; PFCs from aluminium smelting and semiconductor processing; SF<sub>6</sub> from use in flat panel screens (liquid crystal display) and semi-conductors, magnesium die casting, electrical equipment, aluminium melting, and others, and CH<sub>4</sub> and N<sub>2</sub>O from chemical industry sources and food-industry waste streams. Total emission from these sources was about 0.4 GtCO<sub>2</sub>-eq in 2000 (*medium agreement, medium evidence*) [7.1.3].

The projections for industrial CO<sub>2</sub> emissions for 2030 under the SRES-B2<sup>2</sup> scenarios are around 14 GtCO<sub>2</sub> (including electricity use) (see Figure TS.18). The highest average growth

**Table TS.9:** Projected industrial sector emissions of non-CO<sub>2</sub> GHGs, MtCO<sub>2</sub>-eq/yr [Table 7.3].

Region	1990	2000	2010	2030
Pacific OECD	38	53	47	49
North America	147	117	96	147
Western Europe	159	96	92	109
Central and Eastern Europe	31	21	22	27
EECCA	37	20	21	26
Developing Asia	34	91	118	230
Latin America	17	18	21	38
Sub Saharan Africa	6	10	11	21
Middle East and North Africa	2	3	10	20
World	470	428	438	668

Note: Emissions from refrigeration equipment used in industrial processes included; emissions from all other refrigeration and air-conditioning applications excluded. EECCA = the countries of Eastern Europe, the Caucasus and Central Asia.

Table TS.10: Examples of industrial technology for reducing GHG emissions (not comprehensive). Technologies in italics are under demonstration or development [Table 7.5].

Sector	Energy efficiency	Fuel switching	Power recovery	Renewables	Feedstock change	Product change	Material efficiency	Non-CO <sub>2</sub> GHG	CO <sub>2</sub> capture and storage
<b>Sector wide</b>	Benchmarking; Energy management systems; Efficient motor systems, boilers, furnaces, lighting and heating/ventilation/air conditioning; Process integration	Coal to natural gas and oil	Cogeneration	Biomass, Biogas, PV, Wind turbines, Hydropower	Recycled inputs				Oxy-fuel combustion, CO <sub>2</sub> separation from flue gas
<b>Iron &amp; steel</b>	Smelt reduction, Near net shape casting, Scrap preheating, Dry coke quenching	Natural gas, oil or plastic injection into the BF	Top-gas pressure recovery, By-product gas combined cycle	Charcoal	Scrap	High strength steel	Recycling, High strength steel, Reduction process losses	n/a	Hydrogen reduction, oxygen use in blast furnaces
<b>Non-ferrous metals</b>	<i>Inert anodes</i> , Efficient cell designs				Scrap		Recycling, thinner film and coating	PFC/SF <sub>6</sub> controls	
<b>Chemicals</b>	Membrane separations, Reactive distillation	Natural gas	Pre-coupled gas turbine, Pressure recovery turbine, H <sub>2</sub> recovery		Recycled plastics, bio-feedstock	Linear low density polyethylene, high-perf. plastics	Recycling, Thinner film and coating, Reduced process losses	N <sub>2</sub> O, PFCs, CFCs and HFCs control	CO <sub>2</sub> storage from ammonia, ethylene oxide processes
<b>Petroleum refining</b>	Membrane separation Refinery gas	Natural gas	Pressure recovery turbine, hydrogen recovery	Biofuels	Bio-feedstock		(reduction in transport not included here)	Control technology for N <sub>2</sub> O/CH <sub>4</sub>	From hydrogen production
<b>Cement</b>	Precalciner kiln, Roller mill, <i>fluidized bed kiln</i>	Waste fuels, Biogas, Biomass	Drying with gas turbine, power recovery	Biomass fuels, Biogas	Slags, pozzolanes	Blended cement <i>Geo-polymers</i>		n/a	Oxyfuel combustion in kiln
<b>Glass</b>	Cullet preheating Oxyfuel furnace	Natural gas	<i>Air bottoming cycle</i>	n/a	Increased cullet use	High-strength thin containers	Recycling	n/a	Oxyfuel <sub>L</sub> combustion
<b>Pulp and paper</b>	Efficient pulping, Efficient drying, Shoe press, Condebelt drying	Biomass, Landfill gas	<i>Black liquor gasification combined cycle</i>	Biomass fuels (bark, black liquor)	Recycling, Non-wood fibres	Fibre orientation, Thinner paper	Reduction cutting and process losses	n/a	Oxyfuel combustion in lime kiln
<b>Food</b>	Efficient drying, Membranes	Biogas, Natural gas	Anaerobic digestion, Gasification	Biomass, By-products, Solar drying			Reduction process losses, Closed water use		

rates in industrial-sector CO<sub>2</sub> emissions are projected for developing countries. Growth in the regions of Central and Eastern Europe, the Caucasus and Central Asia, and Developing Asia is projected to slow in both scenarios for 2000–2030. CO<sub>2</sub> emissions are expected to decline in the Pacific OECD, North America and Western Europe regions for B2 after 2010. For non-CO<sub>2</sub> GHG emissions from the industrial sector, emissions by 2030 are projected to increase globally by a factor of 1.4, from 470 MtCO<sub>2</sub>-eq. (130 MtC-eq) in 1990 to 670 MtCO<sub>2</sub>-eq (180 MtC-eq.) in 2030 assuming no further action is taken to control these emissions. Mitigation efforts led to a decrease in non-CO<sub>2</sub> GHG emissions between 1990 and 2000, and many programmes for additional control are underway (see Table TS.9) (*high agreement, medium evidence*) [7.1.3].

### **Description and assessment of mitigation technologies and practices, options and potentials, costs and sustainability**

Historically, the industrial sector has achieved reductions in energy intensity and emission intensity through adoption of energy efficiency and specific mitigation technologies, particularly in energy-intensive industries. The aluminium industry reported >70% reduction in PFC-emission intensity over the period 1990–2004 and the ammonia industry reported that plants designed in 2004 have a 50% reduction in energy intensity compared with those designed in 1960. Continuing to modernize ammonia-production facilities around the world will result in further energy-efficiency improvements. Reductions in refining energy intensity have also been reported [7.4.2, 7.4.3, 7.4.4].

The low technical and economic capacity of SMEs pose challenges for the diffusion of sound environmental technology, though some innovative R&D is taking place in SMEs.

A wide range of measures and technologies have the potential to reduce industrial GHG emissions. These technologies can be grouped into the categories of energy efficiency, fuel switching, power recovery, renewables, feedstock change, product change and material efficiency (Table TS.10). Within each category, some technologies, such as the use of more efficient electric motors, are broadly applicable across all industries, while others, such as top-gas pressure recovery in blast furnaces, are process-specific.

Later in the period to 2030, there will be a substantial additional potential from further energy-efficiency improvements and application of Carbon Capture and Storage (CCS)<sup>17</sup> and non-GHG process technologies. Examples of such new technologies that are currently in the R&D phase include inert electrodes for aluminium manufacture and hydrogen for metal production (*high agreement, much evidence*) [7.2, 7.3, 7.4].

Mitigation potentials and costs in 2030 have been estimated in an industry-by-industry assessment of energy-intensive industries and an overall assessment of other industries. The approach yielded mitigation potentials of about 1.1 GtCO<sub>2</sub>-eq at a cost of <20 US\$/tCO<sub>2</sub> (74 US\$/tC-eq); about 3.5 GtCO<sub>2</sub>-eq at costs below <50 US\$/tCO<sub>2</sub> (180 US\$/tC-eq); and about 4 GtCO<sub>2</sub>-eq/yr (0.60–1.4 GtC-eq/yr) at costs <US\$100/tCO<sub>2</sub>-eq (<US\$370/tC-eq) under the B2 scenario. The largest mitigation potentials are in the steel, cement and pulp and paper industries, and in the control of non-CO<sub>2</sub> gases, and much of the potential is available at <50 US\$/tCO<sub>2</sub>-eq (<US\$ 180/tC-eq). Application of CCS technology offers a large additional potential, albeit at higher cost.

A recently completed global study for nine groups of technologies indicates a mitigation potential for the industrial sector of 2.5–3.0 GtCO<sub>2</sub>-eq/yr (0.68–0.82 GtC-eq/yr) in 2030 at costs of <25 US\$/tCO<sub>2</sub> (<92US\$/tC) (2004\$). While the estimate of mitigation potential is in the range found in this assessment, the estimate of mitigation cost is significantly lower (*medium agreement, medium evidence*) [7.5].

### **Interaction of mitigation options with vulnerability and adaptation**

Linkages between adaptation and mitigation in the industrial sector are limited. Many mitigation options (e.g., energy efficiency, heat and power recovery, recycling) are not vulnerable to climate change and therefore create no adaptation link. Others, such as fuels or feedstock switching (e.g. to biomass or other renewable energy sources) may be vulnerable to climate change [7.8].

### **Effectiveness of and experience with climate policies, potentials, barriers and opportunities/implementation issues**

Full use of available mitigation options is not being made in either industrialized or developing nations. In many areas of the world, GHG mitigation is not demanded by either the market or government regulation. In these areas, companies will invest in GHG mitigation to the extent that other factors provide a return for their investments. This return can be economic; for example, energy-efficiency projects that provide an economic pay-out, or can be in terms of achieving larger corporate goals, for example, a commitment to sustainable development. The economic potential as outlined above will only be realized if policies and regulations are in place. Relevant in this respect is that, as noted above, most energy-intensive industries are located in developing countries. Slow rate of capital stock turnover is also a barrier in many industries, as is the lack of the financial and technical resources needed to implement mitigation options, and limitations in the ability of industrial firms, particularly small and medium-sized enterprises, to

<sup>17</sup> See IPCC Special Report on CO<sub>2</sub> Capture and Storage

access and absorb information about available options (*high agreement, much evidence*) [7.9.1].

Voluntary agreements between industry and government to reduce energy use and GHG emissions have been used since the early 1990s. Well-designed agreements, which set realistic targets and have sufficient government support, often as part of a larger environmental policy package, and a real threat of increased government regulation or energy/GHG taxes if targets are not achieved, can provide more than business-as-usual energy savings or emission reductions. Some have accelerated the application of best available technology and led to reductions in emissions compared with the baseline, particularly in countries with traditions of close cooperation between government and industry. However, the majority of voluntary agreements have not achieved significant emission reductions beyond business-as-usual. Corporations, sub-national governments, non-government organizations (NGOs) and civil groups are adopting a wide variety of voluntary actions, independent of government authorities, which may limit GHG emissions, stimulate innovative policies, and encourage the deployment of new technologies. By themselves, however, they generally have limited impact.

Policies that reduce the barriers to adoption of cost-effective, low-GHG emission technologies (e.g., lack of information, absence of standards and unavailability of affordable financing for first purchases of modern technology) can be effective. Many countries, both developed and developing, have financial schemes available to promote energy saving in industry. According to a World Energy Council survey, 28 countries provide some sort of grant or subsidy for industrial energy-efficiency projects. Fiscal measures are also frequently used to stimulate energy savings in industry. However, a drawback to financial incentives is that they are often also used by investors who would have made the investment without the incentive. Possible solutions to improve cost-effectiveness are to restrict schemes to specific target groups and/or techniques (selected lists of equipment, only innovative technologies), or use a direct criterion of cost-effectiveness [7.9.3].

Several national, regional or sectoral CO<sub>2</sub> emissions trading systems either exist or are being developed. The further refinement of these trading systems could be informed by evidence that suggests that in some important aspects, participants from industrial sectors face a significantly different situation to those from the electricity sector. For instance, responses to carbon emission price in industry tend to be slower because of the more limited technology portfolio and absence of short-term fuel-switching possibilities, making predictable allocation mechanisms and stable price signals a more important issue for industry [7.9.4].

As noted in the TAR, industrial enterprises of all sizes are vulnerable to changes in government policy and consumer preferences. That is why a stable policy regime is so important for industry (*high agreement, much evidence*) [7.9].

## **Integrated and non-climate policies affecting emissions of greenhouse gases**

Policies aimed at balancing energy security, environmental protection and economic development can have a positive or negative impact on mitigation. Sustainable development policies focusing on energy efficiency, dematerialization, and use of renewables support GHG mitigation objectives. Waste-management policies reduce industrial sector GHG emissions by reducing energy use through the re-use of products. Air-pollutant reduction measures can have synergy with GHG-emissions reduction when reduction is achieved by shifting to low-carbon fuels, but do not always reduce GHG emissions as many require the use of additional energy.

In addition to implementing the mitigation options discussed above, achieving sustainable development will require industrial development pathways that minimize the need for future mitigation (*high agreement, medium evidence*). Large companies have greater resources, and usually more incentives, to factor environmental and social considerations into their operations than small and medium enterprises (SMEs), but SMEs provide the bulk of employment and manufacturing capacity in many countries. Integrating SME development strategy into broader national strategies for development is consistent with sustainable development objectives. Energy-intensive industries are now committing to a number of measures towards human capital development, health and safety, community development etc., which are consistent with the goal of corporate social responsibility (*high agreement, much evidence*) [7.7; 7.8].

## **Co-benefits of greenhouse gas mitigation policies**

The co-benefits of industrial GHG mitigation include: reduced emissions of air pollutants, and waste (which in turn reduce environmental compliance and waste disposal costs), increased production and product quality, lower maintenance and operating costs, an improved working environment, and other benefits such as decreased liability, improved public image and worker morale, and delaying or reducing capital expenditures. The reduction of energy use can indirectly contribute to reduced health impacts of air pollutants particularly where no air-pollution regulation exists (*high agreement, much evidence*) [7.10].

## **Technology research, development, deployment, diffusion and transfer**

Commercially available industrial technology provides a very large potential to reduce GHG emissions. However, even with the application of this technology, many industrial processes would still require much more energy than the thermodynamic ideal, suggesting a large additional potential for energy-efficiency improvement and GHG mitigation potential. In addition, some industrial processes emit GHGs that are independent of heat and power use. Commercial technology to eliminate these emissions does not currently exist for some of

these processes, for example, development of an inert electrode to eliminate process emissions from aluminium manufacture and the use of hydrogen to reduce iron and non-ferrous metal ores. These new technologies must also meet a host of other criteria, including cost competitiveness, safety and regulatory requirements, as well as winning customer acceptance. Industrial technology research, development, deployment and diffusion are carried out both by governments and companies, ideally in complementary roles. Because of the large economic risks inherent in technologies with GHG emission mitigation as the main purpose, government programmes are likely to be needed in order to facilitate a sufficient level of research and development. It is appropriate for governments to identify fundamental barriers to technology and find solutions to overcome these barriers, but companies should bear the risks and capture the rewards of commercialization.

In addition, government information, energy audits, reporting, and benchmarking programmes promote technology transfer and diffusion. The key factors determining private-sector technology deployment and diffusion are competitive advantage, consumer acceptance, country-specific characteristics, protection of intellectual property rights, and regulatory frameworks (*medium agreement, medium evidence*) [7.11].

### Long-term outlook

Many technologies offer long-term potential for mitigating industrial GHG emissions, but interest has focused on three areas: biological processing, use of hydrogen and nanotechnology.

Given the complexity of the industrial sector, achieving low GHG emissions is the sum of many cross-cutting and individual sector transitions. Because of the speed of capital stock turnover in at least some branches of industry, inertia by ‘technology lock-in’ may occur. Retrofitting provides opportunities in the meantime, but basic changes in technology occur only when the capital stock is installed or replaced (*high agreement, much evidence*) [7.12].

## 8 Agriculture

### Status of the sector, future trends in production and consumption, and implications

Technological developments have allowed remarkable progress in agricultural output per unit of land, increasing per capita food availability despite a consistent decline in per capita agricultural land area (*high agreement, much evidence*). However, progress has been uneven across the world, with rural poverty and malnutrition remaining in some countries. The share of animal products in the diet has increased progressively in developing countries, while remaining constant in the developed world (*high agreement, much evidence*).

Production of food and fibre has more than kept pace with the sharp increase in demand in a more populated world, so that the global average daily availability of calories per capita has increased, though with regional exceptions. However, this growth has been at the expense of increasing pressure on the environment and dwindling natural resources, and has not solved problems of food security and widespread child malnutrition in poor countries (*high agreement, much evidence*).

The absolute area of global arable land has increased to about 1400 Mha, an overall increase of 8% since the 1960s (5% decrease in developed countries and 22% increase in developing countries). This trend is expected to continue into the future, with a projected additional 500 Mha converted to agriculture from 1997–2020, mostly in Latin America and Sub-Saharan Africa (*medium agreement, limited evidence*).

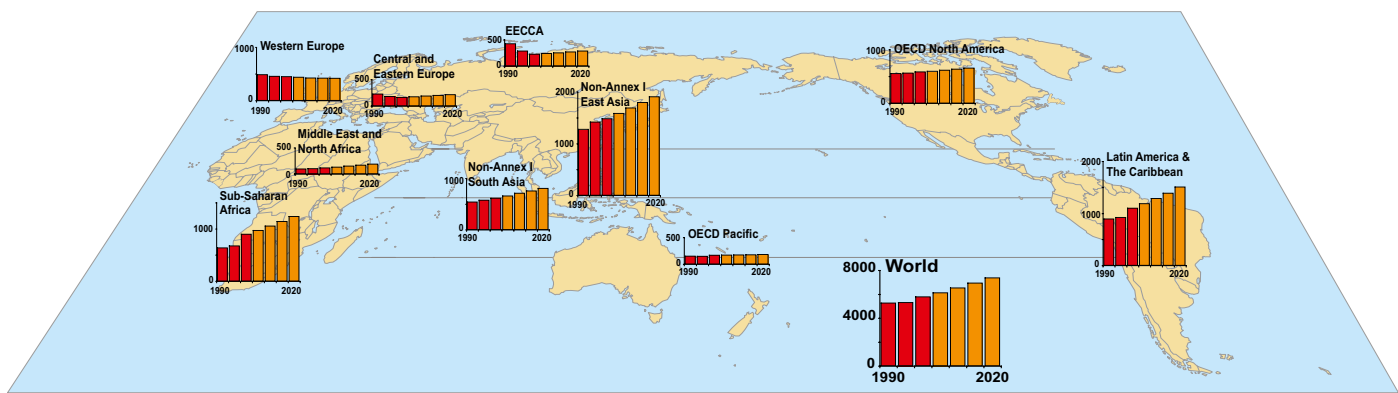
Economic growth and changing lifestyles in some developing countries are causing a growing demand for meat and dairy products. From 1967–1997, meat demand in developing countries rose from 11 to 24 kg per capita per year, achieving an annual growth rate of more than 5% by the end of that period. Further increases in global meat demand (about 60% by 2020) are projected, mostly in developing regions such as South and Southeast Asia, and Sub-Saharan Africa (*medium agreement, much evidence*) [8.2].

### Emission trends

For 2005, agriculture accounted for an estimated emission of 5.1 to 6.1 GtCO<sub>2</sub>-eq (10–12% of total global anthropogenic emissions of GHGs). CH<sub>4</sub> contributed 3.3 GtCO<sub>2</sub>-eq and N<sub>2</sub>O 2.8 GtCO<sub>2</sub>-eq. Of global anthropogenic emissions in 2005, agriculture accounted for about 60% of N<sub>2</sub>O and about 50% of CH<sub>4</sub> (*medium agreement, medium evidence*). Despite large annual exchanges of CO<sub>2</sub> between the atmosphere and agricultural lands, the net flux is estimated to be approximately balanced, with net CO<sub>2</sub> emissions of only around 0.04 GtCO<sub>2</sub>/yr (emissions from electricity and fuel use in agriculture are covered in the buildings and transport sector respectively) (*low agreement, limited evidence*) [8.3].

Trends in GHG emissions in agriculture are responsive to global changes: increases are expected as diets change and population growth increases food demand. Future climate change may eventually release more soil carbon (though the effect is uncertain as climate change may also increase soil carbon inputs through high production). Emerging technologies may permit reductions of emissions per unit of food produced, but absolute emissions are likely to grow (*medium agreement, medium evidence*).

Without additional policies, agricultural N<sub>2</sub>O and CH<sub>4</sub> emissions are projected to increase by 35–60% and ~60%, respectively, to 2030, thus increasing more rapidly than the 14% increase of non-CO<sub>2</sub> GHG observed from 1990 to 2005 (*medium agreement, limited evidence*) [8.3.2].



**Figure TS.19:** Historic and projected  $N_2O$  and  $CH_4$  emissions ( $MtCO_2\text{-eq.}$ ) in the agricultural sector of ten world regions, 1990–2020 [Figure 8.2].

Note: EECCA=Countries of Eastern Europe, the Caucasus and Central Asia.

Both the magnitude of the emissions and the relative importance of the different sources vary widely among world regions (Figure TS.19). In 2005, the group of five regions consisting mostly of non-Annex I countries were responsible for 74% of total agricultural emissions [8.3].

**Mitigation technologies, practices, options, potentials and costs**

Considering all gases, the economic potentials for agricultural mitigation by 2030 are estimated to be about 1600, 2700 and 4300  $MtCO_2\text{-eq/yr}$  at carbon prices of up to 20, 50 and 100  $US\$/tCO_2\text{-eq}$ , respectively for a SRES B2 baseline (see Table TS.11) (*medium agreement, limited evidence*) [8.4.3].

Improved agricultural management can reduce net GHG emissions, often affecting more than one GHG. The effectiveness of these practices depends on factors such as climate, soil type and farming system (*high agreement, much evidence*).

About 90% of the total mitigation arises from sink enhancement (soil C sequestration) and about 10% from emission reduction (*medium agreement, medium evidence*). The most prominent mitigation options in agriculture (with potentials shown in  $Mt$

$CO_2\text{eq/yr}$  for carbon prices up to 100  $US\$/tCO_2\text{-eq}$  by 2030) are (see also Figure TS.20):

- restoration of cultivated organic soils (1260)
- improved cropland management (including agronomy, nutrient management, tillage/residue management and water management (including irrigation and drainage) and set-aside / agro-forestry (1110)
- improved grazing land management (including grazing intensity, increased productivity, nutrient management, fire management and species introduction (810)
- restoration of degraded lands (using erosion control, organic amendments and nutrient amendments (690).

Lower, but still substantial mitigation potential is provided by:

- rice management (210)
- livestock management (including improved feeding practices, dietary additives, breeding and other structural changes, and improved manure management (improved storage and handling and anaerobic digestion) (260) (*medium agreement, limited evidence*).

In addition, 770  $MtCO_2\text{-eq/yr}$  could be provided by 2030 by improved energy efficiency in agriculture. This amount is, however, for a large part included in the mitigation potential of buildings and transport [8.1; 8.4].

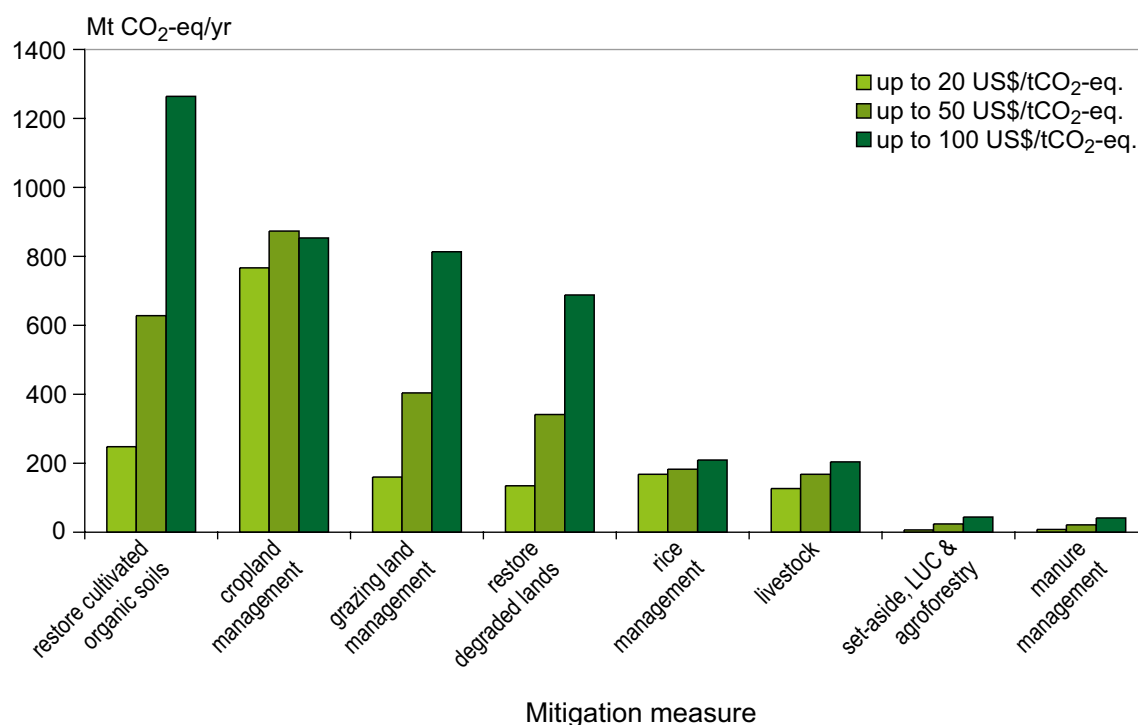
At lower carbon prices, low cost measures most similar to current practice are favoured (e.g., cropland management options), but at higher carbon prices, more expensive measures with higher mitigation potentials per unit area are favoured (e.g., restoration of cultivated organic / peaty soils; Figure TS.20) (*medium agreement, limited evidence*) [8.4.3].

GHG emissions could also be reduced by substitution of fossil fuels by energy production from agricultural feedstocks (e.g., crop residues, dung, energy crops), which are counted in energy end-use sectors (particularly energy supply and transport). There are no accurate estimates of future agricultural biomass supply, with figures ranging from 22 EJ/yr in 2025

**Table TS.11:** Estimates of global agricultural economic GHG mitigation potential ( $MtCO_2\text{-eq/yr}$ ) by 2030 under different assumed carbon prices for a SRES B2 baseline [Table 8.7].

	Carbon price ( $US\$/tCO_2\text{-eq}$ )		
	Up to 20	Up to 50	Up to 100
OECD	330 (60-470)	540 (300-780)	870 (460-1280)
EIT	160 (30-240)	270 (150-390)	440 (230-640)
Non-OECD/ EIT	1140 (210-1660)	1880 (1040-2740)	3050 (1610-4480)

Note: figures in brackets show standard deviation around the mean estimate, potential excluding energy-efficiency measures and fossil fuel offsets from bio-energy.



**Figure TS.20:** Potential for GHG agricultural mitigation in 2030 at a range of carbon prices for a SRES B2 baseline [Figure 8.9].

Note: B2 scenario shown, though the pattern is similar for all SRES scenarios. Energy-efficiency measures (770 MtCO<sub>2</sub>-eq) are included in the mitigation potential of the buildings and energy sector.

to more than 400 EJ/yr in 2050. The actual contribution of agriculture to the mitigation potential by using bio-energy depends, however, on the relative prices of fuels and the balance of demand and supply. Top-down assessments that include assumptions on such a balance estimate the economic mitigation potential of biomass energy supplied from agriculture to be 70–1260 MtCO<sub>2</sub>-eq/yr at up to 20 US\$/tCO<sub>2</sub>-eq, and 560–2320 MtCO<sub>2</sub>-eq/yr at up to 50 US\$/tCO<sub>2</sub>-eq. There are no estimates for the additional potential from top-down models at carbon prices up to 100 US\$/tCO<sub>2</sub>-eq, but the estimate for prices above 100 US\$/tCO<sub>2</sub>-eq is 2720 MtCO<sub>2</sub>-eq/yr. These potentials represent mitigation of 5–80%, and 20–90% of all other agricultural mitigation measures combined, at carbon prices of up to 20, and up to 50 US\$/tCO<sub>2</sub>-eq, respectively. Above the level where agricultural products and residues form the sole feedstock, bio-energy competes with other land-uses for available land, water and other resources. The mitigation potentials of bio-energy and improved energy efficiency are not included in Table TS.11 or Figure TS.20, as the potential is counted in the user sectors, mainly transport and buildings, respectively (*medium agreement, medium evidence*) [8.4.4].

The estimates of mitigation potential in the agricultural sector are towards the lower end of the ranges indicated in the Second Assessment Report (SAR) and TAR. This is due mainly to the different time scales considered (2030 here versus 2050 in TAR). In the medium term, much of the mitigation potential is derived from removal of CO<sub>2</sub> from the atmosphere and its

conversion to soil carbon, but the magnitude of this process will diminish as soil carbon approaches maximum levels, and long-term mitigation will rely increasingly on reducing emissions of N<sub>2</sub>O, CH<sub>4</sub>, and CO<sub>2</sub> from energy use, the benefits of which persist indefinitely (*high agreement, much evidence*) [8.4.3].

### Interactions of mitigation options with vulnerability and adaptation

Agricultural actions to mitigate GHGs could: a) reduce vulnerability (e.g. if soil carbon sequestration reduces the impacts of drought) or b) increase vulnerability (e.g., if heavy dependence on biomass energy makes energy supply more sensitive to climatic extremes). Policies to encourage mitigation and/or adaptation in agriculture may need to consider these interactions (*medium agreement, limited evidence*). Similarly, adaptation-driven actions may either a) favour mitigation (e.g., return of residues to fields to improve water-holding capacity will also sequester carbon) or b) hamper mitigation (e.g., use of more nitrogen fertilizer to overcome falling yields, leading to increased N<sub>2</sub>O emissions). Strategies that simultaneously increase adaptive capacity, reduce vulnerability and mitigate climate change are likely to present fewer adoption barriers than those with conflicting impacts. For example increasing soil organic matter content can both improve fertility and reduce the impact of drought, improving adaptive capacity, making agriculture less vulnerable to climate change, while also sequestering carbon (*medium agreement, medium evidence*) [8.5].



## Effectiveness of climate policies: opportunities, barriers and implementation issues

Actual levels of GHG mitigation practices in the agricultural sector are below the economic potential for the measures reported above (*medium agreement, limited evidence*). Little progress in implementation has been made because of the costs of implementation and other barriers, including: pressure on agricultural land, demand for agricultural products, competing demands for water as well as various social, institutional and educational barriers (*medium agreement, limited evidence*). Soil carbon sequestration in European croplands, for instance, is likely to be negligible by 2010, despite significant economic potential. Many of these barriers will not be overcome without policy/economic incentives (*medium agreement, limited evidence*) [8.6].

## Integrated and non-climate policies affecting emissions of greenhouse gases

The adoption of mitigation practices will often be driven largely by goals not directly related to climate change. This leads to varying mitigation responses among regions, and contributes to uncertainty in estimates of future global mitigation potential. Policies most effective at reducing emissions may be those that also achieve other societal goals. Some rural development policies undertaken to fight poverty, such as water management and agro-forestry, are synergistic with mitigation (*medium agreement, limited evidence*). For example, agro-forestry undertaken to produce fuel wood or to buffer farm incomes against climate variation may also increase carbon sequestration. In many regions, agricultural mitigation options are influenced most by non-climate policies, including macro-economic, agricultural and environmental policies. Such policies may be based on UN conventions (e.g., Biodiversity and Desertification), but are often driven by national or regional issues. Among the most beneficial non-climate policies are those that promote sustainable use of soils, water and other resources in agriculture since these help to increase soil carbon stocks and minimize resource (energy, fertilizer) waste (*high agreement, medium evidence*) [8.7].

## Co-benefits of greenhouse gas mitigation policies

Some agricultural practices yield purely ‘win-win’ outcomes, but most involve trade-offs. Agro-ecosystems are inherently complex. The co-benefits and trade-offs of an agricultural practice may vary from place to place because of differences in climate, soil or the way the practice is adopted (*high agreement, medium evidence*).

In producing bio-energy, for example, if the feedstock is crop residues, soil organic matter may be depleted as less carbon is returned, thus reducing soil quality; conversely, if the feedstock is a densely-rooted perennial crop, soil organic matter may be replenished, thereby improving soil quality.

Many agricultural mitigation activities show synergy with the goals of sustainability. Mitigation policies that encourage efficient use of fertilizers, maintain soil carbon and sustain agricultural production are likely to have the greatest synergy with sustainable development (*high agreement, medium evidence*).

For example, increasing soil carbon can also improve food security and economic returns. Other mitigation options have less certain impacts on sustainable development. For example, the use of some organic amendments may improve carbon sequestration, but impacts on water quality may vary depending on the amendment. Co-benefits often arise from improved efficiency, reduced cost and environmental co-benefits. Trade-offs relate to competition for land, reduced agricultural productivity and environmental stresses (*medium agreement, limited evidence*) [8.4.5].

## Technology research, development, deployment, diffusion and transfer

Many of the mitigation strategies outlined for the agriculture sector employ existing technology. For example, reduction in emissions per unit of production will be achieved by increases in crop yields and animal productivity. Such increases in productivity can occur through a wide range of practices – better management, genetically modified crops, improved cultivars, fertilizer-recommendation systems, precision agriculture, improved animal breeds, improved animal nutrition, dietary additives and growth promoters, improved animal fertility, bio-energy feed stocks, anaerobic slurry digestion and CH<sub>4</sub> capture systems – all of which reflect existing technology (*high agreement, much evidence*). Some strategies involve new uses of existing technologies. For example, oils have been used in animal diets for many years to increase dietary energy content, but their role and feasibility as a CH<sub>4</sub> suppressant is still new and not fully defined. For some technologies, more research and development will be needed [8.9].

## Long-term outlook

Global food demand may double by 2050, leading to intensified production practices (e.g., increasing use of nitrogen fertilizer). In addition, projected increases in the consumption of livestock products will increase CH<sub>4</sub> and N<sub>2</sub>O emissions if livestock numbers increase, leading to growing emissions in the baseline after 2030. (*high agreement, medium evidence*). Agricultural mitigation measures will help to reduce GHG emissions per unit of product, relative to the baseline. However, until 2030 only about 10% of the mitigation potential is related to CH<sub>4</sub> and N<sub>2</sub>O. Deployment of new mitigation practices for livestock systems and fertilizer applications will be essential to prevent an increase in emissions from agriculture after 2030.

Projecting long-term mitigation potentials is also hampered by other uncertainties. For example, the effects of climate change are unclear: future climate change may reduce soil

**Table TS.12:** Estimates of forest area, net changes in forest area (negative numbers indicating decrease), carbon stock in living biomass and growing stock in 1990, 2000 and 2005 [Table 9.1].

Region	Forest area (mill. ha)	Annual change (mill. ha/yr)		Carbon stock in living biomass (MtCO <sub>2</sub> )			Growing stock in 2005
	2005	1990-2000	2000-2005	1990	2000	2005	(million m <sup>3</sup> )
<b>Africa</b>	635.412	-4.4	-4.0	241267	228067	222933	64957
<b>Asia</b>	571.577	-0.8	1.0	150700	130533	119533	47111
<b>Europe<sup>a)</sup></b>	1001.394	0.9	0.7	154000	158033	160967	107264
<b>North and Central America</b>	705.849	-0.3	-0.3	150333	153633	155467	78582
<b>Oceania</b>	206.254	-0.4	-0.4	42533	41800	41800	7361
<b>South America</b>	831.540	-3.8	-4.3	358233	345400	335500	128944
<b>World</b>	3952.026	-8.9	-7.3	1097067	1057467	1036200	434219

Note:

<sup>a)</sup> including whole Russian Federation.

carbon-sequestration rates, or could even release soil carbon, though the effect is uncertain as climate change may also increase soil carbon inputs through higher plant production. Some studies have suggested that technological improvements could potentially counteract the negative impacts of climate change on cropland and grassland soil carbon stocks, making technological improvement a key factor in future GHG mitigation. Such technologies could, for example, act through increasing production, thereby increasing carbon returns to the soil and reducing the demand for fresh cropland. (*high agreement, medium evidence*) [8.10].

## 9 Forestry

Since the TAR, new mitigation estimates have become available from the local scale to the global scale. Major economic reviews and global assessments have become available. There is early research into the integration of mitigation and adaptation options and the linkages to sustainable development. There is increased attention on reducing emissions from deforestation as a low cost mitigation option, one that will have significant positive side effects. There is some evidence that climate change impacts can also constrain the mitigation potential of forests.

### Status of the sector, development trends including production and consumption, and implications

Global forest cover is 3952 million ha (Table TS.12), about 30% of the world's land area. Most relevant for the carbon cycle is that between 2000 and 2005 gross deforestation continued at a rate of 12.9 million ha/yr, mainly as a result of converting forests to agricultural land, but also due to expansion of settlements and infrastructure, often for logging. In the 1990s, gross deforestation was slightly higher, 13.1 million ha/yr. Due

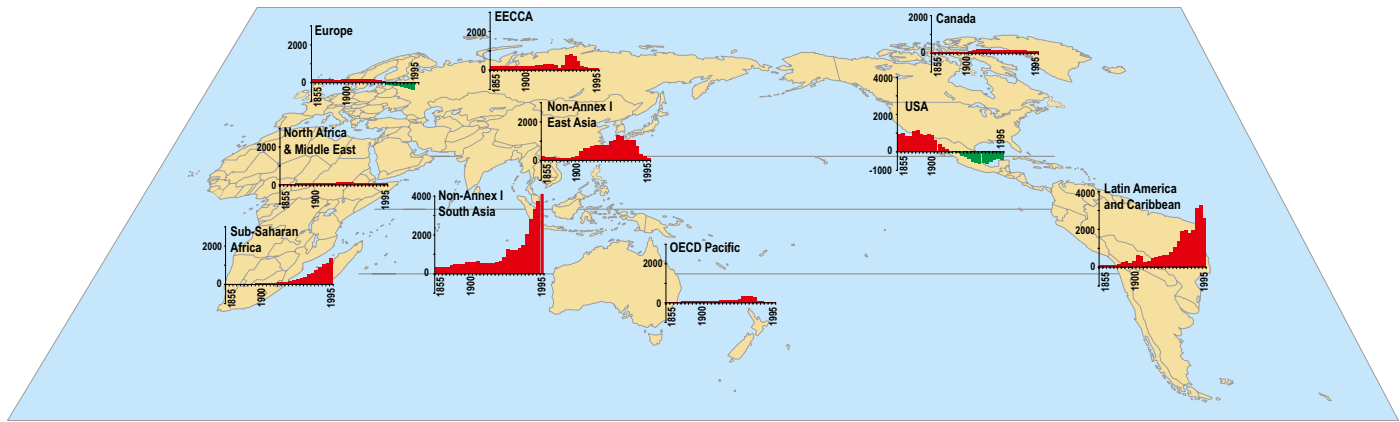
to afforestation, landscape restoration and natural expansion of forests, the net loss of forest between 2000 and 2005 was 7.3 million ha/yr, with the largest losses in South America, Africa and Southeast Asia. This net rate of loss was lower than the 8.9 million ha/yr loss in the 1990s (*medium agreement, medium evidence*) [9.2.1].

### Emission sources and sinks; trends

On the global scale, during the last decade of the 20<sup>th</sup> century, deforestation in the tropics and forest regrowth in the temperate zone and parts of the boreal zone remained the major factors responsible for CO<sub>2</sub> emissions and removals, respectively (Table TS.12, Figure TS.21). Emissions from deforestation in the 1990s are estimated at 5.8 GtCO<sub>2</sub>/yr.

However, the extent to which the loss of carbon due to tropical deforestation is offset by expanding forest areas and accumulating woody biomass in the boreal and temperate zone is an area of disagreement between actual land observations and estimates using top-down models. The top-down methods based on inversion of atmospheric transport models estimate the net terrestrial carbon sink for the 1990s, the balance of sinks in northern latitudes and sources in the tropics, to be about 9.5 GtCO<sub>2</sub>. The new estimates are consistent with the increase previously found in the terrestrial carbon sink in the 1990s over the 1980s, but the new sink estimates and the rate of increase may be smaller than previously reported. The residual sink estimate resulting from inversion of atmospheric transport models is significantly higher than any global sink estimate based on land observations.

The growing understanding of the complexity of the effects of land-surface change on the climate system shows the importance of considering the role of surface albedo, the fluxes of sensible and latent heat, evaporation and other factors in formulating policy for climate change mitigation in the forest



**Figure TS.21:** Historical forest carbon balance (MTCO<sub>2</sub>) per region, 1855–2000 [Figure 9.2].

Notes: green = sink. EECCA =Countries of Eastern Europe, the Caucasus and Central Asia. Data averaged per 5-year period; year marks starting year of period.

sector. Complex modelling tools are needed to fully consider the climatic effect of changing land surface and to manage carbon stocks in the biosphere, but are not yet available. The potential effect of projected climate change on the net carbon balance in forests remains uncertain [9.3; 9.4].

As even the current functioning of the biosphere is uncertain, projecting the carbon balance of the global forestry sector remains very difficult. Generally, there is a lack of widely accepted studies and thus a lack of baselines. Trends for development in non-OECD countries, and thus of the deforestation rate, are unclear. In OECD countries and in economies in transition, development of management trends, the wood market, and impacts of climate change remain unclear. Long-term models as reported in Chapter 3, show baseline CO<sub>2</sub> emissions from land-use change and forestry in 2030 that are the same or slightly lower than in 2000 (medium agreement, medium evidence) [9.3; 9.4].

**Description and assessment of mitigation technologies and practices, options and potentials, costs and sustainability**

Terrestrial carbon dynamics are characterized by long periods of small rates of carbon uptake per hectare, interrupted by short periods of rapid and large releases of carbon during disturbances or harvest. While individual stands in a forest may be sources or sinks, the carbon balance of the forest is determined by the sum of the net balance of all stands.

Options available to reduce emissions by sources and/or increase removals by sinks in the forest sector are grouped into four general categories:

- maintaining or increasing the forest area;
- maintaining or increasing the site-level carbon density;
- maintaining or increasing the landscape-level carbon density and

- increasing off-site carbon stocks in wood products and enhancing product and fuel substitution.

Each mitigation activity has a characteristic time sequence of actions, carbon benefits and costs (Figure TS.22). Relative to a baseline, the largest short-term gains are always achieved through mitigation activities aimed at avoiding emissions (reduced deforestation or degradation, fire protection, slash burning, etc.).

Mitigation Activities	Type of Impact	Timing of Impact	Timing of Cost
1A Increase forest area (e.g. new forests)	↑	Delayed	Delayed
1B Maintain forest area (e.g. prevent deforestation, LUC)	↓	Immediate	Up-front
2A Increase site-level C density (e.g. intensive management, fertilize)	↑	Delayed	Delayed
2B Maintain site-level C density (e.g. avoid degradation)	↓	Immediate	Up-front
3A Increase landscape-scale C stocks (e.g. SFM, agriculture, etc.)	↑	Delayed	Delayed
3B Maintain landscape-scale C stocks (e.g. suppress disturbances)	↓	Immediate	Up-front
4A Increase off-site C in products (but must also meet 1B, 2B and 3B)	↑	Sustained or repeatable	Up-front
4B Increase bioenergy and substitution (but must also meet 1B, 2B and 3B)	↓	Sustained or repeatable	Up-front

**Legend**

Type of Impact	Timing (change in Carbon over time)	Timing of cost (dollars (\$) over time)
Enhance sink ↑	Delayed	Delayed
Reduce source ↓	Immediate	Up-front
	Sustained or repeatable	On-going

**Figure TS.22:** Generalized summary of the options available in the forest sector and their type and timing of effects on carbon stocks and the timing of costs [Figure 9.4].

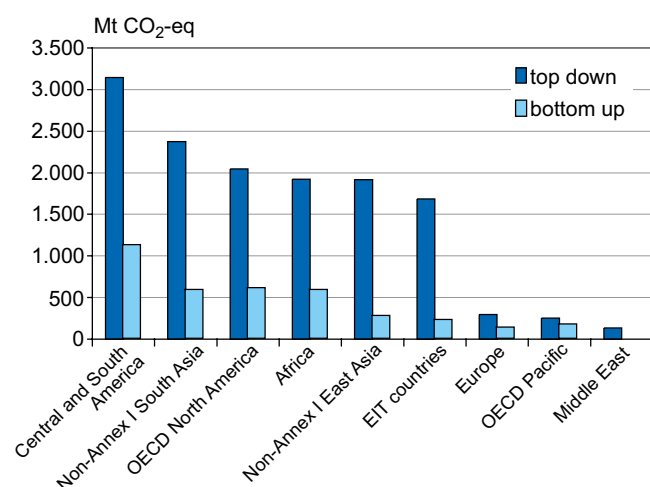
All forest-management activities aimed at increasing site-level and landscape-level carbon density are common practices that are technically feasible, but the extent and area over which they can be implemented could be increased considerably. Economic considerations are typically the main constraint, because retaining additional carbon on site delays revenues from harvest.

In the long term, a sustainable forest-management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit.

### Regional modelling assessments

Bottom-up regional studies show that forestry mitigation options have the economic potential (at costs up to 100 US\$/tCO<sub>2</sub>-eq) to contribute 1.3-4.2 MtCO<sub>2</sub>/yr (average 2.7 GtCO<sub>2</sub>/yr) in 2030 excluding bio-energy. About 50% can be achieved at a cost under 20 US\$/tCO<sub>2</sub> (1.6 GtCO<sub>2</sub>/yr) with large differences between regions. The combined effects of reduced deforestation and degradation, afforestation, forest management, agroforestry and bio-energy have the potential to increase from the present to 2030 and beyond. This analysis assumes gradual implementation of mitigation activities starting now (*medium agreement, medium evidence*) [9.4.4].

Global top-down models predict mitigation potentials of 13.8 GtCO<sub>2</sub>-eq/yr in 2030 at carbon prices less than or equal to 100 US\$/tCO<sub>2</sub>. The sum of regional predictions is 22% of this value for the same year. Regional studies tend to use more detailed data and consider a wider range of mitigation options, and thus may more accurately reflect regional circumstances and constraints than simpler, more aggregated global models. However, regional studies vary in model structure, coverage, analytical approach and assumptions (including baseline



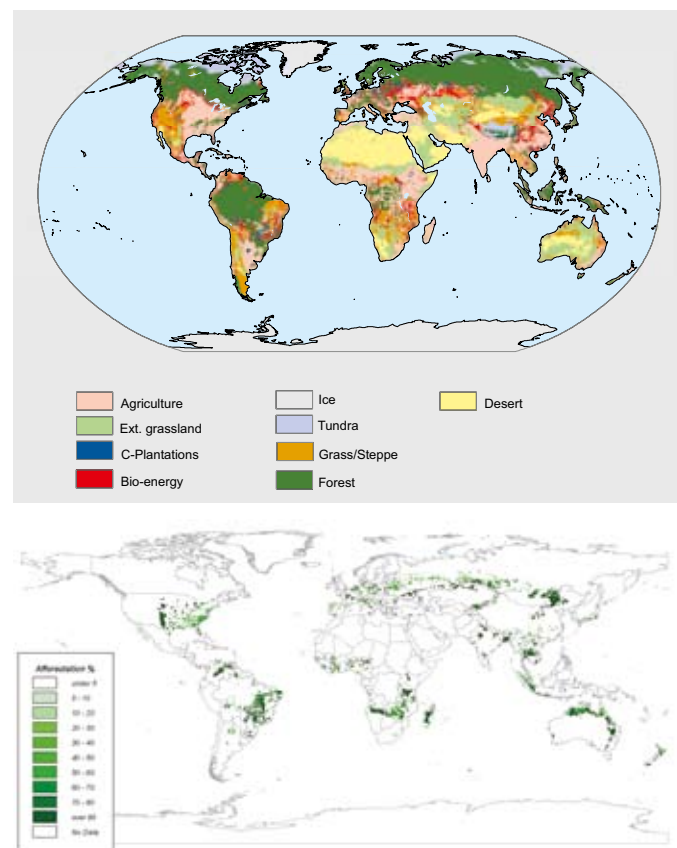
**Figure TS.23:** Comparison of outcomes of economic mitigation potential at <100 US\$/tCO<sub>2</sub>-eq in 2030 in the forestry sector, as based on top-down global models versus the regional modelling results [Figure 9.13].

assumptions). Further research is required to narrow the gap in the estimates of mitigation potential from global and regional assessments (*medium agreement, medium evidence*) [9.4.3].

The best estimate of the economic mitigation potential for the forestry sector at this stage therefore cannot be more certain than a range between 2.7 and 13.8 GtCO<sub>2</sub>/yr in 2030, for costs <100 US\$/tCO<sub>2</sub>; for costs <20 US\$/tCO<sub>2</sub> the range is 1.6 to 5 GtCO<sub>2</sub>/yr. About 65% of the total mitigation potential (up to 100 US\$/tCO<sub>2</sub>-eq) is located in the tropics and about 50% of the total could be achieved by reducing emissions from deforestation (*low agreement, medium evidence*).

Forestry can also contribute to the provision of bio-energy from forest residues. The potential of bio-energy, however, is counted in the power supply, transportation (biofuels), industry and building sectors (see Chapter 11 for an overview). Based on bottom-up studies of potential biomass supply from forestry, and assuming that all of that will be used (which depends entirely on the cost of forestry biomass compared with other sources) a contribution in the order of 0.4 GtCO<sub>2</sub>/yr could come from forestry.

Global top-down models are starting to provide insight on where and which of the carbon mitigation options can best be allocated on the globe (Figure TS.24).



**Figure TS.24:** Allocation of global afforestation activities as given by two global top-down models. Top: location of bio-energy and carbon plantations in the world in 2100; bottom: percentage of a grid cell afforested in 2100 [Figure 9.11].

## Interactions of mitigation options with vulnerability and adaptation

Mitigation activities for forestry can be designed to be compatible with adapting to climate change, maintaining biodiversity and promoting sustainable development. Comparing environmental and social co-benefits and costs with the carbon benefit will highlight trade-offs and synergies and help promote sustainable development.

The literature on the interaction between forestry mitigation and climate change is in its infancy. Forests are likely to be impacted by climate change, which could reduce their mitigation potential. A primary management adaptation option is to reduce as many ancillary stresses on the forest as possible. Maintaining widely dispersed and viable populations of individual species minimizes the probability of localized catastrophic events causing species extinction. Formation of protected areas or nature reserves is an example of mitigation as well as adaptation. Protecting areas (with corridors) also leads to conservation of biodiversity, in turn reducing vulnerability to climate change.

Forestry-mitigation projects provide adaptation co-benefits for other sectors. Examples include agro-forestry reducing the vulnerability to drought of rain-fed crop income, mangroves reducing the vulnerability of coastal settlements, and shelter belts slowing desertification (*medium agreement, medium evidence*) [9.5].

## Effectiveness of and experience with climate policies, potentials, barriers and opportunities/ implementation issues

Forestry can make a very significant contribution to a low cost global mitigation portfolio that provides synergies with adaptation and sustainable development. Chapter 9 of this report identifies a whole set of options and policies to achieve this mitigation potential. However, this opportunity has so far not been taken because of the current institutional context, lack of incentives for forest managers and lack of enforcement of existing regulations. Without better policy instruments, only a small portion of this potential is likely to be realized.

Realization of the mitigation potential requires institutional capacity, investment capital, technology, R&D and transfer, as well as appropriate (international) policies and incentives. In many regions, their absence has been a barrier to implementation of forestry-mitigation activities. Notable exceptions exist, however, such as regional successes in reducing deforestation rates and implementing afforestation programmes (*high agreement, much evidence*).

Multiple and location-specific strategies are required to guide mitigation policies in the sector. The optimum choices depend on the current state of the forests, the dominant drivers of forest change, and the anticipated future dynamics of the forests within each region. Participation of all stakeholders and policy-makers

is necessary to promote mitigation projects and design an optimal mix of measures. Integration of mitigation in the forestry sector into land-use planning could be important in this respect.

Most existing policies to slow tropical deforestation have had minimal impact due to lack of regulatory and institutional capacity or countervailing profitability incentives. In addition to more dedicated enforcement of regulations, well-constructed carbon markets or other environmental service payment schemes may help overcome barriers to reducing deforestation by providing positive financial incentives for retaining forest cover.

There have been several proposals to operationalize activities post 2012, including market-based as well as non-market based approaches; for example, through a dedicated fund to voluntarily reduce emissions from deforestation. Policy measures such as subsidies and tax exemptions have been used successfully to encourage afforestation and reforestation both in developed and developing countries. Care must be taken, however, to avoid possible negative environmental and social impacts of large-scale plantation establishment.

Despite relative low costs and many potential positive side effects of afforestation and reforestation under the Clean Development Mechanism (CDM), not many project activities are yet being implemented due to a number of barriers, including the late agreement on and complexity of the rules governing afforestation and reforestation CDM project activities. The requirements for forestry mitigation projects to become viable on a larger scale include certainty over future commitments, streamlined and simplified rules, and reductions in transaction costs. Standardization of project assessment can play an important role in overcoming uncertainties among potential buyers, investors and project participants (*high agreement, medium evidence*) [9.6].

## Forests and Sustainable Development

While the assessment in the forestry chapter identifies remaining uncertainties about the magnitude of the mitigation benefits and costs, the technologies and knowledge required to implement mitigation activities exist today. Forestry can make a significant and sustained contribution to a global mitigation portfolio, while also meeting a wide range of social, economic and ecological objectives. Important co-benefits can be gained by considering forestry mitigation options as an element of broader land-management plans.

Plantations can contribute positively, for example, to employment, economic growth, exports, renewable energy supply and poverty alleviation. In some instances, plantations may also lead to negative social impacts such as loss of grazing land and source of traditional livelihoods. Agro-forestry can produce a wide range of economic, social and environmental benefits; probably wider than large-scale afforestation. Since ancillary benefits tend to be local rather than global, identifying

and accounting for them can reduce or partially compensate the costs of the mitigation measures (*high agreement, medium evidence*) [9.7].

### Technology research, development, deployment, diffusion and transfer

The deployment, diffusion and transfer of technologies such as improved forest-management systems, forest practices and processing technologies including bio-energy, are key to improving the economic and social viability of the different mitigation options. Governments could play a critical role in providing targeted financial and technical support, promoting the participation of communities, institutions and NGOs (*high agreement, much evidence*) [9.8].

### Long-term outlook

Uncertainties in the carbon cycle, the uncertain impacts of climate change on forests and its many dynamic feedbacks, time-lags in the emission-sequestration processes, as well as uncertainties in future socio-economic paths (e.g., to what extent deforestation can be substantially reduced in the coming decades) cause large variations in future carbon balance projections for forests.

Overall, it is expected that in the long-term, mitigation activities will help increase the carbon sink, with the net balance depending on the region. Boreal primary forests will either be small sources or sinks depending on the net effect of enhancement of growth versus a loss of soil organic matter and emissions from increased fires. Temperate forests will probably continue to be net carbon sinks, favoured also by enhanced forest growth due to climate change. In the tropical regions, human-induced land-use changes are expected to continue to drive the dynamics for decades. Beyond 2040, depending very particularly on the effectiveness of policies aimed at reducing forest degradation and deforestation, tropical forests may become net sinks, depending on the influence of climate change. Also, in the medium to long term, commercial bio-energy is expected to become increasingly important.

Developing optimum regional strategies for climate change mitigation involving forests will require complex analyses of the trade-offs (synergies and competition) in land-use between forestry and other land-uses, trade-offs between forest conservation for carbon storage and other environmental services such as biodiversity and watershed conservation and sustainable forest harvesting to provide society with carbon-containing fibre, timber and bio-energy resources, and trade-offs among utilization strategies of harvested wood products aimed at maximizing storage in long-lived products, recycling, and use for bio-energy [9.9].

## 10 Waste management

### Status of the sector, development trends and implications

Waste generation is related to population, affluence and urbanization. Current global rates of post-consumer waste generation are estimated to be 900-1300 Mt/yr. Rates have been increasing in recent years, especially in developing countries with rapid population growth, economic growth and urbanization. In highly developed countries, a current goal is to decouple waste generation from economic driving forces such as GDP — recent trends suggest that per capita rates of post-consumer waste generation may be peaking as a result of recycling, re-use, waste minimization, and other initiatives (*medium agreement, medium evidence*) [10.1, 10.2].

Post-consumer waste is a small contributor to global GHG emissions (<5%), with landfill CH<sub>4</sub> accounting for >50% of current emissions. Secondary sources of emissions are wastewater CH<sub>4</sub> and N<sub>2</sub>O; in addition, minor emissions of CO<sub>2</sub> result from incineration of waste containing fossil carbon. In general, there are large uncertainties with respect to quantification of direct emissions, indirect emissions and mitigation potentials for the waste sector, which could be reduced by consistent and coordinated data collection and analysis at the national level. There are currently no inventory methods for annual quantification of GHG emissions from waste transport, nor for annual emissions of fluorinated gases from post-consumer waste (*high agreement, much evidence*) [10.3].

It is important to emphasize that post-consumer waste constitutes a significant renewable energy resource that can be exploited through thermal processes (incineration and industrial co-combustion), landfill gas utilization and use of anaerobic digester biogas. Waste has an economic advantage in comparison to many biomass resources because it is regularly collected at public expense. The energy content of waste can be most efficiently exploited using thermal processes: during combustion, energy is obtained directly from biomass (paper products, wood, natural textiles, food) and from fossil carbon sources (plastics, synthetic textiles). Assuming an average heating value of 9 GJ/t, global waste contains >8 EJ of available energy, which could increase to 13 EJ (nearly 2% of primary energy demand) in 2030 (*medium agreement, medium evidence*) [10.1]. Currently, more than 130 million tonnes/yr of waste are combusted worldwide, which is equivalent to >1 EJ/yr. The recovery of landfill CH<sub>4</sub> as a source of renewable energy was commercialized more than 30 years ago with a current energy value of >0.2 EJ/yr. Along with thermal processes, landfill gas and anaerobic digester gas can provide important local sources of supplemental energy (*high agreement, much evidence*) [10.1, 10.3].

Because of landfill gas recovery and complementary measures (increased recycling and decreased landfilling through the implementation of alternative technologies), emissions of CH<sub>4</sub> from landfills in developed countries have been largely stabilized. Choices for mature, large-scale waste management technologies to avoid or reduce GHG emissions compared with landfilling include incineration for waste-to-energy and biological processes such as composting or mechanical-biological treatment (MBT). However, in developing countries, landfill CH<sub>4</sub> emissions are increasing as more controlled (anaerobic) landfilling practices are being implemented. This is especially true for rapidly urbanizing areas where engineered landfills provide a more environmentally acceptable waste-disposal strategy than open dumpsites by reducing disease vectors, toxic odours, uncontrolled combustion and pollutant emissions to air, water and soil. Paradoxically, higher GHG emissions occur as the aerobic production of CO<sub>2</sub> (by burning and aerobic decomposition) is shifted to anaerobic production of CH<sub>4</sub>. To a large extent, this is the same transition to sanitary landfilling that occurred in many developed countries during 1950–1970. The increased CH<sub>4</sub> emissions can be mitigated by accelerating the introduction of engineered gas recovery, aided by Kyoto mechanisms such as CDM and Joint Implementation (JI). As of late October 2006, landfill gas recovery projects accounted for 12% of the average annual Certified Emission Reductions (CERs) under CDM. In addition, alternative waste management strategies such as recycling and composting can be implemented in developing countries. Composting can provide an affordable, sustainable alternative to engineered landfills, especially where more labour-intensive, lower-technology strategies are applied to selected biodegradable waste streams (*high agreement, medium evidence*) [10.3].

Recycling, re-use and waste minimization initiatives, both public and private, are indirectly reducing GHG emissions by decreasing the mass of waste requiring disposal. Depending on regulations, policies, markets, economic priorities and local constraints, developed countries are implementing increasingly higher recycling rates to conserve resources, offset fossil fuel use, and avoid GHG generation. Quantification of global recycling rates is not currently possible because of varying baselines and definitions; however, local reductions of >50% have been achieved. Recycling could be expanded practically in many countries to achieve additional reductions. In developing countries, waste scavenging and informal recycling are common practices. Through various diversion and small-scale recycling activities, those who make their living from decentralized waste management can significantly reduce the mass of waste that requires more centralized solutions. Studies indicate that low-technology recycling activities can also generate significant employment through creative microfinance and other small-scale investments. The challenge is to provide safer, healthier working conditions than currently experienced by waste scavengers at uncontrolled dumpsites (*medium agreement, medium evidence*) [10.3].

For wastewater, only about 60% of the global population has sanitation coverage (sewerage). For wastewater treatment, almost 90% of the population in developed countries but less than 30% in developing countries has improved sanitation (including sewerage and waste water treatment, septic tanks, or latrines). In addition to GHG mitigation, improved sanitation and wastewater management provide a wide range of health and environmental co-benefits (*high agreement, much evidence*) [10.2, 10.3].

With respect to both waste and wastewater management in developing countries, two key constraints to sustainable development are the lack of financial resources and the selection of appropriate and truly sustainable technologies for a particular setting. It is a significant and costly challenge to implementing waste and wastewater collection, transport, recycling, treatment and residuals management in many developing countries. However, the implementation of sustainable waste and wastewater infrastructure yields multiple co-benefits to assist with the implementation of Millennium Development Goals (MDGs) via improved public health, conservation of water resources, and reduction of untreated discharges to air, surface water, groundwater, soils and coastal zones (*high agreement, much evidence*) [10.4].

### Emission trends

With total 2005 emissions of approximately 1300 MtCO<sub>2</sub>-eq/yr, the waste sector contributes about 2–3% of total GHG emissions from Annex I and EIT countries and 4–5% from non-Annex I countries (see Table TS.13). For 2005–2020, business-as-usual (BAU) projections indicate that landfill CH<sub>4</sub> will remain the largest source at 55–60% of the total. Landfill CH<sub>4</sub> emissions are stabilizing and decreasing in many developed countries as a result of increased landfill gas recovery combined with waste diversion from landfills through recycling, waste minimization and alternative thermal and biological waste management strategies. However, landfill CH<sub>4</sub> emissions are increasing in developing countries because of larger quantities of municipal solid waste from rising urban populations, increasing economic development and, to some extent, the replacement of open burning and dumping by engineered landfills. Without additional measures, a 50% increase in landfill CH<sub>4</sub> emissions from 2005 to 2020 is projected, mainly from the Non-Annex I countries. Wastewater emissions of CH<sub>4</sub> and N<sub>2</sub>O from developing countries are also rising rapidly with increasing urbanization and population. Moreover, because the wastewater emissions in Table TS.13 are based on human sewage only and are not available for all developing countries, these emissions are underestimated (*high agreement, medium evidence*) [10.1, 10.2, 10.3, 10.4].

**Table TS.13:** Trends for GHG emissions from waste using 1996 and 2006 UNFCCC inventory guidelines, extrapolations and BAU projections (MtCO<sub>2</sub>-eq, rounded) [Table 10.3].

Source	1990	1995	2000	2005	2010	2015	2020	Notes
Landfill CH <sub>4</sub>	550	585	590	635	700	795	910	Averaged using 1996/2006 guidelines
Wastewater <sup>a</sup> CH <sub>4</sub>	450	490	520	590	600	630	670	1996 guidelines
Wastewater <sup>a</sup> N <sub>2</sub> O	80	90	90	100	100	100	100	1996 guidelines
Incineration CO <sub>2</sub>	40	40	50	50	50	60	60	2006 guidelines
<b>Total</b>	<b>1120</b>	<b>1205</b>	<b>1250</b>	<b>1375</b>	<b>1450</b>	<b>1585</b>	<b>1740</b>	

Note:

<sup>a)</sup> wastewater emissions are underestimated - see text.

### Description and assessment of mitigation technologies and practices, options and potentials, costs and sustainability

Existing waste management technologies can effectively mitigate GHG emissions from this sector – a wide range of mature, low- to high-technology, environmentally-effective strategies are commercially available to mitigate emissions and provide co-benefits for improved public health and safety, soil protection, pollution prevention and local energy supply. Collectively, these technologies can directly reduce GHG emissions (through landfill CH<sub>4</sub> recovery and utilization, improved landfill practices, engineered wastewater management, utilization of anaerobic digester biogas) or avoid significant GHG generation (through controlled composting of organic waste, state-of-the-art incineration, expanded sanitation coverage). In addition, waste minimization, recycling and re-use represent an important and increasing potential for indirect reduction of GHG emissions through the conservation of raw materials, improved energy and resource efficiency and fossil fuel avoidance. For developing countries, environmentally responsible waste management at an appropriate level of technology promotes sustainable development and improves public health (*high agreement, much evidence*) [10.4].

Because waste management decisions are often made locally without concurrent quantification of GHG mitigation, the importance of the waste sector for reducing global GHG emissions has been underestimated (*high agreement, medium evidence*) [10.1; 10.4]. Flexible strategies and financial incentives can expand waste management options to achieve GHG mitigation goals—in the context of integrated waste management, local technology decisions are a function of many competing variables, including waste quantity and characteristics, cost and financing issues, regulatory constraints and infrastructure requirements, including available land area and collection/transportation considerations. Life-cycle assessment (LCA) can provide decision-support tools (*high agreement, much evidence*) [10.4].

Landfill CH<sub>4</sub> emissions are directly reduced through engineered gas extraction and recovery systems consisting

of vertical wells and/or horizontal collectors. In addition, landfill gas offsets the use of fossil fuels for industrial or commercial process heating, onsite generation of electricity or as a feedstock for synthetic natural gas fuels. Commercial recovery of landfill CH<sub>4</sub> has occurred at full scale since 1975 with documented utilization in 2003 at 1150 plants recovering 105 MtCO<sub>2</sub>-eq/yr. Because there are also many projects that flare gas without utilization, the total recovery is likely to be at least double this figure (*high agreement, medium evidence*) [10.1; 10.4]. A linear regression using historical data from the early 1980s to 2003 indicates a growth rate for landfill CH<sub>4</sub> utilization of approximately 5% per year. In addition to landfill gas recovery, the further development and implementation of landfill ‘biocovers’ can provide an additional low cost, biological strategy to mitigate emissions since landfill CH<sub>4</sub> (and non-methane volatile organic compounds (NMVOCs)) emissions are also reduced by aerobic microbial oxidation in landfill-cover soils (*high agreement, much evidence*) [10.4].

Incineration and industrial co-combustion for waste-to-energy provide significant renewable energy benefits and fossil fuel offsets at >600 plants worldwide, while producing very minor GHG emissions compared with landfilling. Thermal processes with advanced emission controls are a proven technology but more costly than controlled landfilling with landfill gas recovery (*high agreement, medium evidence*) [10.4].

Controlled biological processes can also provide important GHG mitigation strategies, preferably using source-separated waste streams. Aerobic composting of waste avoids GHG generation and is an appropriate strategy for many developed and developing countries, either as a stand-alone process or as part of mechanical-biological treatment. In many developing countries, notably China and India, small-scale low-technology anaerobic digestion has also been practised for decades. Since higher-technology incineration and composting plants have proved unsustainable in a number of developing countries, lower-technology composting or anaerobic digestion can be implemented to provide sustainable waste management solutions (*high agreement, medium evidence*) [10.4].

For 2030, the total economic reduction potential for CH<sub>4</sub> emissions from landfilled waste at costs of <20 US\$/tCO<sub>2</sub>-eq



**Table TS.14:** Ranges for economic mitigation potential for regional landfill CH<sub>4</sub> emissions at various cost categories in 2030, see notes [Table 10.5].

Region	Projected emissions in 2030 (MtCO <sub>2</sub> -eq)	Total economic mitigation potential at <100 US\$/tCO <sub>2</sub> -eq (MtCO <sub>2</sub> -eq)	Economic mitigation potential (MtCO <sub>2</sub> -eq) at various cost categories (US\$/tCO <sub>2</sub> -eq)			
			<0	0-20	20-50	50-100
<b>OECD</b>	360	100-200	100-120	20-100	0-7	1
<b>EIT</b>	180	100	30-60	20-80	5	1-10
<b>Non-OECD</b>	960	200-700	200-300	30-100	0-200	0-70
<b>Global</b>	1500	400-1000	300-500	70-300	5-200	10-70

## Notes:

- 1) Costs and potentials for wastewater mitigation are not available.
- 2) Regional numbers are rounded to reflect the uncertainty in the estimates and may not equal global totals.
- 3) Landfill carbon sequestration not considered.
- 4) The timing of measures limiting landfill disposal affects the annual mitigation potential in 2030. The upper limits assume that landfill disposal is limited in the coming years to 15% of the waste generated globally. The lower limits reflect a more realistic timing for implementation of measures reducing landfill disposal.

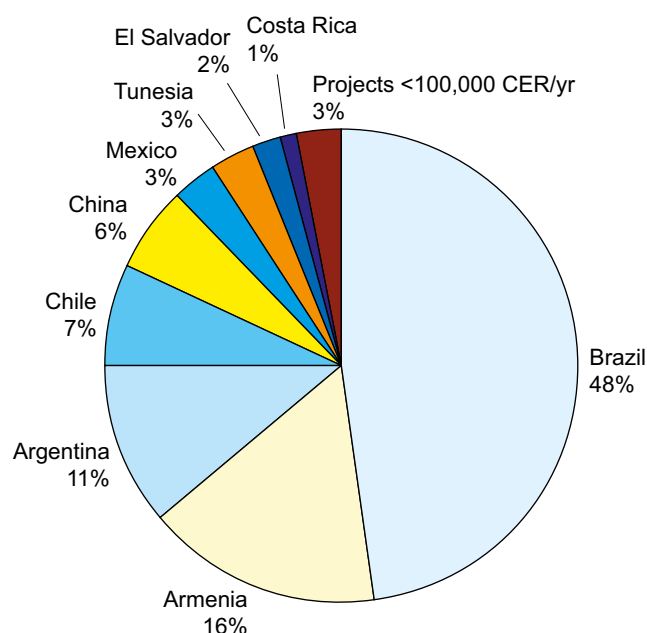
ranges between 400 and 800 MtCO<sub>2</sub>-eq. Of this total, 300–500 MtCO<sub>2</sub>-eq/yr has negative cost (Table TS.14). For the long term, if energy prices continue to increase, there will be more profound changes in waste management strategies related to energy and materials recovery in both developed and developing countries. Thermal processes, which have higher unit costs than landfilling, become more viable as energy prices increase. Because landfills continue to produce CH<sub>4</sub> for many decades, both thermal and biological processes are complementary to increased landfill gas recovery over shorter time frames (*high agreement, limited evidence*) [10.4].

For wastewater, increased levels of improved sanitation in developing countries can provide multiple benefits for GHG mitigation, improved public health, conservation of water resources and reduction of untreated discharges to water and soils. Historically, urban sanitation in developed countries has focused on centralized sewerage and wastewater treatment plants, which are too expensive for rural areas with low population density and may not be practical to implement in rapidly growing, peri-urban areas with high population density. It has been demonstrated that a combination of low cost technology with concentrated efforts for community acceptance, participation and management can successfully expand sanitation coverage. Wastewater is also a secondary water resource in countries with water shortages where water re-use and recycling could assist many developing and developed countries with irregular water supplies. These measures also encourage smaller wastewater treatment plants with reduced nutrient loads and proportionally lower GHG emissions. Estimates of global or regional mitigation costs and potentials for wastewater are not currently available (*high agreement, limited evidence*) [10.4].

### Effectiveness of and experience with climate policies, potentials, barriers and opportunities/implementation issues

Because landfill CH<sub>4</sub> is the dominant GHG from this sector, a major strategy is the implementation of standards that encourage or mandate landfill CH<sub>4</sub> recovery. In developed countries, landfill CH<sub>4</sub> recovery has increased as a result of direct regulations requiring landfill gas capture, voluntary measures including GHG-emissions credits trading and financial incentives (including tax credits) for renewable energy or green power. In developing countries, it is anticipated that landfill CH<sub>4</sub> recovery will increase during the next two decades as controlled landfilling is phased in as a major waste disposal strategy. JI and the CDM have already proved to be useful mechanisms for external investment from industrialized countries, especially for landfill gas recovery projects where the lack of financing is a major impediment. The benefits are twofold: reduced GHG emissions with energy benefits from landfill CH<sub>4</sub> plus upgraded landfill design and operations. Currently (late October 2006), under the CDM, the annual average CERs for the 33 landfill gas recovery projects constitute about 12% of the total. Most of these projects (Figure TS.25) are located in Latin-American countries (72% of landfill gas CERs), dominated by Brazil (9 projects; 48% of CERs) (*high agreement, medium evidence*) [10.4].

In the EU, landfill gas recovery is mandated at existing sites, while the landfilling of organic waste is being phased out via the landfill directive (1999/31/EC). This directive requires, by 2016, a 65% reduction relative to 1995 in the mass of biodegradable organic waste that is landfilled annually. As a result, post-consumer waste is being diverted to incineration and to mechanical and biological treatment (MBT) before landfilling to recover recyclables and reduce the organic carbon content. In 2002, EU waste-to-energy plants generated about 40 million GJ of electrical and 110 million GJ of thermal energy, while between 1990 and 2002, landfill CH<sub>4</sub> emissions in the EU decreased by



**Figure TS.25:** Distribution of landfill gas CDM projects based on average annual CERs for registered projects late October, 2006 [Figure 10.9].

Note: Includes 11 MtCO<sub>2</sub>-eq/yr CERs for landfill CH<sub>4</sub> out of 91 MtCO<sub>2</sub>-eq/yr total. Projects <100,000 CERs/yr are located in Israel, Bolivia, Bangladesh and Malaysia.

almost 30% due to the landfill directive and related national legislation (*high agreement, much evidence*) [10.4, 10.5].

### ***Integrated and non-climate policies affecting emissions of greenhouse gases: GHG mitigation as the co-benefit of waste policies and regulations; role of sustainable development***

GHG mitigation is often not the primary driver, but is itself a co-benefit of policies and measures in the waste sector that address broad environmental objectives, encourage energy recovery from waste, reduce use of virgin materials, restrict choices for ultimate waste disposal, promote waste recycling and re-use and encourage waste minimization. Policies and measures to promote waste minimization, re-use and recycling indirectly reduce GHG emissions from waste. These measures include Extended Producer Responsibility (EPR), unit pricing (or PAYT/‘Pay As You Throw’) and landfill taxes. Other measures include separate and efficient collection of recyclables together with both unit pricing and landfill tax systems. Some Asian countries are encouraging ‘circular economy’ or ‘sound material-cycle society’ as a new development strategy whose core concept is the circular (closed) flow of materials and the use of raw materials and energy through multiple phases. Because of limited data, differing baselines and other regional conditions, it is not currently possible to quantify the global effectiveness of these strategies in reducing GHG emissions (*medium agreement, medium evidence*) [10.5].

In many countries, waste and wastewater management policies are closely integrated with environmental policies

and regulations pertaining to air, water and soil quality as well as to renewable energy initiatives. Renewable-energy programmes include requirements for electricity generation from renewable sources, mandates for utilities to purchase power from small renewable providers, renewable energy tax credits, and green power initiatives, which allow consumers to choose renewable providers. In general, the decentralization of electricity generation capacity via renewables can provide strong incentives for electrical generation from landfill CH<sub>4</sub> and thermal processes for waste-to-energy (*high agreement, much evidence*) [10.5].

Although policy instruments in the waste sector consist mainly of regulations, there are also economic measures in a number of countries to encourage particular waste management technologies, recycling and waste minimization. These include incinerator subsidies or tax exemptions for waste-to-energy. Thermal processes can most efficiently exploit the energy value of post-consumer waste, but must include emission controls to limit emissions of secondary air pollutants. Subsidies for the construction of incinerators have been implemented in several countries, usually combined with standards for energy efficiency. Tax exemptions for electricity generated by waste incinerators and for waste disposal with energy recovery have also been adopted (*high agreement, much evidence*) [10.5].

The co-benefits of effective and sustainable waste and wastewater collection, transport, recycling, treatment and disposal include GHG mitigation, improved public health, conservation of water resources and reductions in the discharge of untreated pollutants to air, soil, surface water and groundwater. Because there are many examples of abandoned waste and wastewater plants in developing countries, it must be stressed that a key aspect of sustainable development is the selection of appropriate technologies that can be sustained within the specific local infrastructure (*high agreement, medium evidence*) [10.5].

### **Technology research, development and diffusion**

In general, the waste sector is characterized by mature technologies that require further diffusion in developing countries. Advances under development include:

- Landfilling: Implementation of optimized gas collection systems at an early stage of landfill development to increase long-term gas collection efficiency. Optimization of landfill biodegradation (bioreactors) to provide greater process control and shorter waste degradation lifetimes. Construction of landfill ‘biocovers’ that optimize microbial oxidation of CH<sub>4</sub> and NMVOCs to minimize emissions.
- Biological processes: For developing countries, lower-technology, affordable sustainable composting and anaerobic digestion strategies for source-separated biodegradable waste.
- Thermal processes: Advanced waste-to-energy technologies that can provide higher thermal and electrical efficiencies

than current incinerators (10–20% net electrical efficiency). Increased implementation of industrial co-combustion using feedstocks from various waste fractions to offset fossil fuels. Gasification and pyrolysis of source-separated waste fractions in combination with improved, lower-cost separation technologies for production of fuels and feedstocks.

- Recycling, re-use, waste minimization, pre-treatment (improved mechanical-biological treatment processes) Innovations in recycling technology and process improvements resulting in decreased use of virgin materials, energy conservation, and fossil fuel offsets. Development of innovative but low-technology recycling solutions for developing countries.
- Wastewater: New low-technology ecological designs for improved sanitation at the household and small community level, which can be implemented sustainably for efficient small-scale wastewater treatment and water conservation in both developed and developing countries (*high agreement, limited evidence*) [10.5; 10.6].

### Long-term outlook, systems transitions

To minimize future GHG emissions from the waste sector, it is important to preserve local options for a wide range of integrated and sustainable management strategies. Furthermore, primary reductions in waste generation through recycling, re-use, and waste minimization can provide substantial benefits for the conservation of raw materials and energy. Over the long term, because landfills continue to produce CH<sub>4</sub> for decades, landfill gas recovery will be required at existing landfills even as many countries change to non-landfilling technologies such as incineration, industrial co-combustion, mechanical-biological treatment, large-scale composting and anaerobic digestion. In addition, the ‘back-up’ landfill will continue to be a critical component of municipal solid waste planning. In developing countries, investment in improved waste and wastewater management confers significant co-benefits for public health and safety, environmental protection and infrastructure development.

## 11 Mitigation from a cross-sectoral perspective

### Mitigation options across sectors

While many of the technological, behavioural and policy options mentioned in Chapters 4–10 concern specific sectors, some technologies and policies reach across many sectors; for example, the use of biomass and the switch from high-carbon fuels to gas affect energy supply, transport, industry and buildings. Apart from potentials for common technologies, these examples also highlight possible competition for resources, such as finance and R&D support [11.2.1].

The bottom-up compilation of mitigation potentials by sector is complicated by interactions and spill-overs between

sectors, over time and over regions and markets. A series of formal procedures has been used to remove potential double counting, such as reduction of the capacity needed in the power sector due to electricity saving in industry and the buildings sector. An integration of sector potentials in this way is required to summarize the sectoral assessments of Chapters 4–10. The uncertainty of the outcome is influenced by issues of comparability of sector calculations, difference in coverage between the sectors (e.g., the transport sector) and the aggregation itself, in which only the main and direct sector interactions have been taken into account [11.3.1].

The top-down estimates were derived from stabilization scenarios, i.e., runs towards long-term stabilization of atmospheric GHG concentration [3.6].

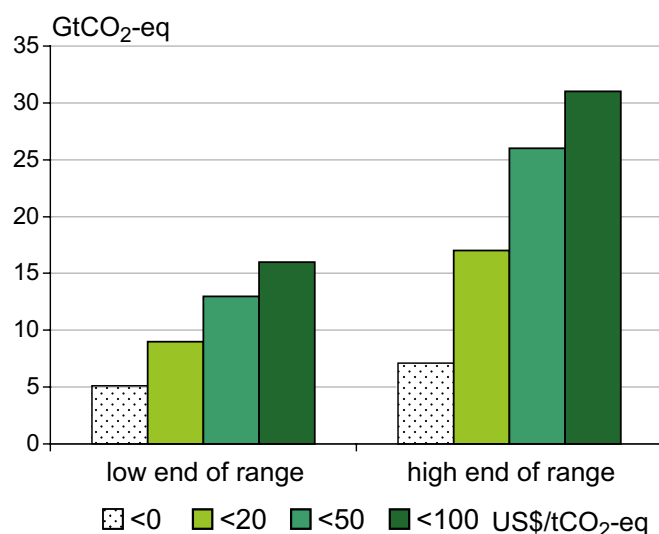
Figure TS.26A and Table TS.15 show that the bottom-up assessments emphasize the opportunities for no-regrets options in many sectors, with a bottom-up estimate for all sectors by 2030 of about 6 GtCO<sub>2</sub>-eq at negative costs; that is, net benefits. A large share of the no-regrets options is in the building sector. The total for bottom-up low cost options (no-regrets and other options costing less than 20 US\$/tCO<sub>2</sub>-eq) is around 13 GtCO<sub>2</sub>-eq (ranges are discussed below). There are additional bottom-up potentials of around 6 and 4 GtCO<sub>2</sub>-eq at additional costs of <50 and 100 US\$/tCO<sub>2</sub>-eq respectively (*medium agreement, medium evidence*) [11.3.1].

There are several qualifications to these estimates in addition to those mentioned above. First, in the bottom-up estimates a set of emission-reduction options, mainly for co-generation, parts of the transport sector and non-technical options such as behavioural changes, are excluded because the available literature did not allow a reliable assessment. It is estimated that the bottom-up potentials are therefore underestimated by 10–15%. Second, the chapters identify a number of key sensitivities that have not been quantified, relating to energy prices, discount rates and the scaling-up of regional results for the agricultural and forestry options. Third, there is a lack of estimates for many EIT countries and substantial parts of the non-OECD/EIT region [11.3.1].

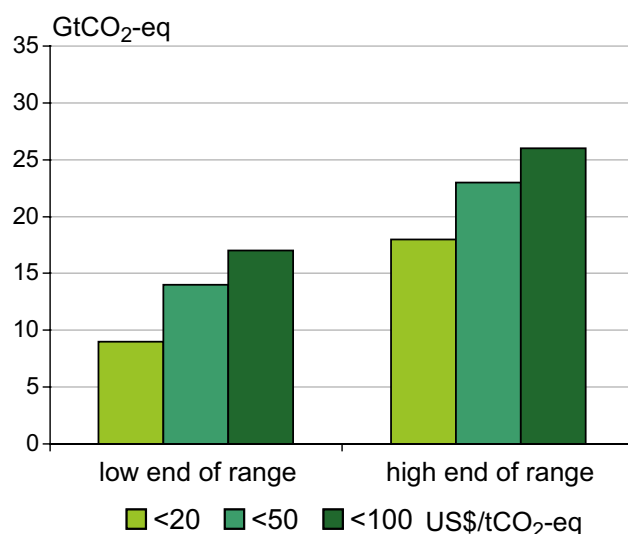
The estimates of potentials at carbon prices <20 US\$/tCO<sub>2</sub>-eq are lower than the TAR bottom-up estimates that were evaluated for carbon prices <27 US\$/tCO<sub>2</sub>-eq, due to better information in recent literature (*high agreement, much evidence*).

Figure TS.15 and Table TS.16 show that the overall bottom-up potentials are comparable with those of the 2030 results from top-down models, as reported in Chapter 3.

At the sectoral level, there are larger differences between bottom-up and top-down, mainly because the sector definitions in top-down models often differ from those in bottom-up assessments (table TS.17). Although there are slight differences



**Figure TS.26A:** Global economic mitigation potential in 2030 estimated from bottom-up studies. Data from Table TS.15. [Figure 11.3].



**Figure TS.26B:** Global economic mitigation potential in 2030 estimated from top-down studies. Data from Table TS.16. [Figure 11.3].

between the baselines assumed for top-down and bottom-up assessments, the results are close enough to provide a robust estimate of the overall economic mitigation potential by 2030. The mitigation potential at carbon prices of <100 US\$/tCO<sub>2</sub>-eq is about 25–50% of 2030 baseline emissions (*high agreement, much evidence*).

Table TS.17 shows that for point-of-emission analysis<sup>18</sup> a large part of the long-term mitigation potential is in the energy-

supply sector. However, for an end-use sector analysis as used for the results in Figure TS.27, the highest potential lies in the building and agriculture sectors. For agriculture and forestry, top-down estimates are lower than those from bottom-up studies. This is because these sectors are generally not well covered in top-down models. The energy supply and industry estimates from top-down models are generally higher than those from bottom-up assessments (*high agreement, medium evidence*) [11.3.1].

**Table TS.15:** Global economic mitigation potential in 2030 estimated from bottom-up studies [11.3].

Carbon price (US\$/tCO <sub>2</sub> -eq)	Economic potential (GtCO <sub>2</sub> -eq/yr)	Reduction relative to SRES A1 B (68 GtCO <sub>2</sub> -eq/yr) (%)	Reduction relative to SRES B2 (49 GtCO <sub>2</sub> -eq/yr) (%)
0	5-7	7-10	10-14
20	9-17	14-25	19-35
50	13-26	20-38	27-52
100	16-31	23-46	32-63

**Table TS.16:** Global economic mitigation potential in 2030 estimated from top-down studies [11.3].

Carbon price (US\$/tCO <sub>2</sub> -eq)	Economic potential (GtCO <sub>2</sub> -eq/yr)	Reduction relative to SRES A1 B (68 GtCO <sub>2</sub> -eq/yr) (%)	Reduction relative to SRES B2 (49 GtCO <sub>2</sub> -eq/yr) (%)
20	9-18	13-27	18-37
50	14-23	21-34	29-47
100	17-26	25-38	35-53

<sup>18</sup> In a point-of-emission analysis, emissions from electricity use are allocated to the energy-supply sector. In an end-use sector analysis, emissions from electricity are allocated to the respective end-use sector (particularly relevant for industry and buildings).

**Table TS.17: Economic potential for sectoral mitigation by 2030: comparison of bottom-up (from Table 11.3) and top-down estimates (from Section 3.6) [Table 11.5].**

Chapter of report	Sectors	Sector-based ('bottom-up') potential by 2030 (GtCO <sub>2</sub> -eq/yr)				Economy-wide model ('top-down') snapshot of mitigation by 2030 (GtCO <sub>2</sub> -eq/yr)	
		End-use sector allocation (allocation of electricity savings to end-use sectors)		Point-of-emissions allocation (emission reductions from end-use electricity savings allocated to energy supply sector)		Low	High
		Carbon price <20 US\$/tCO <sub>2</sub> -eq					
		Low	High	Low	High	Low	High
4	Energy supply & conversion	1.2	2.4	4.4	6.4	3.9	9.7
5	Transport	1.3	2.1	1.3	2.1	0.1	1.6
6	Buildings	4.9	6.1	1.9	2.3	0.3	1.1
7	Industry	0.7	1.5	0.5	1.3	1.2	3.2
8	Agriculture	0.3	2.4	0.3	2.4	0.6	1.2
9	Forestry	0.6	1.9	0.6	1.9	0.2	0.8
10	Waste	0.3	0.8	0.3	0.8	0.7	0.9
11	<b>Total</b>	9.3	17.1	9.1	17.9	8.7	17.9
<b>Carbon price &lt;50 US\$/tCO<sub>2</sub>-eq</b>							
4	Energy supply & conversion	2.2	4.2	5.6	8.4	6.7	12.4
5	Transport	1.5	2.3	1.5	2.3	0.5	1.9
6	Buildings	4.9	6.1	1.9	2.3	0.4	1.3
7	Industry	2.2	4.7	1.6	4.5	2.2	4.3
8	Agriculture	1.4	3.9	1.4	3.9	0.8	1.4
9	Forestry	1.0	3.2	1.0	3.2	0.2	0.8
10	Waste	0.4	1.0	0.4	1.0	0.8	1.0
11	<b>Total</b>	13.3	25.7	13.2	25.8	13.7	22.6
<b>Carbon price &lt;100 US\$/tCO<sub>2</sub>-eq</b>							
4	Energy supply & conversion	2.4	4.7	6.3	9.3	8.7	14.5
5	Transport	1.6	2.5	1.6	2.5	0.8	2.5
6	Buildings	5.4	6.7	2.3	2.9	0.6	1.5
7	Industry	2.5	5.5	1.7	4.7	3.0	5.0
8	Agriculture	2.3	6.4	2.3	6.4	0.9	1.5
9	Forestry	1.3	4.2	1.3	4.2	0.2	0.8
10	Waste	0.4	1.0	0.4	1.0	0.9	1.1
11	<b>Total</b>	15.8	31.1	15.8	31.1	16.8	26.2

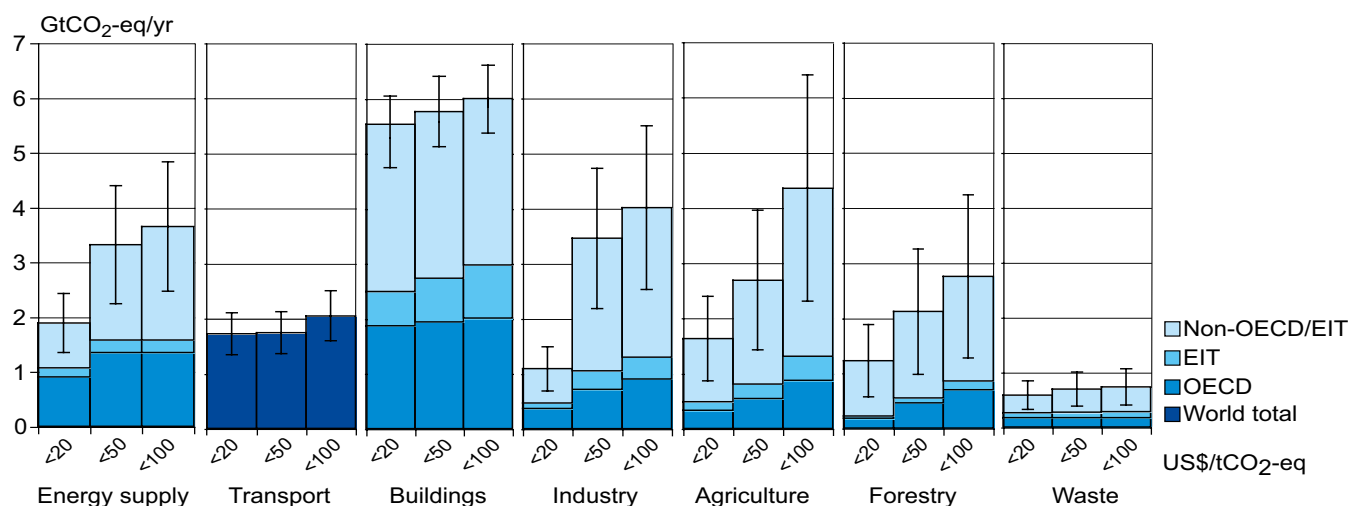
Sources: Tables 3.16, 3.17 and 11.3

See notes to Tables 3.16, 3.17 and 11.3, and Annex 11.1.

Bio-energy options are important for many sectors by 2030, with substantial growth potential beyond, although no complete integrated studies are available for supply-demand balances. Key preconditions for such contributions are the development of biomass capacity (energy crops) in balance with investments in agricultural practices, logistic capacity and markets, together with commercialization of second-generation biofuel production. Sustainable biomass production and use

could ensure that issues in relation to competition for land and food, water resources, biodiversity and socio-economic impacts are not creating obstacles (*high agreement, limited evidence*) [11.3.1.4].

Apart from the mitigation options mentioned in the sectoral Chapters 4–10, geo-engineering solutions to the enhanced greenhouse effect have been proposed. However, options



**Figure TS.27:** Estimated sectoral economic potential for global mitigation for different regions as a function of carbon price in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments. A full explanation of the derivation of this figure is found in Section 11.3.

Notes:

1. The ranges for global economic potentials as assessed in each sector are shown by vertical lines. The ranges are based on end-use allocations of emissions, meaning that emissions of electricity use are counted towards the end-use sectors and not to the energy supply sector.
2. The estimated potentials have been constrained by the availability of studies particularly at high carbon price levels.
3. Sectors used different baselines. For industry the SRES B2 baseline was taken, for energy supply and transport the WEO 2004 baseline was used; the building sector is based on a baseline in between SRES B2 and A1B; for waste, SRES A1B driving forces were used to construct a waste specific baseline, agriculture and forestry used baselines that mostly used B2 driving forces.
4. Only global totals for transport are shown because international aviation is included [5.4].
5. Categories excluded are: non-CO<sub>2</sub> emissions in buildings and transport, part of material efficiency options, heat production and cogeneration in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10-15%.

to remove CO<sub>2</sub> directly from the air, for example, by iron fertilization of the oceans, or to block sunlight, remain largely speculative and may have a risk of unknown side effects. Blocking sunlight does not affect the expected escalation in atmospheric CO<sub>2</sub> levels, but could reduce or eliminate the associated warming. This disconnection of the link between CO<sub>2</sub> concentration and global temperature could have beneficial consequences, for example, in increasing the productivity of agriculture and forestry (in as far as CO<sub>2</sub> fertilization is effective), but they do not mitigate or address other impacts such as further acidification of the oceans. Detailed cost estimates for these options have not been published and they are without a clear institutional framework for implementation (*medium agreement, limited evidence*) [11.2.2].

### Mitigation costs across sectors and macro-economic costs

The costs of implementing the Kyoto Protocol are estimated to be much lower than the TAR estimates due to US rejection of the Protocol. With full use of the Kyoto flexible mechanisms, costs are estimated at less than 0.05% of Annex B (without US) GDP (TAR Annex B: 0.1–1.1%). Without flexible mechanisms,

costs are now estimated at less than 0.1% (TAR 0.2–2%) (*high agreement, much evidence*) [11.4].

Modelling studies of post-2012 mitigation have been assessed in relation to their global effects on CO<sub>2</sub> abatement by 2030, the carbon prices required and their effects on GDP or GNP (for the long-term effects of stabilization after 2030 see Chapter 3). For Category IV<sup>19</sup> pathways (stabilization around 650 ppm CO<sub>2</sub>-eq) with CO<sub>2</sub> abatement less than 20% below baseline and up to 25 US\$/tCO<sub>2</sub> carbon prices, studies suggest that gross world product would be, at worst, some 0.7% below baseline by 2030, consistent with the median of 0.2% and the 10–90 percentile range of –0.6 to 1.2% for the full set of scenarios given in Chapter 3.

Effects are more uncertain for the more stringent Category III pathways (stabilization around 550 ppm CO<sub>2</sub>-eq) with CO<sub>2</sub> abatement less than 40% and up to 50 US\$/tCO<sub>2</sub> carbon prices, with most studies suggesting costs less than 1% of global gross world product, consistent with the median of 0.6% and the 10–90 percentile range of 0 to 2.5% for the full set in Chapter 3. Again, the estimates are heavily dependent on approaches and assumptions. The few studies with baselines that require

19 See Chapter 3 for the definition of Category III and IV pathways.

higher CO<sub>2</sub> reductions to achieve the targets require higher carbon prices and most report higher GDP costs. For category I and II studies (stabilization between 445 and 535 ppm CO<sub>2</sub>-eq) costs are less than 3% GDP loss, but the number of studies is relatively small and they generally use low baselines. The lower estimates of the studies assessed here, compared with the full set of studies reported in Chapter 3, are caused mainly by a larger share of studies that allow for enhanced technological innovation triggered by policies, particularly for more stringent mitigation scenarios (*high agreement, medium evidence*) [11.4].

All approaches indicate that no single sector or technology will be able to address the mitigation challenge successfully on its own, suggesting the need for a diversified portfolio based on a variety of criteria. Top-down assessments agree with the bottom-up results in suggesting that carbon prices around 20-50 US\$/tCO<sub>2</sub>-eq (73-183 US\$/tC-eq) are sufficient to drive large-scale fuel-switching and make both CCS and low-carbon power sources economic as technologies mature. Incentives of this order might also play an important role in avoiding deforestation. The various short- and long-term models come up with differing estimates, the variation of which can be explained mainly by approaches and assumptions regarding the use of revenues from carbon taxes or permits, treatment of technological change, degree of substitutability between internationally traded products, and the disaggregation of product and regional markets (*high agreement, much evidence*) [11.4, 11.5, 11.6].

The development of the carbon price and the corresponding emission reductions will determine the level at which atmospheric GHG concentrations can be stabilized. Models suggest that a predictable and ongoing gradual increase in the carbon price that would reach 20–50 US\$/tCO<sub>2</sub>-eq by 2020–2030 corresponds with Category III stabilization (550 ppm CO<sub>2</sub>-eq). For Category IV (650 ppm CO<sub>2</sub>-eq), such a price level could be reached after 2030. For stabilization at levels between 450 and 550 ppm CO<sub>2</sub>-eq, carbon prices of up to 100 US\$/tCO<sub>2</sub>-eq need to be reached by around 2030 (*medium agreement, medium evidence*) [11.4, 11.5, 11.6].

In all cases, short-term pathways towards lower stabilization levels, particularly for Category III and below, would require many additional measures around energy efficiency, low-carbon energy supply, other mitigation actions and avoidance of investment in very long-lived carbon-intensive capital stock. Studies of decision-making under uncertainty emphasize the need for stronger early action, particularly on long-lived infrastructure and other capital stock. Energy sector infrastructure (including power stations) alone is projected to require at least US\$ 20 trillion investment to 2030 and the options for stabilization will be heavily constrained by the nature and carbon intensity of this investment. Initial estimates for lower carbon scenarios show a large redirection of investment, with net additional investments ranging from negligible to less than 5% (*high agreement, much evidence*) [11.6].

As regards portfolio analysis of government actions, a general finding is that a portfolio of options that attempts to balance emission reductions across sectors in a manner that appears equitable (e.g., by equal percentage reduction), is likely to be more costly than an approach primarily guided by cost-effectiveness. Portfolios of energy options across sectors that include low-carbon technologies will reduce risks and costs, because fossil fuel prices are expected to be more volatile relative to the costs of alternatives, in addition to the usual benefits from diversification. A second general finding is that costs will be reduced if options that correct the two market failures of climate change damages and technological innovation benefits are combined, for example, by recycling revenues from permit auctions to support energy-efficiency and low-carbon innovations (*high agreement, medium evidence*) [11.4].

### Technological change across sectors

A major development since the TAR has been the inclusion in many top-down models of endogenous technological change. Using different approaches, modelling studies suggest that allowing for endogenous technological change may lead to substantial reductions in carbon prices as well as GDP costs, compared with most of the models in use at the time of the TAR (when technological change was assumed to be included in the baseline and largely independent of mitigation policies and action). Studies without induced technological change show that carbon prices rising to 20 to 80 US\$/tCO<sub>2</sub>-eq by 2030 and 30 to 155 US\$/tCO<sub>2</sub>-eq by 2050 are consistent with stabilization at around 550 ppm CO<sub>2</sub>-eq by 2100. For the same stabilization level, studies since TAR that take into account induced technological change lower these price ranges to 5 to 65 US\$/tCO<sub>2</sub>-eq in 2030 and 15 to 130 US\$/tCO<sub>2</sub>-eq in 2050. The degree to which costs are reduced hinges critically on the assumptions about the returns from climate change mitigation R&D expenditures, spill-overs between sectors and regions, crowding-out of other R&D, and, in models including learning-by-doing, learning rates (*high agreement, much evidence*) [11.5].

Major technological shifts like carbon capture and storage, advanced renewables, advanced nuclear and hydrogen require a long transition as learning-by-doing accumulates and markets expand. Improvement of end-use efficiency therefore offers more important opportunities in the short term. This is illustrated by the relatively high share of the buildings and industry sector in the 2030 potentials (Table TS.17). Other options and sectors may play a more significant role in the second half of the century (see Chapter 3) (*high agreement, much evidence*) [11.6].

### Spill-over effects from mitigation in Annex I countries on Non-Annex I countries

Spill-over effects of mitigation from a cross-sectoral perspective are the effects of mitigation policies and measures in one country or group of countries on sectors in other countries. One aspect of spill-over is so-called ‘carbon leakage’:

the increase in CO<sub>2</sub> emissions outside the countries taking domestic measures divided by the emission reductions within these countries. The simple indicator of carbon leakage does not cover the complexity and range of effects, which include changes in the pattern and magnitude of global emissions. Modelling studies provide wide-ranging outcomes on carbon leakages depending on their assumptions regarding returns to scale, behaviour in the energy-intensive industry, trade elasticities and other factors. As in the TAR, the estimates of carbon leakage from implementation of the Kyoto Protocol are generally in the range of 5–20% by 2010. Empirical studies on the energy-intensive industries with exemptions under the EU Emission Trading Scheme (ETS) highlight that transport costs, local market conditions, product variety and incomplete information favour local production, and conclude that carbon leakage is unlikely to be substantial (*medium agreement, medium evidence*) [11.7].

Effects of existing mitigation actions on competitiveness have been studied. The empirical evidence seems to indicate that losses of competitiveness in countries implementing Kyoto are not significant, confirming a finding in the TAR. The potential beneficial effect of technology transfer to developing countries arising from technological development brought about by Annex I action may be substantial for energy-intensive industries, but has not so far been quantified in a reliable manner (*medium agreement, low evidence*) [11.7].

Perhaps one of the most important ways in which spill-overs from mitigation actions in one region affect others is through the effect on world fossil fuel prices. When a region reduces its fossil fuel demand because of mitigation policy, it will reduce the world demand for that commodity and so put downward pressure on the prices. Depending on the response of the fossil fuel producers, oil, gas or coal prices may fall, leading to loss of revenues by the producers, and lower costs of imports for the consumers. As in the TAR, nearly all modelling studies that have been reviewed show more pronounced adverse effects on oil-producing countries than on most Annex I countries that are taking the abatement measures. Oil-price protection strategies may limit income losses in the oil-producing countries (*high agreement, limited evidence*) [11.7].

### Co-benefits of mitigation

Many recent studies have demonstrated significant benefits of carbon-mitigation strategies on human health, mainly because they also reduce other airborne emissions, for example, SO<sub>2</sub>, NO<sub>x</sub> and particulate matter. This is projected to result in the prevention of tens of thousands of premature deaths in Asian and Latin American countries annually, and several thousands in Europe. However, monetization of mortality risks remains controversial, and hence a large range of benefit estimates can be found in the literature. However, all studies agree that the monetized health benefits may offset a substantial fraction of the mitigation costs (*high agreement, much evidence*) [11.8].

In addition, the benefits of avoided emissions of air pollutants have been estimated for agricultural production and the impact of acid precipitation on natural ecosystems. Such near-term benefits provide the basis for a no-regrets GHG-reduction policy, in which substantial advantages accrue even if the impact of human-induced climate change turns out to be less than current projections show. Including co-benefits other than those for human health and agricultural productivity (e.g., increased energy security and employment) would further enhance the cost savings (*high agreement, limited evidence*) [11.8].

A wealth of new literature has pointed out that addressing climate change and air pollution simultaneously through a single set of measures and policies offers potentially large reductions in the costs of air-pollution control. An integrated approach is needed to address those pollutants and processes for which trade-offs exist. This is, for instance, the case for NO<sub>x</sub> controls for vehicles and nitric acid plants, which may increase N<sub>2</sub>O emissions, or the increased use of energy-efficient diesel vehicles, which emit relatively more fine particulate matter than their gasoline equivalents (*high agreement, much evidence*) [11.8].

### Adaptation and mitigation

There can be synergies or trade-offs between policy options that can support adaptation and mitigation. The synergy potential is high for biomass energy options, land-use management and other land-management approaches. Synergies between mitigation and adaptation could provide a unique contribution to rural development, particularly in least-developed countries: many actions focusing on sustainable natural resource management could provide both significant adaptation benefits and mitigation benefits, mostly in the form of carbon sequestration. However, in other cases there may be trade-offs, such as the growth of energy crops that may affect food supply and forestry cover, thereby increasing vulnerability to the impacts of climate change (*medium agreement, limited evidence*) [11.9].

## 12 Sustainable development and mitigation

### Relationship between sustainable development and climate change mitigation

The concept of sustainable development was adopted by the World Commission on Environment and Development and there is agreement that sustainable development involves a comprehensive and integrated approach to economic, social and environmental processes. Discussions on sustainable development, however, have focused primarily on the environmental and economic dimensions. The importance of social, political and cultural factors is only now getting more recognition. Integration is essential in order to articulate



development trajectories that are sustainable, including addressing the climate change problem [12.1].

Although still in the early stages, there is growing use of indicators to measure and manage the sustainability of development at the macro and sectoral levels, which is driven in part by the increasing emphasis on accountability in the context of governance and strategy initiatives. At the sectoral level, progress towards sustainable development is beginning to be measured and reported by industry and governments using, *inter alia*, green certification, monitoring tools or emissions registries. Review of the indicators shows, however, that few macro-indicators include measures of progress with respect to climate change (*high agreement, much evidence*) [12.1.3].

Climate change is influenced not only by the climate-specific policies that are put in place (the ‘climate first approach’), but also by the mix of development choices that are made and the development trajectories that these policies lead to (the ‘development first approach’) - a point reinforced by global scenario analysis published since the TAR. Making development more sustainable by changing development paths can thus make a significant contribution to climate goals. It is important to note, however, that changing development pathways is not about choosing a mapped-out path, but rather about navigating through an uncharted and evolving landscape (*high agreement, much evidence*) [12.1.1].

It has further been argued that sustainable development might decrease the vulnerability of all countries, and particularly of developing countries, to climate change impacts. Framing the debate as a development problem rather than an environmental one may better address the immediate goals of all countries, particularly developing countries and their special vulnerability to climate change, while at the same time addressing the driving forces for emissions that are linked to the underlying development path [12.1.2].

### **Making development more sustainable**

Decision-making on sustainable development and climate change mitigation is no longer solely the purview of governments. The literature recognizes the shift to a more inclusive concept of governance, which includes the contributions of various levels of government, the private sector, non-governmental actors and civil society. The more that climate change issues are mainstreamed as part of the planning perspective at the appropriate level of implementation, and the more all these relevant parties are involved in the decision-making process in a meaningful way, the more likely are they to achieve the desired goals (*high agreement, medium evidence*) [12.2.1].

Regarding governments, a substantial body of political theory identifies and explains the existence of national policy styles or political cultures. The underlying assumption of this work is that individual countries tend to process problems in a specific manner, regardless of the distinctiveness or

specific features of any specific problem; a national ‘way of doing things’. Furthermore, the choice of policy instruments is affected by the institutional capacity of governments to implement the instrument. This implies that the preferred mix of policy decisions and their effectiveness in terms of sustainable development and climate change mitigation depend strongly on national characteristics (*high agreement, much evidence*). However, our understanding of which types of policies will work best in countries with particular national characteristics remains sketchy [12.2.3].

The private sector is a central player in ecological and sustainability stewardship. Over the past 25 years, there has been a progressive increase in the number of companies that are taking steps to address sustainability issues at either the firm or industry level. Although there has been progress, the private sector has the capacity to play a much greater role in making development more sustainable if awareness that this will probably benefit its performance grows (*medium agreement, medium evidence*) [12.2.3].

Citizen groups play a significant role in stimulating sustainable development and are critical actors in implementing sustainable development policy. Apart from implementing sustainable development projects themselves, they can push for policy reform by awareness-raising, advocacy and agitation. They can also pull policy action by filling the gaps and providing policy services, including in the areas of policy innovation, monitoring and research. Interactions can take the form of partnerships or be through stakeholder dialogues that can provide citizens’ groups with a lever for increasing pressure on both governments and industry (*high agreement, medium evidence*) [12.2.3].

Deliberative public-private partnerships work most effectively when investors, local governments and citizen groups are willing to work together to implement new technologies, and provide arenas to discuss such technologies that are locally inclusive (*high agreement, medium evidence*) [12.2.3].

### **Implications of development choices for climate change mitigation**

In a heterogeneous world, an understanding of different regional conditions and priorities is essential for mainstreaming climate change policies into sustainable-development strategies. Region- and country-specific case studies demonstrate that different development paths and policies can achieve notable emissions reductions, depending on the capacity to realize sustainability and climate change objectives [12.3].

In industrialized countries, climate change continues to be regarded mainly as a separate, environmental problem to be addressed through specific climate change policies. A fundamental and broad discussion in society on the implications of development pathways for climate change in general and climate change mitigation in particular in the industrialized

countries has not been seriously initiated. Priority mitigation areas for countries in this group may be in energy efficiency, renewable energy, CCS, etc. However, low-emission pathways apply not only to energy choices. In some regions, land-use development, particularly infrastructure expansion, is identified as a key variable determining future GHG emissions [12.2.1; 12.3.1].

Economies in transition as a single group no longer exist. Nevertheless, Central and Eastern Europe and the countries of Eastern Europe, the Caucasus and Central Asia (EECCA) do share some common features in socio-economic development and in climate change mitigation and sustainable development. Measures to decouple economic and emission growth would be especially important for this group [12.2.1; 12.3.1].

Some large developing countries are projected to increase their emissions at a faster rate than the industrialized world and the rest of developing nations as they are in the stage of rapid industrialization. For these countries, climate change mitigation and sustainable-development policies can complement one another; however, additional financial and technological resources would enhance their capacity to pursue a low-carbon path of development [12.2.1; 12.3.1].

For most other developing countries, adaptive and mitigative capacities are low and development aid can help to reduce their vulnerability to climate change. It can also help to reduce their emissions growth while addressing energy-security and energy-access problems. CDM can provide financial resources for such developments. Members of the Organization of the Petroleum-Exporting Countries (OPEC) are unique in the sense that they may be adversely affected by development paths that reduce the demand for fossil fuels. Diversification of their economies is high on their agenda [12.2.1; 12.3.1].

Some general conclusions emerge from the case studies reviewed in this chapter on how changes in development pathways at the sectoral level have (or could) lower emissions (*high agreement, medium evidence*) [12.2.4]:

- GHG emissions are influenced by, but not rigidly linked to, economic growth: policy choices can make a difference.
- Sectors where effective production is far below the maximum feasible production with the same amount of inputs – that is, sectors that are far from their production frontier – have opportunities to adopt ‘win-win-win’ policies, that is, policies that free up resources and bolster growth, meet other sustainable-development goals and also reduce GHG emissions relative to baseline.
- Sectors where production is close to the optimal given available inputs – i.e., sectors that are closer to the production frontier – also have opportunities to reduce emissions by meeting other sustainable development goals. However, the closer one gets to the production frontier, the more trade-offs are likely to appear.

- What matters is not only that a ‘good’ choice is made at a certain point in time, but also that the initial policy is sustained for a long time – sometimes several decades – to really have effects.
- It is often not one policy decision, but an array of decisions that are needed to influence emissions. This raises the issue of coordination between policies in several sectors and at various scales.

Mainstreaming requires that non-climate policies, programmes and/or individual actions take climate change mitigation into consideration, in both developing and developed countries. However, merely piggybacking climate change on to an existing political agenda is unlikely to succeed. The ease or difficulty with which mainstreaming is accomplished will depend on both mitigation technologies or practices, and the underlying development path. Weighing other development benefits against climate benefits will be a key basis for choosing development sectors for mainstreaming. Decisions about macro-economic policy, agricultural policy, multilateral development bank lending, insurance practices, electricity market reform, energy security, and forest conservation, for example, which are often treated as being apart from climate policy, can have profound impacts on emissions, the extent of mitigation required, and the costs and benefits that result. However, in some cases, such as shifting from biomass cooking to liquid petroleum gas (LPG) in rural areas in developing countries, it may be rational to disregard climate change considerations because of the small increase in emissions when compared with its development benefits (see Table TS.18) (*high agreement, medium evidence*) [12.2.4].

In general terms, there is a high level of agreement on the qualitative findings in this chapter about the linkages between mitigation and sustainable development: the two are linked, and synergies and trade-offs can be identified. However, the literature about the links and more particularly, about how these links can be put into action in order to capture synergies and avoid trade-offs, is as yet sparse. The same applies to good practice guidance for integrating climate change considerations into relevant non-climate policies, including analysis of the roles of different actors. Elaborating possible development paths that nations and regions can pursue – beyond more narrowly conceived GHG emissions scenarios or scenarios that ignore climate change – can provide the context for new analysis of the links, but may require new methodological tools (*high agreement, limited evidence*) [12.2.4].

### **Implications of mitigation choices for sustainable development trajectories**

There is a growing understanding of the opportunities to choose mitigation options and their implementation in such a way that there will be no conflict with or even benefits for other dimensions of sustainable development; or, where trade-offs are inevitable, to allow rational choices to be made. A summary of

**Table TS.18: Mainstreaming climate change into development choices – selected examples [Table 12.3].**

Selected sectors	Non-climate policy instruments and actions that are candidates for mainstreaming	Primary decision-makers and actors	Global GHG emissions by sector that could be addressed by non-climate policies (% of global GHG emissions) <sup>a, d</sup>		Comments
<b>Macro economy</b>	Implement non-climate taxes/subsidies and/or other fiscal and regulatory policies that promote SD	State (governments at all levels)	100	Total global GHG emissions	Combination of economic, regulatory, and infrastructure non-climate policies could be used to address total global emissions.
<b>Forestry</b>	Adoption of forest conservation and sustainable management practices	State (governments at all levels) and civil society (NGOs)	7	GHG emissions from deforestation	Legislation/regulations to halt deforestation, improve forest management, and provide alternative livelihoods can reduce GHG emissions and provide other environmental benefits.
<b>Electricity</b>	Adoption of cost-effective renewables, demand-side management programmes, and reduction of transmission and distribution losses	State (regulatory commissions), market (utility companies) and, civil society (NGOs, consumer groups)	20 <sup>b</sup>	Electricity sector CO <sub>2</sub> emissions (excluding auto producers)	Rising share of GHG-intensive electricity generation is a global concern that can be addressed through non-climate policies.
<b>Petroleum imports</b>	Diversifying imported and domestic fuel mix and reducing economy's energy intensity to improve energy security	State and market (fossil fuel industry)	20 <sup>b</sup>	CO <sub>2</sub> emissions associated with global crude oil and product imports	Diversification of energy sources to address oil security concerns could be achieved such that GHG emissions are not increased.
<b>Rural energy in developing countries</b>	Policies to promote rural LPG, kerosene and electricity for cooking	State and market (utilities and petroleum companies), civil society (NGOs)	<2 <sup>c</sup>	GHG emissions from biomass fuel use, not including aerosols	Biomass used for rural cooking causes health impacts due to indoor air pollution, and releases aerosols that add to global warming. Displacing all biomass used for rural cooking in developing countries with LPG would emit 0.70 GtCO <sub>2</sub> -eq., a relatively modest amount compared with 2004 total global GHG emissions.
<b>Insurance for building and transport sectors</b>	Differentiated premiums, liability insurance exclusions, improved terms for green products	State and market (insurance companies)	20	Transport and building sector GHG emissions	Escalating damages due to climate change are a source of concern to insurance industry. Insurance industry could address these through the types of policies noted here.
<b>International finance</b>	Country and sector strategies and project lending that reduces emissions	State (international financial institutions) and market (commercial banks)	25 <sup>b</sup>	CO <sub>2</sub> emissions from developing countries (non-Annex I)	International financial institutions can adopt practices so that loans for GHG-intensive projects in developing countries that lock-in future emissions are avoided.

## Notes:

- Data from Chapter 1 unless noted otherwise.
- CO<sub>2</sub> emissions from fossil fuel combustion only; IEA (2006).
- CO<sub>2</sub> emissions only. Authors estimate, see text.
- Emissions indicate the relative importance of sectors in 2004. Sectoral emissions are not mutually exclusive, may overlap, and hence sum up to more than total global emissions, which are shown in the Macro economy row.

**Table TS.19: Sectoral mitigation options and sustainable development (economic, local environmental and social) considerations: synergies and trade-offs [Table 12.4].**

Sector and mitigation options	Potential SD synergies and conditions for implementation	Potential SD trade-offs
<b>Energy supply and use: Chapters 4-7</b>		
Energy efficiency improvement in all sectors (buildings, transportation, industry, and energy supply) (Chapters 4-7)	<ul style="list-style-type: none"> <li>- Almost always cost-effective, reduces or eliminates local pollutant emissions and consequent health impacts, improves indoor comfort and reduces indoor noise levels, creates business opportunities and jobs and improves energy security</li> <li>- Government and industry programmes can help overcome lack of information and principal agent problems</li> <li>- Programmes can be implemented at all levels of government and industry</li> <li>- Important to ensure that low-income household energy needs are given due consideration, and that the process and consequences of implementing mitigation options are, or the result is, gender-neutral</li> </ul>	<ul style="list-style-type: none"> <li>- Indoor air pollution and health impacts of improving the thermal efficiency of biomass cooking stoves in developing country rural areas are uncertain</li> </ul>
Fuel switching and other options in the transportation and buildings sectors (Chapters 5 and 6)	<ul style="list-style-type: none"> <li>- CO<sub>2</sub> reduction costs may be offset by increased health benefits</li> <li>- Promotion of public transport and non-motorized transport has large and consistent social benefits</li> <li>- Switching from solid fuels to modern fuels for cooking and heating indoors can reduce indoor air pollution and increase free time for women in developing countries</li> <li>- Institutionalizing planning systems for CO<sub>2</sub> reduction through coordination between national and local governments is important for drawing up common strategies for sustainable transportation systems</li> </ul>	<ul style="list-style-type: none"> <li>- Diesel engines are generally more fuel-efficient than gasoline engines and thus have lower CO<sub>2</sub> emissions, but increase particle emissions.</li> <li>- Other measures (CNG buses, hybrid diesel-electric buses and taxi renovation) may provide little climate benefit.</li> </ul>
Replacing imported fossil fuels with domestic alternative energy sources (DAES) (Chapter 4)	<ul style="list-style-type: none"> <li>- Important to ensure that DAES is cost-effective</li> <li>- Reduces local air pollutant emissions.</li> <li>- Can create new indigenous industries (e.g., Brazil ethanol programme) and hence generate employment</li> </ul>	<ul style="list-style-type: none"> <li>- Balance of trade improvement is traded off against increased capital required for investment</li> <li>- Fossil fuel-exporting countries may face reduced exports</li> <li>- Hydropower plants may displace local populations and cause environmental damage to water bodies and biodiversity</li> </ul>
Replacing domestic fossil fuel with imported alternative energy sources (IAES) (Chapter 4)	<ul style="list-style-type: none"> <li>- Almost always reduces local pollutant emissions</li> <li>- Implementation may be more rapid than DAES</li> <li>- Important to ensure that IAES is cost-effective</li> <li>- Economies and societies of energy-exporting countries would benefit</li> </ul>	<ul style="list-style-type: none"> <li>- Could reduce energy security</li> <li>- Balance of trade may worsen but capital needs may decline</li> </ul>
<b>Forestry sector: Chapter 9</b>		
Afforestation	<ul style="list-style-type: none"> <li>- Can reduce wasteland, arrest soil degradation, and manage water runoff</li> <li>- Can retain soil carbon stocks if soil disturbance at planting and harvesting is minimized</li> <li>- Can be implemented as agroforestry plantations that enhance food production</li> <li>- Can generate rural employment and create rural industry</li> <li>- Clear delineation of property rights would expedite implementation of forestation programmes</li> </ul>	<ul style="list-style-type: none"> <li>- Use of scarce land could compete with agricultural land and diminish food security while increasing food costs</li> <li>- Monoculture plantations can reduce biodiversity and are more vulnerable to disease</li> <li>- Conversion of floodplain and wetland could hamper ecological functions</li> </ul>
Avoided deforestation	<ul style="list-style-type: none"> <li>- Can retain biodiversity, water and soil management benefits, and local rainfall patterns</li> <li>- Reduce local haze and air pollution from forest fires</li> <li>- If suitably managed, it can bring revenue from ecotourism and from sustainably harvested timber sales</li> <li>- Successful implementation requires involving local dwellers in land management and/or providing them alternative livelihoods, enforcing laws to prevent migrants from encroaching on forest land.</li> </ul>	<ul style="list-style-type: none"> <li>- Can result in loss of economic welfare for certain stakeholders in forest exploitation (land owners, migrant workers)</li> <li>- Reduced timber supply may lead to reduced timber exports and increased use of GHG-intensive construction materials</li> <li>- Can result in deforestation with consequent SD implications elsewhere</li> </ul>
Forest Management	<ul style="list-style-type: none"> <li>- See afforestation</li> </ul>	<ul style="list-style-type: none"> <li>- Fertilizer application can increase N<sub>2</sub>O production and nitrate runoff degrading local (ground)water quality</li> <li>- Prevention of fires and pests has short term benefits but can increase fuel stock for later fires unless managed properly</li> </ul>

Table TS.19. Continued.

Sector and mitigation options	Potential SD synergies and conditions for implementation	Potential SD trade-offs
<b>Bio-energy (chapter 8 en 9)</b>		
Bio-energy production	<ul style="list-style-type: none"> <li>- Mostly positive when practised with crop residues (shells, husks, bagasse and/or tree trimmings).</li> <li>- Creates rural employment.</li> <li>- Planting crops/trees exclusively for bio-energy requires that adequate agricultural land and labour is available to avoid competition with food production</li> </ul>	<ul style="list-style-type: none"> <li>- Can have negative environmental consequences if practised unsustainably - biodiversity loss, water resource competition, increased use of fertilizer and pesticides.</li> <li>- Potential problem with food security (location-specific) and increased food costs.</li> </ul>
<b>Agriculture: Chapter 8</b>		
Cropland management (management of nutrients, tillage, residues, and agroforestry; water, rice, and set-aside)	<ul style="list-style-type: none"> <li>- Improved nutrient management can improve groundwater quality and environmental health of the cultivated ecosystem</li> </ul>	<ul style="list-style-type: none"> <li>- Changes in water policies could lead to clash of interests and threaten social cohesiveness</li> <li>- Could lead to water overuse</li> </ul>
Grazing land management	<ul style="list-style-type: none"> <li>- Improves livestock productivity, reduces desertification, and provide social security for the poor</li> <li>- Requires laws and enforcement to ban free grazing</li> </ul>	
Livestock management	<ul style="list-style-type: none"> <li>- Mix of traditional rice cultivation and livestock management would enhance incomes even in semi-arid and arid regions</li> </ul>	
<b>Waste management: Chapter 10</b>		
Engineered sanitary landfilling with landfill gas recovery to capture methane gas	<ul style="list-style-type: none"> <li>- Can eliminate uncontrolled dumping and open burning of waste, improving health and safety for workers and residents.</li> <li>- Sites can provide local energy benefits and public spaces for recreation and other social purposes within the urban infrastructure.</li> </ul>	<ul style="list-style-type: none"> <li>- When done unsustainably can cause leaching that leads to soil and groundwater contamination with potentially negative health impacts</li> </ul>
Biological processes for waste and wastewater (composting, anaerobic digestion, aerobic and anaerobic wastewater processes)	<ul style="list-style-type: none"> <li>- Can destroy pathogens and provide useful soil amendments if properly implemented using source-separated organic waste or collected wastewater.</li> <li>- Can generate employment</li> <li>- Anaerobic processes can provide energy benefits from CH<sub>4</sub> recovery and use.</li> </ul>	<ul style="list-style-type: none"> <li>- A source of odours and water pollution if not properly controlled and monitored.</li> </ul>
Incineration and other thermal processes	<ul style="list-style-type: none"> <li>- Obtain the most energy benefit from waste.</li> </ul>	<ul style="list-style-type: none"> <li>- Expensive relative to controlled landfilling and composting.</li> <li>- Unsustainable in developing countries if technical infrastructure not present.</li> <li>- Additional investment for air pollution controls and source separation needed to prevent emissions of heavy metals and other air toxics.</li> </ul>
Recycling, re-use, and waste minimization	<ul style="list-style-type: none"> <li>- Provide local employment as well as reductions in energy and raw materials for recycled products.</li> <li>- Can be aided by NGO efforts, private capital for recycling industries, enforcement of environmental regulations, and urban planning to segregate waste treatment and disposal activities from community life.</li> </ul>	<ul style="list-style-type: none"> <li>- Uncontrolled waste scavenging results in severe health and safety problems for those who make their living from waste</li> <li>- Development of local recycling industries requires capital.</li> </ul>

Note: Material in this table is drawn from the Chapters 4–11. Where new material is introduced, it is referenced in the accompanying text below, which describes the SD implications of mitigation options in each sector.

the sustainable development implications of the main climate change mitigation options is given in Table TS.19 [12.3].

The sustainable development benefits of mitigation options vary within a sector and between regions (*high agreement, much evidence*):

- Generally, mitigation options that improve the productivity of resource use, whether energy, water, or land, yield positive benefits across all three dimensions of sustainable development. Other categories of mitigation options have a more uncertain impact and depend on the wider socio-economic context within which the option is being implemented.
- Climate-related policies such as energy efficiency and renewable energy are often economically beneficial, improve energy security and reduce local pollutant emissions. Many energy-supply mitigation options can be designed to also achieve sustainable development benefits such as avoided displacement of local populations, job creation and health benefits.
- Reducing deforestation can have significant biodiversity, soil and water conservation benefits, but may result in a loss of economic welfare for some stakeholders. Appropriately designed forestation and bio-energy plantations can lead to restoration of degraded land, manage water runoff, retain soil carbon and benefit rural economies, but may compete with land for food production and be negative for biodiversity.
- There are good possibilities for reinforcing sustainable development through mitigation actions in most sectors, but particularly in the waste management, transportation and buildings sectors, notably through decreased energy use and reduced pollution [12.3].

## 13 Policies, instruments and co-operative agreements

### Introduction

This chapter discusses national policy instruments and their implementation, initiatives of the private sector, local governments and non-governmental organizations, and cooperative international agreements. Wherever feasible, national policies and international agreements are discussed in the context of four principle criteria by which they can be evaluated; that is, environmental effectiveness, cost-effectiveness, distributional considerations and institutional feasibility. There are a number of additional criteria that could also be explicitly considered, such as effects on competitiveness and administrative costs. Criteria may be applied by governments in making ex-ante choices among instruments and in ex-post evaluation of the performance of instruments [13.1].

### National policy instruments, their implementation and interactions

The literature continues to reflect that a wide variety of national policies and measures are available to governments to limit or reduce GHG emissions. These include: regulations and standards, taxes and charges, tradable permits, voluntary agreements, phasing out subsidies and providing financial incentives, research and development and information instruments. Other policies, such as those affecting trade, foreign direct investments and social development goals can also affect GHG emissions. In general, climate change policies, if integrated with other government policies, can contribute to sustainable development in both developed and developing countries (see Chapter 12) [13.1].

Reducing emissions across all sectors and gases requires a portfolio of policies tailored to fit specific national circumstances. While the literature identifies advantages and disadvantages for any given instrument, the above-mentioned criteria are widely used by policy makers to select and evaluate policies.

All instruments can be designed well or poorly, stringent or lax. Instruments need to be adjusted over time and supplemented with a workable system of monitoring and enforcement. Furthermore, instruments may interact with existing institutions and regulations in other sectors of society (*high agreement, much evidence*) [13.1].

The literature provides a good deal of information to assess how well different instruments meet the above-mentioned criteria (see Table TS.20) [13.2]. Most notably, it suggests that:

- **Regulatory measures and standards** generally provide environmental certainty. They may be preferable when lack of information or other barriers prevent firms and consumers from responding to price signals. Regulatory standards do not generally give polluters incentives to develop new technologies to reduce pollution, but there are a few examples whereby technology innovation has been spurred by regulatory standards. Standards are common practice in the building sector and there is strong innovation. Although relatively few regulatory standards have been adopted solely to reduce GHG emissions, standards have reduced these gases as a co-benefit (*high agreement, much evidence*) [13.2].
- **Taxes and charges** (which can be applied to carbon or all GHGs) are given high marks for cost effectiveness since they provide some assurance regarding the marginal cost of pollution control. They cannot guarantee a particular level of emissions, but conceptually taxes can be designed to be environmentally effective. Taxes can be politically difficult to implement and adjust. As with regulations, their environmental effectiveness depends on their stringency. As with nearly all other policy instruments, care is needed to prevent perverse effects (*high agreement, much evidence*) [13.2].

**Table TS.20: National environmental policy instruments and evaluative criteria [Table 13.1].**

Instrument	Criteria			
	Environmental effectiveness	Cost-effectiveness	Meets distributional considerations	Institutional feasibility
<b>Regulations and standards</b>	Emission levels set directly, though subject to exceptions Depends on deferrals and compliance	Depends on design; uniform application often leads to higher overall compliance costs	Depends on level playing field; small/new actors may be disadvantaged	Depends on technical capacity; popular with regulators, in countries with weak functioning markets
<b>Taxes and charges</b>	Depends on ability to set tax at a level that induces behavioural change	Better with broad application; higher administrative costs where institutions are weak	Regressive; can be improved with revenue recycling	Often politically unpopular; may be difficult to enforce with underdeveloped institutions
<b>Tradable permits</b>	Depends on emissions cap, participation and compliance	Decreases with limited participation and fewer sectors	Depends on initial permit allocation, may pose difficulties for small emitters	Requires well-functioning markets and complementary institutions
<b>Voluntary agreements</b>	Depends on programme design, including clear targets, a baseline scenario, third-party involvement in design and review, and monitoring provisions	Depends on flexibility and extent of government incentives, rewards and penalties	Benefits accrue only to participants	Often politically popular; requires significant number of administrative staff
<b>Subsidies and other incentives</b>	Depends on programme design; less certain than regulations/ standards.	Depends on level and programme design; can be market-distorting	Benefits selected participants; possibly some that do not need it	Popular with recipients; potential resistance from vested interests. Can be difficult to phase out
<b>Research and development</b>	Depends on consistent funding, when technologies are developed, and policies for diffusion. May have high benefits in long-term	Depends on programme design and the degree of risk	Initially benefits selected participants, Potentially easy for funds to be misallocated	Requires many separate decisions; Depends on research capacity and long-term funding

Note: Evaluations are predicated on assumptions that instruments are representative of best practice rather than theoretically perfect. This assessment is based primarily on experiences and literature from developed countries, since peer-reviewed articles on the effectiveness of instruments in other countries were limited. Applicability in specific countries, sectors and circumstances – particularly developing countries and economies in transition – may differ greatly. Environmental and cost effectiveness may be enhanced when instruments are strategically combined and adapted to local circumstances.

- **Tradable permits** are an increasingly popular economic instrument to control conventional pollutants and GHGs at the sectoral, national and international level. The volume of emissions allowed determines the carbon price and the environmental effectiveness of this instrument, while the distribution of allowances has implications for competitiveness. Experience has shown that banking provisions can provide significant temporal flexibility and that compliance provisions must be carefully designed, if a permit system is to be effective (*high agreement, much evidence*). Uncertainty in the price of emission reductions under a trading system makes it difficult, a priori, to estimate the total cost of meeting reduction targets [13.2].
- **Voluntary agreements between industry and governments** and information campaigns are politically attractive, raise awareness among stakeholders and have played a role in the evolution of many national policies. The majority of voluntary agreements has not achieved significant emission reductions beyond business-as-usual. However, some recent agreements in a few countries have accelerated the application of best available technology and led to measurable reductions of emissions compared with the baseline (*high agreement, much evidence*). Success factors include clear targets, a baseline scenario, third-party involvement in design and review, and formal provisions for monitoring [13.2].
- **Voluntary actions:** Corporations, sub-national governments, NGOs and civil groups are adopting a wide variety of voluntary actions, independent of government authorities, which may limit GHG emissions, stimulate innovative policies and encourage the deployment of new technologies. By themselves, they generally have limited impact at the national or regional level [13.2].
- **Financial incentives** (subsidies and tax credits) are frequently used by governments to stimulate the diffusion of new, less GHG-emitting technologies. While the economic costs of such programmes are often higher than for the instruments listed above, they are often critical to overcome barriers to the penetration of new technologies (*high agreement, much*

evidence). As with other policies, incentive programmes must be carefully designed to avoid perverse market effects. Direct and indirect subsidies for fossil fuel use and agriculture remain common practice in many countries, although those for coal have declined over the past decade in many OECD countries and in some developing countries (See also Chapter 2, 7 and 11) [13.2].

- **Government support for research and development** is a special type of incentive, which can be an important instrument to ensure that low GHG-emitting technologies will be available in the long-term. However, government funding for many energy-research programmes dropped after the oil crisis in the 1970s and stayed constant, even after the UNFCCC was ratified. Substantial additional investments in, and policies for, R&D are needed to ensure that technologies are ready for commercialization in order to arrive at stabilization of GHGs in the atmosphere (see Chapter 3), along with economic and regulatory instruments to promote their deployment and diffusion (*high agreement, much evidence*) [13.2.1].
- **Information instruments** – sometimes called public disclosure requirements – may positively affect environmental quality by allowing consumers to make better-informed choices. There is only limited evidence that the provision of information can achieve emissions reductions, but it can improve the effectiveness of other policies (*high agreement, much evidence*) [13.2].

Applying an environmentally effective and economically efficient instrument mix requires a good understanding of the environmental issue to be addressed, of the links with other policy areas and the interactions between the different instruments in the mix. In practice, climate-related policies are seldom applied in complete isolation, as they overlap with other national policies relating to the environment, forestry, agriculture, waste management, transport and energy, and in many cases require more than one instrument (*high agreement, much evidence*) [13.2].

### **Initiatives of sub-national governments, corporations and non-governmental organizations**

The preponderance of the literature reviews nationally based governmental instruments, but corporations, local- and regional authorities, NGOs and civil groups can also play a key role and are adopting a wide variety of actions, independent of government authorities, to reduce emissions of GHGs. Corporate actions range from voluntary initiatives to emissions targets and, in a few cases, internal trading systems. The reasons corporations undertake independent actions include the desire to influence or pre-empt government action, to create financial value, and to differentiate a company and its products. Actions by regional, state, provincial and local governments include renewable portfolio standards, energy-efficiency programmes, emission registries and sectoral cap-and-trade mechanisms. These actions are undertaken to influence national policies, address stakeholder concerns, create incentives for new industries, or

create environmental co-benefits. NGOs promote programmes to reduce emissions through public advocacy, litigation and stakeholder dialogue. Many of the above actions may limit GHG emissions, stimulate innovative policies, encourage the deployment of new technologies and spur experimentation with new institutions, but by themselves generally have limited impact. To achieve significant emission reductions, these actions must lead to changes in national policies (*high agreement, much evidence*) [13.4].

### **International agreements (climate change agreements and other arrangements)**

The UNFCCC and its Kyoto Protocol have set a significant precedent as a means of solving a long-term international environmental problem, but are only the first steps towards implementation of an international response strategy to combat climate change. The Kyoto Protocol's most notable achievements are the stimulation of an array of national policies, the creation of an international carbon market and the establishment of new institutional mechanisms. Its economic impacts on the participating countries are yet to be demonstrated. The CDM, in particular, has created a large project pipeline and mobilized substantial financial resources, but it has faced methodological challenges regarding the determination of baselines and additionality. The protocol has also stimulated the development of emissions trading systems, but a fully global system has not been implemented. The Kyoto Protocol is currently constrained by the modest emission limits and will have a limited effect on atmospheric concentrations. It would be more effective if the first commitment period were to be followed up by measures to achieve deeper reductions and the implementation of policy instruments covering a higher share of global emissions (*high agreement, much evidence*) [13.3].

Many options are identified in the literature for achieving emission reductions both under and outside the Convention and its Kyoto Protocol, for example: revising the form and stringency of emission targets; expanding the scope of sectoral and sub-national agreements; developing and adopting common policies; enhancing international RD&D technology programmes; implementing development-oriented actions, and expanding financing instruments (*high agreement, much evidence*). Integrating diverse elements such as international R&D cooperation and cap-and-trade programmes within an agreement is possible, but comparing the efforts made by different countries would be complex and resource-intensive (*medium agreement, medium evidence*) [13.3].

There is a broad consensus in the literature that a successful agreement will have to be environmentally effective, cost-effective, incorporate distributional considerations and equity, and be institutionally feasible (*high agreement, much evidence*) [13.3].



A great deal of new literature is available on potential structures for and the substance of future international agreements. As has been noted in previous IPCC reports, because climate change is a globally common problem, any approach that does not include a larger share of global emissions will be more costly or less environmentally effective. (*high agreement, much evidence*) (See Chapter 3) [13.3].

Most proposals for future agreements in the literature include a discussion of goals, specific actions, timetables, participation, institutional arrangements, reporting and compliance provisions. Other elements address incentives, non-participation and non-compliance penalties (*high agreement, much evidence*) [13.3].

### Goals

The specification of clear goals is an important element of any climate agreement. They can both provide a common vision about the near-term direction and offer longer-term certainty, which is called for by business. Goal-setting also helps structure commitments and institutions, provides an incentive to stimulate action and helps establish criteria against which to measure the success in implementing measures (*high agreement, much evidence*) [13.3].

The choice of the long-term ambition significantly influences the necessary short-term action and therefore the design of the international regime. Abatement costs depend on the goal, vary with region and depend on the allocation of emission allowances among regions and the level of participation (*high agreement, much evidence*) [13.3].

Options for the design of international regimes can incorporate goals for the short, medium and long term. One option is to set a goal for long-term GHG concentrations or a temperature stabilization goal. Such a goal might be based on physical impacts to be avoided or conceptually on the basis of the monetary and non-monetary damages to be avoided. An alternative to agreeing on specific CO<sub>2</sub> concentration or temperature levels is an agreement on specific long-term actions such as a technology R&D and diffusion target – for example, ‘eliminating carbon emissions from the energy sector by 2060’. An advantage of such a goal is that it might be linked to specific actions (*high agreement, much evidence*) [13.3].

Another option would be to adopt a ‘hedging strategy’, defined as a shorter-term goal on global emissions, from which it is still possible to reach a range of desirable long-term goals. Once the short-term goal is reached, decisions on next steps can be made in light of new knowledge and decreased levels of uncertainty (*medium agreement, medium evidence*) [13.3].

### Participation

Participation of states in international agreements can vary from very modest to extensive. Actions to be taken by participating countries can be differentiated both in terms of when such action is undertaken, who takes the action and what

the action will be. States participating in the same ‘tier’ would have the same (or broadly similar) types of commitments. Decisions on how to allocate states to tiers can be based on formalized quantitative or qualitative criteria, or be ‘ad hoc’. Under the principle of sovereignty, states may choose the tier into which they are grouped (*high agreement, much evidence*) [13.3].

An agreement can have static participation or may change over time. In the latter case, states can ‘graduate’ from one tier of commitments to another. Graduation can be linked to passing of quantitative thresholds for certain parameters (or combinations of parameters) that have been predefined in the agreement, such as emissions, cumulative emissions, GDP per capita, relative contribution to temperature increase or other measures of development, such as the human development index (HDI) (*high agreement, much evidence*) [13.3].

Some argue that an international agreement needs to include only the major emitters to be effective, since the largest 15 countries (including the EU-25 as one) make up 80% of global GHG emissions. Others assert that those with historical responsibility must act first. Still another view holds that technology development is the critical factor for a global solution to climate change, and thus agreements must specifically target technology development in Annex I countries – which in turn could offset some or all emissions leakage in Non-Annex I countries. Others suggest that a climate regime is not exclusively about mitigation, but also encompasses adaptation – and that a far wider array of countries is vulnerable to climate change and must be included in any agreement (*high agreement, much evidence*) [13.3].

### Regime stringency: linking goals, participation and timing

Under most equity interpretations, developed countries as a group would need to reduce their emissions significantly by 2020 (10–40% below 1990 levels) and to still lower levels by 2050 (40–95% below 1990 levels) for low to medium stabilization levels (450–550ppm CO<sub>2</sub>-eq) (see also Chapter 3). Under most of the regime designs considered for such stabilization levels, developing-country emissions need to deviate below their projected baseline emissions within the next few decades (*high agreement, much evidence*). For most countries, the choice of the long-term ambition level will be more important than the design of the emission-reduction regime [13.3].

The total global costs are highly dependent on the baseline scenario, marginal abatement cost estimates, the assumed concentration stabilization level (see also Chapters 3 and 11) and the level (size of the coalition) and degree of participation (how and when allowances are allocated). If, for example some major emitting regions do not participate in the reductions immediately, the global costs of the participating regions will be higher if the goal is maintained (see also Chapter 3). Regional abatement costs are dependent on the allocation of emission allowances to regions, particularly the timing. However, the

assumed stabilization level and baseline scenario are more important in determining regional costs [11.4; 13.3].

### ***Commitments, timetables and actions***

There is a significant body of new literature that identifies and evaluates a diverse set of options for commitments that could be taken by different groups. The most frequently evaluated type of commitment is the binding absolute emission reduction cap as included in the Kyoto Protocol for Annex I countries. The broad conclusion from the literature is that such regimes provide certainty about future emission levels of the participating countries (assuming caps are met). Many authors propose that caps be reached using a variety of ‘flexibility’ approaches, incorporating multiple GHGs and sectors as well as multiple countries through emission trading and/or project-based mechanisms (*high agreement, much evidence*) [13.3].

While a variety of authors propose that absolute caps be applied to all countries in the future, many have raised concerns that the rigidity of such an approach may unreasonably restrict economic growth. While no consensus approach has emerged, the literature provides multiple alternatives to address this problem, including ‘dynamic targets’ (where the obligation evolves over time), and limits on prices (capping the costs of compliance at a given level – which while limiting costs, would also lead to exceeding the environmental target). These options aim at maintaining the advantages of international emissions trading while providing more flexibility in compliance (*high agreement, much evidence*). However, there is a trade-off between costs and certainty in achieving an emissions level. [13.3]

### ***Market mechanisms***

International market-based approaches can offer a cost-effective means of addressing climate change if they incorporate a broad coverage of countries and sectors. So far, only a few domestic emissions-trading systems are in place, the EU ETS being by far the largest effort to establish such a scheme, with over 11,500 plants allocated and authorized to buy and sell allowances (*high agreement, high evidence*) [13.2].

Although the Clean Development Mechanism is developing rapidly, the total financial flows for technology transfer have so far been limited. Governments, multilateral organizations and private firms have established nearly 6 billion US\$ in carbon funds for carbon-reduction projects, mainly through the CDM. Financial flows to developing countries through CDM projects are reaching levels in the order of several billion US\$/yr. This is higher than the flows through the Global Environment Facility (GEF), comparable to the energy-oriented development assistance flows, but at least an order of magnitude lower than all foreign direct investment (FDI) flows (*high agreement, much evidence*) [13.3].

Many have asserted that a key element of a successful climate change agreement will be its ability to stimulate the

development and transfer of technology – without which it may be difficult to achieve emission reductions on a significant scale. Transfer of technology to developing countries depends mainly on investments. Creating enabling conditions for investments and technology uptake and international technology agreements are important. One mechanism for technology transfer is to establish innovative ways of mobilizing investments to cover the incremental cost of mitigating and adapting to climate change. International technology agreements could strengthen the knowledge infrastructure (*high agreement, much evidence*) [13.3].

A number of researchers have suggested that sectoral approaches may provide an appropriate framework for post-Kyoto agreements. Under such a system, specified targets could be set, starting with particular sectors or industries that are particularly important, politically easier to address, globally homogeneous or relatively insulated from competition with other sectors. Sectoral agreement may provide an additional degree of policy flexibility and make comparing efforts within a sector between countries easier, but may be less cost-effective, since trading within a single sector will be inherently more costly than trading across all sectors (*high agreement, much evidence*) [13.3].

### ***Coordination/harmonization of policies***

Coordinated policies and measures could be an alternative to or complement internationally agreed targets for emission reductions. A number of policies have been discussed in the literature that would achieve this goal, including taxes (such as carbon or energy taxes); trade coordination/liberalization; R&D; sectoral policies and policies that modify foreign direct investment. Under one proposal, all participating nations – industrialized and developing alike – would tax their domestic carbon usage at a common rate, thereby achieving cost-effectiveness. Others note that while an equal carbon price across countries is economically efficient, it may not be politically feasible in the context of existing tax distortions (*high agreement, much evidence*) [13.3].

### ***Non-climate policies and links to sustainable development***

There is considerable interaction between policies and measures taken at the national and sub-national level with actions taken by the private sector and between climate change mitigation and adaptation policies and policies in other areas. There are a number of non-climate national policies that can have an important influence on GHG emissions (see Chapter 12) (*high agreement, much evidence*). New research on future international agreements could focus on understanding the inter-linkages between climate policies, non-climate policies and sustainable development, and how to accelerate the adoption of existing technology and policy tools [13.3].

An overview of how various approaches to international climate change agreements, as discussed above, perform against the criteria, given in the introduction, is presented in

**Table TS.21:** Assessment of international agreements on climate change<sup>a</sup> [Table 13.3].

Approach	Environmental effectiveness	Cost effectiveness	Meets distributional considerations	Institutional feasibility
National emission targets and international emission trading (including offsets)	Depends on participation, and compliance	Decreases with limited participation and reduced gas and sector coverage	Depends on initial allocation	Depends on capacity to prepare inventories and compliance. Defections weaken regime stability
Sectoral agreements	Not all sectors amenable to such agreements, limiting overall effectiveness. Effectiveness depends on whether agreement is binding or non-binding	Lack of trading across sectors increases overall costs, although may be cost-effective within individual sectors. Competitive concerns reduced within each sector	Depends on participation. Within-sector competitiveness concerns alleviated if treated equally at global level	Requires many separate decisions and technical capacity. Each sector may require cross-country institutions to manage agreements
Coordinated policies and measures	Individual measures can be effective; emission levels may be uncertain; success will be a function of compliance	Depends on policy design	Extent of coordination could limit national flexibility; but may increase equity	Depends on number of countries; (easier among smaller groups of countries than at the global level)
Cooperation on Technology RD & D <sup>b</sup>	Depends on funding, when technologies are developed and policies for diffusion	Varies with degree of R&D risk Cooperation reduces individual national risk	Intellectual property concerns may negate the benefits of cooperation	Requires many separate decisions. Depends on research capacity and long-term funding
Development-oriented actions	Depends on national policies and design to create synergies	Depends on the extent of synergies with other development objectives	Depends on distributional effects of development policies	Depends on priority given to sustainable development in national policies and goals of national institutions
Financial mechanisms	Depends on funding	Depends on country and project type	Depends on project and country selection criteria	Depends on national institutions
Capacity building	Varies over time and depends on critical mass	Depends on programme design	Depends on selection of recipient group	Depends on country and institutional frameworks

<sup>a</sup>) The table examines each approach based on its capacity to meet its internal goals – not in relation to achieving a global environmental goal. If such targets are to be achieved, a combination of instruments needs to be adopted. Not all approaches have equivalent evaluation in the literature; evidence for individual elements of the matrix varies.

Table TS.21. Future international agreements would have stronger support if they meet these criteria (*high agreement, much evidence*) [13.3].

## 14 Gaps in knowledge

Gaps in knowledge refer to two aspects of climate change mitigation:

- Where additional data collection, modelling and analysis could narrow knowledge gaps, and the resulting improved knowledge and empirical experience could assist decision-making on climate change mitigation measures and policies; to some extent, these gaps are reflected in the uncertainty statements in this report.
- Where research and development could improve mitigation technologies and/or reduce their costs. This important aspect is not treated in this section, but is addressed in the chapters where relevant.

### *Emission data sets and projections*

Despite a wide variety of data sources and databases underlying this report, there are still gaps in accurate and reliable emission data by sector and specific processes, especially with regard to non-CO<sub>2</sub> GHGs, organic or black carbon, and CO<sub>2</sub> from various sources, such as deforestation, decay of biomass and peat fires. Consistent treatment of non-CO<sub>2</sub> GHGs in the methodologies underlying scenarios for future GHG emissions is often lacking [Chapters 1 and 3].

### *Links between climate change and other policies*

A key innovation of this report is the integrated approach between the assessment of climate change mitigation and wider development choices, such as the impacts of (sustainable) development policies on GHG-emission levels and vice versa.

However, there is still a lack of empirical evidence on the magnitude and direction of the interdependence and interaction of sustainable development and climate change, of mitigation and adaptation relationships in relation to development aspects,

and the equity implications of both. The literature on the linkages between mitigation and sustainable development and, more particularly, on how to capture synergies and minimize trade-offs, taking into account state, market and civil society's role, is still sparse. New research is required into the linkages between climate change and national and local policies (including but not limited to energy security, water, health, air pollution, forestry, agriculture) that might lead to politically feasible, economically attractive and environmentally beneficial outcomes. It would also be helpful to elaborate potential development paths that nations and regions can pursue, which would provide links between climate protection and development issues. Inclusion of macro-indicators for sustainable development that can track progress could support such analysis [Chapters 2, 12 and 13].

### ***Studies of costs and potentials***

The available studies of mitigation potentials and costs differ in their methodological treatment and do not cover all sectors, GHGs or countries. Because of different assumptions, for example, with respect to the baseline and definitions of potentials and costs, their comparability is often limited. Also, the number of studies on mitigation costs, potentials and instruments for countries belonging to Economies in Transition and most developing regions is smaller than for developed and selected (major) developing countries.

This report compares costs and mitigation potentials based on bottom-up data from sectoral analyses with top-down costs and potential data from integrated models. The match at the sectoral level is still limited, partly because of lack of or incomplete data from bottom-up studies and differences in sector definitions and baseline assumptions. There is a need for integrated studies that combine top-down and bottom-up elements [Chapters 3, 4, 5, 6, 7, 8, 9 and 10].

Another important gap is the knowledge on spill-over effects (the effects of domestic or sectoral mitigation measures on other countries or sectors). Studies indicate a large range (leakage effects<sup>20</sup> from implementation of the Kyoto Protocol of between 5 and 20% by 2010), but are lacking an empirical basis. More empirical studies would be helpful [Chapter 11].

The understanding of future mitigation potentials and costs depends not only on the expected impact of RD&D on technology performance characteristics but also on 'technology learning', technology diffusion and transfer which are often not taken into account in mitigation studies. The studies on the influence of technological change on mitigation costs mostly have a weak empirical basis and are often conflicting.

Implementation of a mitigation potential may compete with other activities. For instance, the biomass potentials are large, but there may be trade-offs with food production, forestry or nature conservation. The extent to which the biomass potential can be deployed over time is still poorly understood.

In general, there is a continued need for a better understanding of how rates of adoption of climate-mitigation technologies are related to national and regional climate and non-climate policies, market mechanisms (investments, changing consumer preferences), human behaviour and technology evolution, change in production systems, trade and finance and institutional arrangements.

<sup>20</sup> Carbon leakage is an aspect of spill-overs and is the increase in CO<sub>2</sub> emissions outside countries taking domestic measures divided by the emission reductions in these countries.

# Annex I

## Glossary

**Editor: Aviel Verbruggen (Belgium)**

**Notes:** Glossary entries (highlighted in **bold**) are by preference subjects; a main entry can contain **subentries**, also in bold, e.g. **Final Energy** is defined under the entry **Energy**. Some definitions are adapted from Cleveland C.J. and C. Morris, 2006: Dictionary of Energy, Elsevier, Amsterdam. The Glossary is followed by a list of Acronyms/Abbreviations and by a list of Chemical Compounds (Annex II).

### Activities Implemented Jointly (AIJ)

The pilot phase for Joint Implementation, as defined in Article 4.2(a) of the UNFCCC, which allows for project activity among developed countries (and their companies) and between developed and developing countries (and their companies). AIJ is intended to allow parties to the UNFCCC to gain experience in jointly implemented projects. AIJ under the pilot phase do not lead to any credits. Decisions remain about the future of AIJ projects and how they may relate to the Kyoto Mechanisms. As a simple form of tradable permits, AIJ and other market-based schemes represent potential mechanisms for stimulating additional resource flows for reducing emissions. See also Clean Development Mechanism, and Emissions Trading.

### Actual net greenhouse gas removals by sinks

The sum of the verifiable changes in carbon stocks in the carbon pools within the project boundary of an afforestation or reforestation project, minus the increase in GHG emissions as a result of the implementation of the project activity. The term stems from the Clean Development Mechanism (CDM) afforestation and reforestation modalities and procedures.

### Adaptation

Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature-shock resistant plants for sensitive ones, etc.

### Adaptive capacity

The whole of capabilities, resources and institutions of a country or region to implement effective adaptation measures.

### Additionality

Reduction in emissions by sources or enhancement of removals by sinks that is additional to any that would occur in the absence of a Joint Implementation (JI) or a Clean Development Mechanism (CDM) project activity as defined in the Kyoto Protocol Articles on JI and CDM. This definition may be further broadened to include financial, investment, technology, and environmental additionality. Under **financial additionality**, the project activity funding is additional to existing Global Environmental Facility, other financial commitments of parties included in Annex I, Official Development Assistance, and other systems of cooperation. Under **investment additionality**, the value of the Emissions Reduction Unit/Certified Emission Reduction Unit shall significantly improve the financial or commercial viability of the project activity. Under **technology additionality**, the technology used for the project activity shall be the best available for the circumstances of the host party. **Environmental additionality** refers to the environmental integrity of the claimed amount by which greenhouse gas emissions are reduced due to a project relative to its baseline. A project activity is further additional, if the incentive from the sale of emission allowances helps to overcome barriers to its implementation.

### Aerosols

A collection of airborne solid or liquid particles, typically between 0.01 and 10 µm in size and residing in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in several ways: directly through scattering and absorbing radiation, and indirectly through acting as condensation nuclei for cloud formation or modifying the optical properties and lifetime of clouds.

### Afforestation

Direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources<sup>1</sup>. See also Re- and Deforestation.

### Agreement

In this Report, the degree of agreement is the relative level of convergence of the literature as assessed by the authors.

### Alliance of Small Island States (AOSIS)

Formed at the Second World Climate Conference (1990). AOSIS comprises small-island and low-lying coastal developing countries that are particularly vulnerable to the adverse consequences of climate change, such as sea-level rise, coral bleaching, and the increased frequency and intensity of tropical storms. With more than 35 states from the Atlantic, Caribbean, Indian Ocean, Mediterranean, and Pacific, AOSIS share common objectives on environmental and sustainable development matters in the UNFCCC process.

### Ancillary benefits

Policies aimed at some target, e.g. climate change mitigation, may be paired with positive side effects, such as increased resource-use efficiency, reduced emissions of air pollutants associated with fossil fuel use, improved transportation, agriculture, land-use practices, employment, and fuel security. **Ancillary impacts** is also used when the effects may be negative. Policies directed at abating air pollution may consider greenhouse-gas mitigation an ancillary benefit, but this perspective is not considered in this assessment. See also **co-benefits**.

### Annex I countries

The group of countries included in Annex I (as amended in 1998) to the UNFCCC, including all the OECD countries and economies in transition. Under Articles 4.2 (a) and 4.2 (b) of the Convention, Annex I countries committed themselves specifically to the aim of returning individually or jointly to their 1990 levels of greenhouse-gas emissions by the year 2000. By default, the other countries are referred to as Non-Annex I countries.

<sup>1</sup> For a discussion of the term *forest* and related terms such as *afforestation*, *reforestation*, and *deforestation* (ARD), see the IPCC Special Report on Land Use, Land-Use Change and Forestry, Cambridge University Press, 2000.

**Annex II countries**

The group of countries included in Annex II to the UNFCCC, including all OECD countries. Under Article 4.2 (g) of the Convention, these countries are expected to provide financial resources to assist developing countries to comply with their obligations, such as preparing national reports. Annex II countries are also expected to promote the transfer of environmentally sound technologies to developing countries.

**Annex B countries**

The countries included in Annex B to the Kyoto Protocol that have agreed to a target for their greenhouse-gas emissions, including all the Annex I countries (as amended in 1998) except for Turkey and Belarus.

**Anthropogenic emissions**

Emissions of greenhouse gases, greenhouse-gas precursors, and aerosols associated with human activities. These include the burning of fossil fuels, deforestation, land-use changes, livestock, fertilization, etc. that result in a net increase in emissions.

**Assigned Amount (AA)**

Under the Kyoto Protocol, the assigned amount is the quantity of greenhouse-gas emissions that an Annex B country has agreed to as its ceiling for its emissions in the first commitment period (2008 to 2012). The AA is the country's total greenhouse-gas emissions in 1990 multiplied by five (for the five-year commitment period) and by the percentage it agreed to as listed in Annex B of the Kyoto Protocol (e.g. 92% for the EU; 93% for the USA).

**Assigned Amount Unit (AAU)**

An AAU equals 1 tonne (metric ton) of CO<sub>2</sub>-equivalent emissions calculated using the Global Warming Potential.

**Backstop technology**

Models estimating mitigation often characterize an arbitrary carbon-free technology (often for power generation) that becomes available in the future in unlimited supply over the horizon of the model. This allows models to explore the consequences and importance of a generic solution technology without becoming enmeshed in picking the technology. This "backstop" technology might be a nuclear technology, fossil technology with capture and sequestration, solar, or something as yet unimagined. The backstop technology is typically assumed either not to currently exist, or to exist only at higher costs relative to conventional alternatives.

**Banking**

According to the Kyoto Protocol [Article 3 (13)], parties included in Annex I to the UNFCCC may save excess AAUs from the first commitment period for compliance with their respective cap in subsequent commitment periods (post-2012).

**Barrier**

Any obstacle to reaching a goal, adaptation or mitigation potential that can be overcome or attenuated by a policy, programme, or measure. **Barrier removal** includes correcting market failures directly or reducing the transactions costs in the public and private sectors by e.g. improving institutional capacity, reducing risk and uncertainty, facilitating market transactions, and enforcing regulatory policies.

**Baseline**

The reference for measurable quantities from which an alternative outcome can be measured, e.g. a non-intervention scenario is used as a reference in the analysis of intervention scenarios.

**Benchmark**

A measurable variable used as a baseline or reference in evaluating the performance of an organization. Benchmarks may be drawn from internal experience, that of other organizations or from legal requirement and are often used to gauge changes in performance over time.

**Benefit transfer**

An application of monetary values from one particular analysis to another policy-decision setting, often in a geographic area other than the one in which the original study was performed.

**Biochemical Oxygen Demand (BOD)**

The amount of dissolved oxygen consumed by micro-organisms (bacteria) in the bio-chemical oxidation of organic and inorganic matter in waste water.

**Biocovers**

Layers placed on top of landfills that are biologically active in oxidizing methane into CO<sub>2</sub>.

**Biofilters**

Filters using biological material to filter or chemically process pollutants like oxidizing methane into CO<sub>2</sub>.

**Biodiversity**

The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

**Bioenergy**

Energy derived from biomass.

**Biofuel**

Any liquid, gaseous, or solid fuel produced from plant or animal organic matter. E.g. soybean oil, alcohol from fermented sugar, black liquor from the paper manufacturing process, wood as fuel, etc. **Second-generation biofuels** are products such as ethanol and biodiesel derived from ligno-cellulosic biomass by chemical or biological processes.

**Biological options**

Biological options for mitigation of climate change involve one or more of the three strategies: conservation - conserving an existing carbon pool, thereby preventing CO<sub>2</sub> emissions to the atmosphere; sequestration - increasing the size of existing carbon pools, thereby extracting CO<sub>2</sub> from the atmosphere; substitution - substituting biomass for fossil fuels or energy-intensive products, thereby reducing CO<sub>2</sub> emissions.

**Biomass**

The total mass of living organisms in a given area or of a given species usually expressed as dry weight. Organic matter consisting of, or recently derived from, living organisms (especially regarded as fuel) excluding peat. Biomass includes products, by-products and waste derived from such material. **Cellulosic biomass** is biomass from cellulose, the primary structural component of plants and trees

**Black Carbon**

Particle matter in the atmosphere that consists of soot, charcoal and/or possible light-absorbing refractory organic material. Black carbon is operationally defined matter based on measurement of light absorption and chemical reactivity and/or thermal stability.

**Bottom-up models**

Models represent reality by aggregating characteristics of specific activities and processes, considering technological, engineering and cost details. See also **top-down models**.

**Bubble**

Policy instrument for pollution abatement named for its treatment of multiple emission points as if they were contained in an imaginary bubble. Article 4 of the Kyoto Protocol allows a group of countries to meet their target listed in Annex B jointly by aggregating their total emissions under one 'bubble' and sharing the burden (e.g. the EU).

**Carbon Capture and Storage (CCS)**

A process consisting of separation of CO<sub>2</sub> from industrial and energy-related sources, transport to a storage location, and long-term isolation from the atmosphere.

**Carbon cycle**

The set of processes such as photosynthesis, respiration, decomposition, and air-sea exchange, by which carbon continuously cycles through various reservoirs, such as the atmosphere, living organisms, soils, and oceans.

**Carbon dioxide (CO<sub>2</sub>)**

CO<sub>2</sub> is a naturally occurring gas, and a by-product of burning fossil fuels or biomass, of land-use changes and of industrial processes. It is the principal anthropogenic greenhouse gas that affects Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore it has a Global Warming Potential of 1.

**Carbon dioxide fertilization**

The enhancement of the growth of plants because of increased atmospheric CO<sub>2</sub> concentration. Depending on their mechanism of photosynthesis, certain types of plants are more sensitive to changes in atmospheric CO<sub>2</sub> concentration than others.

**Carbon intensity**

The amount of emissions of CO<sub>2</sub> per unit of GDP.

**Carbon leakage**

The part of emissions reductions in Annex B countries that may be offset by an increase of the emissions in the non-constrained countries above their baseline levels. This can occur through (1) relocation of energy-intensive production in non-constrained regions; (2) increased consumption of fossil fuels in these regions through decline in the international price of oil and gas triggered by lower demand for these energies; and (3) changes in incomes (thus in energy demand) because of better terms of trade. Leakage also refers to GHG-related effects of GHG-emission reduction or CO<sub>2</sub>-sequestration project activities that occur outside the project boundaries and that are measurable and attributable to the activity. On most occasions, leakage is understood as counteracting the initial activity. Nevertheless, there may be situations where effects attributable to the activity outside the project area lead to GHG-emission reductions. These are commonly called spill-over. While (negative) leakage leads to a discount of emission reductions as verified, positive spill-over may not in all cases be accounted for.

**Carbon pool**

Carbon pools are: above-ground biomass, belowground biomass, litter, dead wood and soil organic carbon. CDM project participants may choose not to account one or more carbon pools if they provide transparent and verifiable information showing that the choice will not increase the expected net anthropogenic GHG removals by sinks.

**Carbon price**

What has to be paid (to some public authority as a tax rate, or on some emission permit exchange) for the emission of 1 tonne of CO<sub>2</sub> into the atmosphere. In the models and this Report, the carbon price is the social cost of avoiding an additional unit of CO<sub>2</sub> equivalent emission. In some models it is represented by the shadow price of

an additional unit of CO<sub>2</sub> emitted, in others by the rate of carbon tax, or the price of emission-permit allowances. It has also been used in this Report as a cut-off rate for marginal abatement costs in the assessment of economic mitigation potentials.

**Cap**

Mandated restraint as an upper limit on emissions. The Kyoto Protocol mandates emissions caps in a scheduled timeframe on the anthropogenic GHG emissions released by Annex B countries. By 2008-2012 the EU e.g. must reduce its CO<sub>2</sub>-equivalent emissions of six greenhouse gases to a level 8% lower than the 1990-level.

**Capacity building**

In the context of climate change, capacity building is developing technical skills and institutional capabilities in developing countries and economies in transition to enable their participation in all aspects of adaptation to, mitigation of, and research on climate change, and in the implementation of the Kyoto Mechanisms, etc.

**CCS-ready**

If rapid deployment of CCS is desired, new power plants could be designed and located to be 'CCS-ready' by reserving space for the capture installation, designing the unit for optimal performance when capture is added and siting the plant to enable access to storage reservoirs.

**Certified Emission Reduction Unit (CER)**

Equal to one metric tonne of CO<sub>2</sub>-equivalent emissions reduced or sequestered through a Clean Development Mechanism project, calculated using Global Warming Potentials. In order to reflect potential non-permanence of afforestation and reforestation project activities, the use of temporary certificates for Net Anthropogenic Greenhouse Gas Removal was decided by COP 9. See also **Emissions Reduction Units**.

**Chemical oxygen demand (COD)**

The quantity of oxygen required for the complete oxidation of organic chemical compounds in water; used as a measure of the level of organic pollutants in natural and waste waters.

**Chlorofluorocarbons (CFCs)**

Greenhouse gases covered under the 1987 Montreal Protocol and used for refrigeration, air conditioning, packaging, insulation, solvents, or aerosol propellants. Because they are not destroyed in the lower atmosphere, CFCs drift into the upper atmosphere where, given suitable conditions, they break down ozone. These gases are being replaced by other compounds, including hydrochlorofluorocarbons and hydrofluorocarbons, which are greenhouse gases covered under the Kyoto Protocol.

**Clean Development Mechanism (CDM)**

Defined in Article 12 of the Kyoto Protocol, the CDM is intended to meet two objectives: (1) to assist parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the convention; and (2) to assist parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments. Certified Emission Reduction Units from CDM projects undertaken in Non-Annex I countries that limit or reduce GHG emissions, when certified by operational entities designated by Conference of the Parties/ Meeting of the Parties, can be accrued to the investor (government or industry) from parties in Annex B. A share of the proceeds from certified project activities is used to cover administrative expenses as well as to assist developing country parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

**Climate Change (CC)**

Climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Note that UNFCCC, in its Article 1, defines “climate change” as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”. The UNFCCC thus makes a distinction between “climate change” attributable to human activities altering the atmospheric composition, and “climate variability” attributable to natural causes.

**Climate feedback**

An interaction mechanism between processes in the climate system is a climate feedback when the result of an initial process triggers changes in secondary processes that in turn influence the initial one. A positive feedback intensifies the initial process; a negative feedback reduces the initial process. Example of a **positive climate feedback**: higher temperatures as initial process cause melting of the arctic ice leading to less reflection of solar radiation, what leads to higher temperatures. Example of a **negative feedback**: higher temperatures increase the amount of cloud cover (thickness or extent) that could reduce incoming solar radiation and so limit the increase in temperature.

**Climate sensitivity**

In IPCC Reports, equilibrium climate sensitivity refers to the equilibrium change in annual mean global surface temperature following a doubling of the atmospheric CO<sub>2</sub>-equivalent concentration. The evaluation of the equilibrium climate sensitivity is expensive and often hampered by computational constraints.

The **effective climate sensitivity** is a related measure that circumvents the computational problem by avoiding the requirement of equilibrium. It is evaluated from model output for evolving non-equilibrium conditions. It is a measure of the strengths of the feedbacks at a particular time and may vary with forcing history and climate state. The climate sensitivity parameter refers to the equilibrium change in the annual mean global surface temperature following a unit change in radiative forcing (K/W/m<sup>2</sup>)

The **transient climate response** is the change in the global surface temperature, averaged over a 20-year period, centred at the time of CO<sub>2</sub> doubling, i.e., at year 70 in a 1% per year compound CO<sub>2</sub> increase experiment with a global coupled climate model. It is a measure of the strength and rapidity of the surface temperature response to greenhouse gas forcing.

**Climate threshold**

The point at which the atmospheric concentration of greenhouse gases triggers a significant climatic or environmental event, which is considered unalterable, such as widespread bleaching of corals or a collapse of oceanic circulation systems.

**CO<sub>2</sub>-equivalent concentration**

The concentration of carbon dioxide that would cause the same amount of radiative forcing as a given mixture of carbon dioxide and other greenhouse gases.

**CO<sub>2</sub>-equivalent emission**

The amount of CO<sub>2</sub> emission that would cause the same radiative forcing as an emitted amount of a well mixed greenhouse gas, or a mixture of well mixed greenhouse gases, all multiplied with their respective Global Warming Potentials to take into account the differing times they remain in the atmosphere.

**Co-benefits**

The benefits of policies implemented for various reasons at the same time, acknowledging that most policies designed to address greenhouse gas mitigation have other, often at least equally important, rationales (e.g., related to objectives of development, sustainability, and equity). The term co-impact is also used in a more generic sense to cover both positive and negative side of the benefits. See also **ancillary benefits**.

**Co-generation**

The use of waste heat from thermal electricity-generation plants. The heat is e.g. condensing heat from steam turbines or hot flue gases exhausted from gas turbines, for industrial use, buildings or district heating. Synonym for **Combined Heat and Power (CHP)** generation.

**Combined-cycle Gas Turbine (CCGT)**

Power plant that combines two processes for generating electricity. First, gas or light fuel oil feeds a gas turbine that inevitably exhausts hot flue gases (>800°C). Second, heat recovered from these gases, with additional firing, is the source for producing steam that drives a steam turbine. The turbines rotate separate alternators.

It becomes an **integrated CCGT** when the fuel is syngas from a coal or biomass gasification reactor with exchange of energy flows between the gasification and CCGT plants.

**Compliance**

Compliance is whether and to what extent countries do adhere to the provisions of an accord. Compliance depends on implementing policies ordered, and on whether measures follow up the policies. Compliance is the degree to which the actors whose behaviour is targeted by the agreement, local government units, corporations, organizations or individuals, conform to the implementing obligations. See also **implementation**.

**Conference of the Parties (COP)**

The supreme body of the UNFCCC, comprising countries with right to vote that have ratified or acceded to the convention. The first session of the Conference of the Parties (COP-1) was held in Berlin (1995), followed by 2.Geneva (1996), 3.Kyoto (1997), 4.Buenos Aires (1998), 5.Bonn (1999), 6.The Hague/Bonn (2000, 2001), 7.Marrakech (2001), 8.Delhi (2002), 9.Milan (2003), 10.Buenos Aires (2004), 11.Montreal (2005), 12.Nairobi (2006). See also **Meeting of the Parties (MOP)**.

**Contingent Valuation Method (CVM)**

CVM is an approach to quantitatively assess values assigned by people in monetary (willingness to pay) and non monetary (willingness to contribute with time, resources etc.) terms. It is a direct method to estimate economic values for ecosystem and environmental services. A survey of people are asked their willingness to pay for access to, or their willingness to accept compensation for removal of, a specific environmental service, based on a hypothetical scenario and description of the environmental service. See also **values**.

**Cost**

The consumption of resources such as labor time, capital, materials, fuels and so on as the consequence of an action. In economics all resources are valued at their **opportunity cost**, being the value of the most valuable alternative use of the resources. Costs are defined in a variety of ways and under a variety of assumptions that affect their value

**Cost types** include: **administrative costs** of planning, management, monitoring, audits, accounting, reporting, clerical activities, etc. associated with a project or programme; **damage costs** to ecosystems, economies and people due to negative effects from climate change; **implementation costs** of changing existing rules and regulation, capacity building efforts, information, training and education, etc. to put a policy into place; **private costs** are carried



by individuals, companies or other private entities that undertake the action, where **social costs** include additionally the external costs on the environment and on society as a whole.

Costs can be expressed as **total, average (unit, specific)** being the total divided by the number of units of the item for which the cost is being assessed, and **marginal or incremental** costs as the cost of the last additional unit.

The perspectives adopted in this report are: **Project level** considers a “standalone” activity that is assumed not to have significant indirect economic impacts on markets and prices (both demand and supply) beyond the activity itself. The activity can be the implementation of specific technical facilities, infrastructure, demand-side regulations, information efforts, technical standards, etc. **Technology level** considers a specific greenhouse-gas mitigation technology, usually with several applications in different projects and sectors. The literature on technologies covers their technical characteristics, especially evidence on learning curves as the technology diffuses and matures. **Sector level** considers sector policies in a “partial-equilibrium” context, for which other sectors and the macroeconomic variables are assumed to be as given. The policies can include economic instruments related to prices, taxes, trade, and financing, specific large-scale investment projects, and demand-side regulation efforts. **Macroeconomic level** considers the impacts of policies on real income and output, employment and economic welfare across all sectors and markets. The policies include all sorts of economic policies, such as taxes, subsidies, monetary policies, specific investment programmes, and technology and innovation policies. The negative of costs are benefits, and often both are considered together.

#### Cost-benefit analysis

Monetary measurement of all negative and positive impacts associated with a given action. Costs and benefits are compared in terms of their difference and/or ratio as an indicator of how a given investment or other policy effort pays off seen from the society’s point of view.

#### Cost-effectiveness analysis

A special case of cost-benefit analysis in which all the costs of a portfolio of projects are assessed in relation to a fixed policy goal. The policy goal in this case represents the benefits of the projects and all the other impacts are measured as costs or as negative costs (co-benefits). The policy goal can be, for example, a specified goal of emissions reductions of greenhouse gases.

#### Crediting period

The CDM crediting period is the time during which a project activity is able to generate GHG-emission reduction or CO<sub>2</sub> removal certificates. Under certain conditions, the crediting period can be renewed up to two times.

#### Deforestation

The natural or anthropogenic process that converts forest land to non-forest. See **afforestation** and **reforestation**.

#### Demand-side management (DSM)

Policies and programmes for influencing the demand for goods and/or services. In the energy sector, DSM aims at reducing the demand for electricity and energy sources. DSM helps to reduce greenhouse gas emissions.

#### Dematerialization

The process by which economic activity is decoupled from matter–energy throughput, through processes such as eco-efficient production or industrial ecology, allowing environmental impact to fall per unit of economic activity.

#### Deposit-refund system

A deposit or fee (tax) is paid when acquiring a commodity and a

refund or rebate is received for implementation of a specified action (mostly delivering the commodity at a particular place).

#### Desertification

This refers to land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities. The United Nations Convention to Combat Desertification defines land degradation as a reduction or loss, in arid, semi-arid, and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as soil erosion caused by wind and/or water, deterioration of the physical, chemical and biological or economic properties of soil and long-term loss of natural vegetation.

#### Devegetation

This is loss of vegetation density within one land-cover class.

#### Development path

An evolution based on an array of technological, economic, social, institutional, cultural and biophysical characteristics that determine the interactions between human and natural systems, including production and consumption patterns in all countries, over time at a particular scale. **Alternative development paths** refer to different possible trajectories of development, the continuation of current trends being just one of the many paths.

#### Discounting

A mathematical operation making monetary (or other) amounts received or expended at different points in time (years) comparable across time. The operator uses a fixed or possibly time-varying discount rate ( $>0$ ) from year to year that makes future value worth less today. In a **descriptive discounting approach** one accepts the discount rates people (savers and investors) actually apply in their day-to-day decisions (**private discount rate**). In a **prescriptive (ethical or normative) discounting approach** the discount rate is fixed from a social perspective, e.g. based on an ethical judgement about the interests of future generations (**social discount rate**).

#### District heating

Hot water (steam in old systems) is distributed from central stations to buildings and industries in a densely occupied area (a district, a city or an industrialized area such as the Ruhr or Saar in Germany). The insulated two-pipe network functions like a water-based central heating system in a building. The central heat sources can be waste-heat recovery at industrial processes, waste-incineration plants, cogeneration power plants or stand-alone boilers burning fossil fuels or biomass.

#### Double dividend

The extent to which revenue-generating instruments, such as carbon taxes or auctioned (tradable) carbon emission permits can (1) limit or reduce GHG emissions and (2) offset at least part of the potential welfare losses of climate policies through recycling the revenue in the economy to reduce other taxes likely to cause distortions. In a world with involuntary unemployment, the climate change policy adopted may have an effect (a positive or negative ‘third dividend’) on employment. **Weak double dividend** occurs as long as there is a revenue-recycling effect. That is, revenues are recycled through reductions in the marginal rates of distorting taxes. **Strong double dividend** requires that the (beneficial) revenue-recycling effect more than offsets the combination of the primary cost and in this case, the net cost of abatement is negative. See also **interaction effect**.

#### Economies in Transition (EITs)

Countries with their economies changing from a planned economic system to a market economy.

**Economies of scale (scale economies)**

The unit cost of an activity declines when the activity is extended (e.g., more units are produced).

**Ecosystem**

A system of living organisms interacting with each other and their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to the entire planet Earth ultimately.

**Emissions Direct / Indirect**

**Direct emissions** or “point of emission” are defined at the point in the energy chain where they are released and are attributed to that point in the energy chain, whether a sector, a technology or an activity. E.g. emissions from coal-fired power plants are considered direct emissions from the energy supply sector. **Indirect emissions** or emissions “allocated to the end-use sector” refer to the energy use in end-use sectors and account for the emissions associated with the upstream production of the end-use energy. E.g. some emissions associated with electricity generation can be attributed to the buildings sector corresponding to the building sector’s use of electricity.

**Emission factor**

An emission factor is the rate of emission per unit of activity, output or input. E.g. a particular fossil fuel power plant has a CO<sub>2</sub> emission factor of 0.765 kg/kWh generated.

**Emission permit**

An emission permit is a non-transferable or tradable entitlement allocated by a government to a legal entity (company or other emitter) to emit a specified amount of a substance. A **tradable permit** is an economic policy instrument under which rights to discharge pollution - in this case an amount of greenhouse gas emissions - can be exchanged through either a free or a controlled permit-market.

**Emission quota**

The portion of total allowable emissions assigned to a country or group of countries within a framework of maximum total emissions.

**Emissions Reduction Unit (ERU)**

Equal to one metric tonne of CO<sub>2</sub>-equivalent emissions reduced or sequestered arising from a Joint Implementation (defined in Article 6 of the Kyoto Protocol) project. See also **Certified Emission Reduction Unit** and **emissions trading**.

**Emission standard**

A level of emission that by law or by voluntary agreement may not be exceeded. Many standards use emission factors in their prescription and therefore do not impose absolute limits on the emissions.

**Emissions trading**

A market-based approach to achieving environmental objectives. It allows those reducing GHG emissions below their emission cap to use or trade the excess reductions to offset emissions at another source inside or outside the country. In general, trading can occur at the intra-company, domestic, and international levels. The Second Assessment Report by the IPCC adopted the convention of using permits for domestic trading systems and quotas for international trading systems. Emissions trading under Article 17 of the Kyoto Protocol is a tradable quota system based on the assigned amounts calculated from the emission reduction and limitation commitments listed in Annex B of the Protocol.

**Emission trajectories**

These are projections of future emission pathways, or observed emission patterns.

**Energy**

The amount of work or heat delivered. Energy is classified in a variety of types and becomes useful to human ends when it flows from one place to another or is converted from one type into another. **Primary energy** (also referred to as energy sources) is the energy embodied in natural resources (e.g., coal, crude oil, natural gas, uranium) that has not undergone any anthropogenic conversion. It is transformed into **secondary energy** by cleaning (natural gas), refining (oil in oil products) or by conversion into electricity or heat. When the secondary energy is delivered at the end-use facilities it is called **final energy** (e.g., electricity at the wall outlet), where it becomes **usable energy** (e.g., light). Daily, the sun supplies large quantities of energy as rainfall, winds, radiation, etc. Some share is stored in biomass or rivers that can be harvested by men. Some share is directly usable such as daylight, ventilation or ambient heat. **Renewable energy** is obtained from the continuing or repetitive currents of energy occurring in the natural environment and includes non-carbon technologies such as solar energy, hydropower, wind, tide and waves and geothermal heat, as well as carbon-neutral technologies such as biomass. **Embodied energy** is the energy used to produce a material substance (such as processed metals or building materials), taking into account energy used at the manufacturing facility (zero order), energy used in producing the materials that are used in the manufacturing facility (first order), and so on.

**Energy efficiency**

The ratio of useful energy output of a system, conversion process or activity to its energy input.

**Energy intensity**

The ratio of energy use to economic output. At the national level, energy intensity is the ratio of total domestic primary energy use or final energy use to Gross Domestic Product. See also **specific energy use**

**Energy security**

The various security measures that a given nation, or the global community as a whole, must carry out to maintain an adequate energy supply.

**Energy Service Company (ESCO)**

A company that offers energy services to end-users, guarantees the energy savings to be achieved tying them directly to its remuneration, as well as finances or assists in acquiring financing for the operation of the energy system, and retains an on-going role in monitoring the savings over the financing term.

**Environmental effectiveness**

The extent to which a measure, policy or instrument produces a decided, decisive or desired environmental effect.

**Environmentally sustainable technologies**

Technologies that are less polluting, use resources in a more sustainable manner, recycle more of their wastes and products, and handle residual wastes in a more acceptable manner than the technologies that they substitute. They are also more compatible with nationally determined socio-economic, cultural and environmental priorities.

**Evidence**

Information or signs indicating whether a belief or proposition is true or valid. In this Report, the degree of evidence reflects the amount of scientific/technical information on which the Lead Authors are basing their findings.

**Externality / External cost / External benefit**

Externalities arise from a human activity, when agents responsible for the activity do not take full account of the activity's impact on others' production and consumption possibilities, while there exists no compensation for such impact. When the impact is negative, so are external costs. When positive they are referred to as external benefits.

**Feed-in tariff**

The price per unit of electricity that a utility or power supplier has to pay for distributed or renewable electricity fed into the grid by non-utility generators. A public authority regulates the tariff.

**Flaring**

Open air burning of waste gases and volatile liquids, through a chimney, at oil wells or rigs, in refineries or chemical plants and at landfills.

**Forecast**

Projected outcome from established physical, technological, economic, social, behavioral, etc. patterns.

**Forest**

Defined under the Kyoto Protocol as a minimum area of land of 0.05-1.0 ha with tree-crown cover (or equivalent stocking level) of more than 10-30 % with trees with the potential to reach a minimum height of 2-5 m at maturity in situ. A forest may consist either of closed forest formations where trees of various storey and undergrowth cover a high proportion of the ground or of open forest. Young natural stands and all plantations that have yet to reach a crown density of 10-30 % or tree height of 2-5 m are included under forest, as are areas normally forming part of the forest area that are temporarily un-stocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest. See also **Afforestation**, **Deforestation** and **Reforestation**.

**Fossil fuels**

Carbon-based fuels from fossil hydrocarbon deposits, including coal, peat, oil and natural gas.

**Free Rider**

One who benefits from a common good without contributing to its creation or preservation.

**Fuel cell**

A fuel cell generates electricity in a direct and continuous way from the controlled electrochemical reaction of hydrogen or another fuel and oxygen. With hydrogen as fuel it emits only water and heat (no CO<sub>2</sub>) and the heat can be utilized (see **cogeneration**).

**Fuel switching**

In general, this is substituting fuel A for fuel B. In the climate-change discussion it is implicit that fuel A has lower carbon content than fuel B, e.g., natural gas for coal.

**Full-cost pricing**

Setting the final prices of goods and services to include both the private costs of inputs and the external costs created by their production and use.

**G77/China. See Group of 77 and China.****General circulation (climate) model (GCM)**

A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity, i.e. for any one component or combination of components a hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the

extent to which physical, chemical or biological processes are explicitly represented, or the level at which the parameters are assessed empirically. Coupled atmosphere/ocean/sea-ice General Circulation Models provide a comprehensive representation of the climate system. There is an evolution towards more complex models with active chemistry and biology.

**General equilibrium analysis**

General equilibrium analysis considers simultaneously all the markets and feedback effects among these markets in an economy leading to market clearance. See also **market equilibrium**.

**Geo-engineering**

Technological efforts to stabilize the climate system by direct intervention in the energy balance of the Earth for reducing global warming

**Global Environmental Facility (GEF)**

The Global Environment Facility (GEF), established in 1991, helps developing countries fund projects and programmes that protect the global environment. GEF grants support projects related to biodiversity, climate change, international waters, land degradation, the ozone layer, and persistent organic pollutants

**Global warming**

Global warming refers to the gradual increase, observed or projected, in global surface temperature, as one of the consequences of radiative forcing caused by anthropogenic emissions.

**Global Warming Potential (GWP)**

An index, based upon radiative properties of well mixed greenhouse gases, measuring the radiative forcing of a unit mass of a given well mixed greenhouse gas in today's atmosphere integrated over a chosen time horizon, relative to that of CO<sub>2</sub>. The GWP represents the combined effect of the differing lengths of time that these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation. The Kyoto Protocol is based on GWPs from pulse emissions over a 100-year time frame.

**Green accounting**

Attempts to integrate into macroeconomic studies a broader set of social welfare measures, covering e.g., social, environmental, and development oriented policy aspects. Green accounting includes both monetary valuations that attempt to calculate a 'green national product' with the economic damage by pollutants subtracted from the national product, and accounting systems that include quantitative non-monetary pollution, depletion and other data.

**Greenhouse effect**

Greenhouse gases effectively absorb infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus, greenhouse gases trap heat within the surface-troposphere system. This is called the greenhouse effect.

Thermal infrared radiation in the troposphere is strongly coupled to the temperature at the altitude at which it is emitted. In the troposphere, the temperature generally decreases with height. Effectively, infrared radiation emitted to space originates from an altitude with a temperature of, on average, -19°C, in balance with the net incoming solar radiation, whereas the Earth's surface is kept at a much higher temperature of, on average, +14°C.

An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called **enhanced greenhouse effect**.

**Greenhouse gases (GHGs)**

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapour (H<sub>2</sub>O), carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O), methane (CH<sub>4</sub>) and ozone (O<sub>3</sub>) are the primary greenhouse gases in the earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Besides carbon dioxide, nitrous oxide and methane, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons.

**Gross Domestic Product (GDP)**

The sum of gross value added, at purchasers' prices, by all resident and non-resident producers in the economy, plus any taxes and minus any subsidies not included in the value of the products in a country or a geographic region for a given period, normally one year. It is calculated without deducting for depreciation of fabricated assets or depletion and degradation of natural resources.

**Gross National Product (GNP)**

GNP is a measure of national income. It measures value added from domestic and foreign sources claimed by residents. GNP comprises Gross Domestic Product plus net receipts of primary income from non-resident income.

**Gross World Product**

An aggregation of the individual country's Gross Domestic Products to obtain the sum for the world.

**Group of 77 and China (G77/China)**

Originally 77, now more than 130, developing countries that act as a major negotiating bloc in the UNFCCC process. G77/China is also referred to as Non-Annex I countries in the context of the UNFCCC.

**Governance**

The way government is understood has changed in response to social, economic and technological changes over recent decades. There is a corresponding shift from *government* defined strictly by the nation-state to a more inclusive concept of *governance*, recognizing the contributions of various levels of government (global, international, regional, local) and the roles of the private sector, of non-governmental actors and of civil society.

**Hot air**

Under the terms of the 1997 Kyoto Protocol, national emission targets in Annex B are expressed relative to emissions in the year 1990. For countries in the former Soviet Union and Eastern Europe this target has proven to be higher than their current and projected emissions for reasons unrelated to climate-change mitigation activities. Russia and Ukraine, in particular, are expected to have a substantial volume of excess emission allowances over the period 2008-2012 relative to their forecast emissions. These allowances are sometimes referred to as hot air because, while they can be traded under the Kyoto Protocol's flexibility mechanisms, they did not result from mitigation activities.

**Hybrid vehicle**

Any vehicle that employs two sources of propulsion, especially a vehicle that combines an internal combustion engine with an electric motor.

**Hydrofluorocarbons (HFCs)**

One of the six gases or groups of gases to be curbed under the

Kyoto Protocol. They are produced commercially as a substitute for chlorofluorocarbons. HFCs are largely used in refrigeration and semiconductor manufacturing. Their Global Warming Potentials range from 1,300 to 11,700.

**Implementation**

Implementation describes the actions taken to meet commitments under a treaty and encompasses legal and effective phases. **Legal implementation** refers to legislation, regulations, judicial decrees, including other actions such as efforts to administer progress, which governments take to translate international accords into domestic law and policy. **Effective implementation** needs policies and programmes that induce changes in the behaviour and decisions of target groups. Target groups then take effective measures of mitigation and adaptation.

**Income elasticity (of demand)**

This is the ratio of the percentage change in quantity of demand for a good or service to a one percentage change in income. For most goods and services, demand goes up when income grows, making income elasticity positive. When the elasticity is less than one, goods and services are called necessities.

**Industrial ecology**

The relationship of a particular industry with its environment. It often refers to the conscious planning of industrial processes to minimize their negative externalities (e.g., by heat and materials cascading).

**Inertia**

In the context of climate-change mitigation, inertia relates to the difficulty of change resulting from pre-existing conditions within society such as physical man-made capital, natural capital and social non-physical capital, including institutions, regulations and norms. Existing structures lock in societies, making change more difficult.

**Integrated assessment**

A method of analysis that combines results and models from the physical, biological, economic and social sciences, and the interactions between these components in a consistent framework to evaluate the status and the consequences of environmental change and the policy responses to it.

**Integrated Design Process (IDP) of buildings**

Optimizing the orientation and shape of buildings and providing high-performance envelopes for minimizing heating and cooling loads. Passive techniques for heat transfer control, ventilation and daylight access reduce energy loads further. Properly sized and controlled, efficient mechanical systems address the left-over loads. IDP requires an iterative design process involving all the major stakeholders from building users to equipment suppliers, and can achieve 30-75% savings in energy use in new buildings at little or no additional investment cost.

**Intelligent controls**

In this report, the notion of 'intelligent control' refers to the application of information technology in buildings to control heating, ventilation, air-conditioning, and electricity use effectively. It requires effective monitoring of parameters such as temperature, convection, moisture, etc., with appropriate control measurements ('smart metering').

**Interaction effect**

The consequence of the interaction of climate-change policy instruments with existing domestic tax systems, including both cost-increasing tax interaction and cost-reducing revenue-recycling effect. The former reflects the impact that greenhouse gas policies can have on labour and capital markets through their effects on real wages and the real return to capital. Restricting allowable GHG

emissions, raises the carbon price and so the costs of production and the prices of output, thus reducing the real return to labour and capital. With policies that raise revenue for the government, carbon taxes and auctioned permits, the revenues can be recycled to reduce existing distortional taxes. See also **double dividend**.

### Intergovernmental Organization (IGO)

Organizations constituted of governments. Examples include the World Bank, the Organization of Economic Co-operation and Development (OECD), the International Civil Aviation Organization (ICAO), the Intergovernmental Panel on Climate Change (IPCC), and other UN and regional organizations. The Climate Convention allows accreditation of these IGOs to attend negotiating sessions.

### International Energy Agency (IEA)

Established in 1974, the agency is linked with the OECD. It enables OECD member countries to take joint measures to meet oil supply emergencies, to share energy information, to coordinate their energy policies, and to cooperate in developing rational energy use programmes.

### Joint Implementation (JI)

A market-based implementation mechanism defined in Article 6 of the Kyoto Protocol, allowing Annex I countries or companies from these countries to implement projects jointly that limit or reduce emissions or enhance sinks, and to share the Emissions Reduction Units. JI activity is also permitted in Article 4.2(a) of the UNFCCC. See also **Activities Implemented Jointly** and **Kyoto Mechanisms**.

### Kyoto Mechanisms (also called Flexibility Mechanisms)

Economic mechanisms based on market principles that parties to the Kyoto Protocol can use in an attempt to lessen the potential economic impacts of greenhouse gas emission-reduction requirements. They include **Joint Implementation** (Article 6), **Clean Development Mechanism** (Article 12), and **Emissions trading** (Article 17).

### Kyoto Protocol

The Kyoto Protocol to the UNFCCC was adopted at the Third Session of the Conference of the Parties (COP) in 1997 in Kyoto. It contains legally binding commitments, in addition to those included in the FCCC. Annex B countries agreed to reduce their anthropogenic GHG emissions (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) by at least 5% below 1990 levels in the commitment period 2008-2012. The Kyoto Protocol came into force on 16 February 2005.

### Landfill

A landfill is a solid waste disposal site where waste is deposited below, at or above ground level. Limited to engineered sites with cover materials, controlled placement of waste and management of liquids and gases. It excludes uncontrolled waste disposal.

### Land-use

The total of arrangements, activities and inputs undertaken in a certain land-cover type (a set of human actions). The social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation). Land-use change occurs when, e.g., forest is converted to agricultural land or to urban areas.

### Leapfrogging

The ability of developing countries to bypass intermediate technologies and jump straight to advanced clean technologies. Leapfrogging can enable developing countries to move to a low-emissions development trajectory.

### Learning by doing

As researchers and firms gain familiarity with a new technological process, or acquire experience through expanded production they can discover ways to improve processes and reduce cost. Learning by doing is a type of experience-based technological change.

### Levelized cost price

The unique price of the outputs of a project that makes the present value of the revenues (benefits) equal to the present value of the costs over the lifetime of the project. See also **discounting** and **present value**.

### Likelihood

The likelihood of an occurrence, outcome or result, where this can be estimated probabilistically, is expressed in IPCC reports using a standard terminology:

Particular, or a range of, occurrences/outcomes of an uncertain event owning a probability of	>99%	are said to be:	Virtually certain
	>90%		Very likely
	>66%		Likely
	33 to 66%		About as likely as not
	<33%		Unlikely
	<10%		Very unlikely
	<1%		Exceptionally unlikely

### Lock-in effect

Technologies that cover large market shares continue to be used due to factors such as sunk investment costs, related infrastructure development, use of complementary technologies and associated social and institutional habits and structures.

### Low-carbon technology

A technology that over its life cycle causes less CO<sub>2</sub>-eq. emissions than other technological options do. See also **Environmentally sustainable technologies**.

### Macroeconomic costs

These costs are usually measured as changes in Gross Domestic Product or changes in the growth of Gross Domestic Product, or as loss of welfare or consumption.

### Marginal cost pricing

The pricing of goods and services such that the price equals the additional cost arising when production is expanded by one unit. Economic theory shows that this way of pricing maximizes social welfare in a first-best economy.

### Market barriers

In the context of climate change mitigation, market barriers are conditions that prevent or impede the diffusion of cost-effective technologies or practices that would mitigate GHG emissions.

### Market-based regulation

Regulatory approaches using price mechanisms (e.g., taxes and auctioned tradable permits), among other instruments, to reduce GHG emissions.

### Market distortions and imperfections

In practice, markets will always exhibit distortions and imperfections such as lack of information, distorted price signals, lack of competition, and/or institutional failures related to regulation, inadequate delineation of property rights, distortion-inducing fiscal systems, and limited financial markets

### Market equilibrium

The point at which the demand for goods and services equals the supply; often described in terms of price levels, determined in a competitive market, 'clearing' the market.

### Market Exchange Rate (MER)

This is the rate at which foreign currencies are exchanged. Most economies post such rates daily and they vary little across all the exchanges. For some developing economies official rates and black-market rates may differ significantly and the MER is difficult to pin down.

**Material efficiency options**

In this report, options to reduce GHG emissions by decreasing the volume of materials needed for a certain product or service

**Measures**

Measures are technologies, processes, and practices that reduce GHG emissions or effects below anticipated future levels. Examples of measures are renewable energy technologies, waste minimization processes and public transport commuting practices, etc. See also **policies**.

**Methane (CH<sub>4</sub>)**

Methane is one of the six greenhouse gases to be mitigated under the Kyoto Protocol. It is the major component of natural gas and associated with all hydrocarbon fuels, animal husbandry and agriculture. **Coal-bed methane** is the gas found in coal seams.

**Methane recovery**

Methane emissions, e.g., from oil or gas wells, coal beds, peat bogs, gas transmission pipelines, landfills, or anaerobic digesters, are captured and used as a fuel or for some other economic purpose (e.g., chemical feedstock).

**Meeting of the Parties (to the Kyoto Protocol) (MOP)**

The Conference of the Parties (COP) of the UNFCCC serves as the Meeting of the Parties (MOP), the supreme body of the Kyoto Protocol, since the latter entered into force on 16 February 2005. Only parties to the Kyoto Protocol may participate in deliberations and make decisions.

**Millennium Development Goals (MDG)**

A set of time-bound and measurable goals for combating poverty, hunger, disease, illiteracy, discrimination against women and environmental degradation, agreed at the UN Millennium Summit in 2000.

**Mitigation**

Technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce GHG emissions and enhance sinks.

**Mitigative capacity**

This is a country's ability to reduce anthropogenic GHG emissions or to enhance natural sinks, where ability refers to skills, competencies, fitness and proficiencies that a country has attained and depends on technology, institutions, wealth, equity, infrastructure and information. Mitigative capacity is rooted in a country's sustainable development path.

**Montreal Protocol**

The Montreal Protocol on Substances that Deplete the Ozone Layer was adopted in Montreal in 1987, and subsequently adjusted and amended in London (1990), Copenhagen (1992), Vienna (1995), Montreal (1997) and Beijing (1999). It controls the consumption and production of chlorine- and bromine-containing chemicals that destroy stratospheric ozone, such as chlorofluorocarbons, methyl chloroform, carbon tetrachloride, and many others.

**Multi-attribute analysis.**

Integrates different decision parameters and values in a quantitative analysis without assigning monetary values to all parameters. Multi-attribute analysis can combine quantitative and qualitative information.

**Multi-gas**

Next to CO<sub>2</sub> also the other greenhouse gases (methane, nitrous

oxide and fluorinated gases) are taken into account in e.g. achieving reduction of emissions (**multi-gas reduction**) or stabilization of concentrations (**multi-gas stabilization**).

**National Action Plans**

Plans submitted to the COP by parties outlining the steps that they have adopted to limit their anthropogenic GHG emissions. Countries must submit these plans as a condition of participating in the UNFCCC and, subsequently, must communicate their progress to the COP regularly. The National Action Plans form part of the National Communications, which include the national inventory of GHG sources and sinks.

**Net anthropogenic greenhouse gas removals by sinks**

For CDM afforestation and reforestation projects, 'net anthropogenic GHG removals by sinks' equals the actual net GHG removals by sinks minus the baseline net GHG removals by sinks minus leakage.

**Nitrous oxide (N<sub>2</sub>O)**

One of the six types of greenhouse gases to be curbed under the Kyoto Protocol.

**Non-Annex I Countries/Parties**

The countries that have ratified or acceded to the UNFCCC but are not included in Annex I.

**Non-Annex B Countries/Parties**

The countries not included in Annex B of the Kyoto Protocol.

**No-regret policy (options / potential)**

Such policy would generate net social benefits whether or not there is climate change associated with anthropogenic emissions of greenhouse gases. **No-regret options** for GHG emissions reduction refer to 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.

**Normative analysis**

Economic analysis in which judgments about the desirability of various policies are made. The conclusions rest on value judgments as well as on facts and theories.

**Oil sands and oil shale**

Unconsolidated porous sands, sandstone rock and shales containing bituminous material that can be mined and converted to a liquid fuel.

**Opportunities**

Circumstances to decrease the gap between the market potential of any technology or practice and the economic potential or technical potential.

**Ozone (O<sub>3</sub>)**

Ozone, the tri-atomic form of oxygen, is a gaseous atmospheric constituent. In the troposphere, ozone is created both naturally and by photochemical reactions involving gases resulting from human activities. Troposphere ozone acts as a greenhouse gas. In the stratosphere, ozone is created by the interaction between solar ultraviolet radiation and molecular oxygen (O<sub>2</sub>). Stratospheric ozone plays a dominant role in the stratospheric radiative balance. Its concentration is highest in the ozone layer.

**Pareto criterion**

A criterion testing whether an individual's welfare can be increased without making others in the society worse off. A **Pareto improvement** occurs when an individual's welfare is improved without making the welfare of the rest of society worse off. A

**Pareto optimum** is reached when no one's welfare can be increased without making the welfare of the rest of society worse off, given a particular distribution of income. Different income distributions lead to different Pareto optima.

### Passive solar design

Structural design and construction techniques that enable a building to utilize solar energy for heating, cooling, and lighting by non-mechanical means.

### Perfluorocarbons (PFCs)

Among the six greenhouse gases to be abated under the Kyoto Protocol. These are by-products of aluminium smelting and uranium enrichment. They also replace chlorofluorocarbons in manufacturing semiconductors. The Global Warming Potential of PFCs is 6500–9200.

### Policies

In UNFCCC parlance, policies are taken and/or mandated by a government - often in conjunction with business and industry within its own country, or with other countries - to accelerate mitigation and adaptation measures. Examples of policies are carbon or other energy taxes, fuel efficiency standards for automobiles, etc. **Common and co-ordinated or harmonised policies** refer to those adopted jointly by parties. See also **measures**.

### Portfolio analysis

Deals with a portfolio of assets or policies that are characterized by different risks and pay-offs. The objective function is built up around the variability of returns and their risks, leading up to the decision rule to choose the portfolio with highest expected return.

### Post-consumer waste

Waste from consumption activities, e.g. packaging materials, paper, glass, rests from fruits and vegetables, etc.

### Potential

In the context of climate change, potential is the amount of mitigation or adaptation that could be - but is not yet - realized over time. As potential levels are identified: market, economic, technical and physical.

- **Market potential** indicates the amount of GHG mitigation that might be expected to occur under forecast market conditions including policies and measures in place at the time. It is based on private unit costs and discount rates, as they appear in the base year and as they are expected to change in the absence of any additional policies and measures.
- **Economic potential** is in most studies used as the amount of GHG mitigation that is cost-effective for a given carbon price, based on social cost pricing and discount rates, including energy savings, but without most externalities. Theoretically, it is defined as the potential for cost-effective GHG mitigation when non-market social costs and benefits are included with market costs and benefits in assessing the options for particular levels of carbon prices (as affected by mitigation policies) and when using social discount rates instead of private ones. This includes externalities, i.e., non-market costs and benefits such as environmental co-benefits
- **Technical potential** is the amount by which it is possible to reduce GHG emissions or improve energy efficiency by implementing a technology or practice that has already been demonstrated. No explicit reference to costs is made but adopting 'practical constraints' may take into account implicit economic considerations.
- **Physical potential** is the theoretical (thermodynamic) and sometimes, in practice, rather uncertain upper limit to mitigation.

### Precautionary Principle

A provision under Article 3 of the UNFCCC, stipulating that the parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason to postpone such measures, taking into account that policies and measures to deal with climate change should be cost-effective in order to ensure global benefits at the lowest possible cost.

### Precursors

Atmospheric compounds which themselves are not greenhouse gases or aerosols, but which have an effect on greenhouse gas or aerosol concentrations by taking part in physical or chemical processes regulating their production or destruction rates.

### Pre-industrial

The era before the industrial revolution of the late 18th and 19th centuries, after which the use of fossil fuel for mechanization started to increase.

### Present value

The value of a money amount differs when the amount is available at different moments in time (years). To make amounts at differing times comparable and additive, a date is fixed as the 'present'. Amounts available at different dates in the future are discounted back to a present value, and summed to get the present value of a series of future cash flows. **Net present value** is the difference between the present value of the revenues (benefits) with the present value of the costs. See also **discounting**.

### Price elasticity of demand

The ratio of the percentage change in the quantity of demand for a good or service to one percentage change in the price of that good or service. When the absolute value of the elasticity is between 0 and 1, demand is called inelastic; when it is greater than one, demand is called elastic.

### 'Primary market' and 'secondary market' trading

In commodities and financial exchanges, buyers and sellers who trade directly with each other constitute the 'primary market', while buying and selling through exchange facilities represent the 'secondary market'.

### Production frontier

The maximum outputs attainable with the optimal uses of available inputs (natural resources, labour, capital, information).

### Public sector leadership programmes in energy efficiency

Government purchasing and procurement of energy-efficient products and services. Government agencies are responsible for a wide range of energy-consuming facilities and services such as government office buildings, schools, and health care facilities. The government is often a country's largest consumer of energy and largest buyer of energy-using equipment. Indirect beneficial impacts occur when governments act effectively as market leaders. First, government buying power can create or expand demand for energy-efficient products and services. Second, visible government energy-saving actions can serve as an example for others.

### Purchasing Power Parity (PPP)

The purchasing power of a currency is expressed using a basket of goods and services that can be bought with a given amount in the home country. International comparison of, e.g., Gross Domestic Products of countries can be based on the purchasing power of currencies rather than on current exchange rates. PPP estimates tend to lower per capita GDPs in industrialized countries and raise per capita GDPs in developing countries. (**PPP** is also an acronym for polluter-pays-principle).

**Radiative forcing**

Radiative forcing is the change in the net vertical irradiance (expressed in Watts per square metre: W/m<sup>2</sup>) at the tropopause due to an internal change or a change in the external forcing of the climate system, such as, for example, a change in the concentration of CO<sub>2</sub> or in the output of the sun.

**Rebound effect**

After implementation of efficient technologies and practices, part of the savings is taken back for more intensive or other consumption, e.g., improvements in car-engine efficiency lower the cost per kilometre driven, encouraging more car trips or the purchase of a more powerful vehicle.

**Reforestation**

Direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was previously forested but converted to non-forested land. For the first commitment period of the Kyoto Protocol, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on 31 December 1989. See also **afforestation** and **deforestation**.

**Reservoir**

A component of the climate system, other than the atmosphere, which has the capacity to store, accumulate or release a substance of concern, e.g., carbon, a greenhouse gas or a precursor. Oceans, soils, and forests are examples of reservoirs of carbon. **Stock** is the absolute quantity of substance of concerns, held within a reservoir at a specified time. See also **Carbon pool**.

**Safe landing approach.** See **tolerable windows approach**.

**Scenario**

A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts, but are useful to provide a view of the implications of developments and actions.

**Sequestration**

Carbon storage in terrestrial or marine reservoirs. **Biological sequestration** includes direct removal of CO<sub>2</sub> from the atmosphere through land-use change, afforestation, reforestation, carbon storage in landfills and practices that enhance soil carbon in agriculture.

**Shadow pricing**

Setting prices of goods and services that are not, or incompletely, priced by market forces or by administrative regulation, at the height of their social marginal value. This technique is used in cost-benefit analysis.

**Sinks**

Any process, activity or mechanism that removes a greenhouse gas or aerosol, or a precursor of a greenhouse gas or aerosol from the atmosphere.

**Smart metering.** See **Intelligent control**.

**Social cost of carbon (SCC)**

The discounted monetized sum (e.g. expressed as a price of carbon in \$/tCO<sub>2</sub>) of the annual net losses from impacts triggered by an additional ton of carbon emitted today. According to usage in economic theory, the social cost of carbon establishes an economically optimal price of carbon at which the associated marginal costs of mitigation would equal the marginal benefits of mitigation.

**Social unit costs of mitigation**

Carbon prices in US\$/tCO<sub>2</sub> and US\$/tC-eq (as affected by mitigation policies and using social discount rates) required to achieve a particular level of mitigation (**economic potential**) in the form of a reduction below a baseline for GHG emissions. The reduction is usually associated with a policy target, such as a cap in an emissions trading scheme or a given level of stabilization of GHG concentrations in the atmosphere.

**Source**

Source mostly refers to any process, activity or mechanism that releases a greenhouse gas, aerosol or a precursor of a greenhouse gas or aerosol into the atmosphere. Source can also refer to, e.g., an energy source.

**Specific energy use**

The energy used in the production of a unit material, product or service.

**Spill-over effect**

The effects of domestic or sector mitigation measures on other countries or sectors. Spill-over effects can be positive or negative and include effects on trade, carbon leakage, transfer of innovations, and diffusion of environmentally sound technology and other issues.

**Stabilization**

Keeping constant the atmospheric concentrations of one or more GHG (e.g., CO<sub>2</sub>) or of a CO<sub>2</sub>-equivalent basket of GHG. Stabilization analyses or scenarios address the stabilization of the concentration of GHG in the atmosphere.

**Standards**

Set of rules or codes mandating or defining product performance (e.g., grades, dimensions, characteristics, test methods, and rules for use). **Product, technology or performance standards** establish minimum requirements for affected products or technologies. Standards impose reductions in GHG emissions associated with the manufacture or use of the products and/or application of the technology.

**Storyline**

A narrative description of a scenario (or a family of scenarios) that highlights the scenario's main characteristics, relationships between key driving forces, and the dynamics of the scenarios.

**Structural change**

Changes, for example, in the relative share of Gross Domestic Product produced by the industrial, agricultural, or services sectors of an economy; or more generally, systems transformations whereby some components are either replaced or potentially substituted by other ones.

**Subsidy**

Direct payment from the government or a tax reduction to a private party for implementing a practice the government wishes to encourage. The reduction of GHG emissions is stimulated by lowering existing subsidies that have the effect of raising emissions (such as subsidies to fossil fuel use) or by providing subsidies for practices that reduce emissions or enhance sinks (e.g. for insulation of buildings or for planting trees).

**Sulphur hexafluoride (SF<sub>6</sub>)**

One of the six greenhouse gases to be curbed under the Kyoto Protocol. It is largely used in heavy industry to insulate high-voltage equipment and to assist in the manufacturing of cable-cooling systems and semi-conductors. Its Global Warming Potential is 23,900.



### Supplementarity

The Kyoto Protocol states that emissions trading and Joint Implementation activities are to be supplemental to domestic policies (e.g. energy taxes, fuel efficiency standards) taken by developed countries to reduce their GHG emissions. Under some proposed definitions of supplementarity (e.g., a concrete ceiling on level of use), developed countries could be restricted in their use of the Kyoto Mechanisms to achieve their reduction targets. This is a subject for further negotiation and clarification by the parties.

### Sustainable Development (SD)

The concept of sustainable development was introduced in the World Conservation Strategy (IUCN 1980) and had its roots in the concept of a sustainable society and in the management of renewable resources. Adopted by the WCED in 1987 and by the Rio Conference in 1992 as a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations. SD integrates the political, social, economic and environmental dimensions.

### Targets and timetables

A target is the reduction of a specific percentage of GHG emissions from a baseline date (e.g., below 1990 levels) to be achieved by a set date or timetable (e.g., 2008-2012). Under the Kyoto Protocol the EU agreed to reduce its GHG emissions by 8% below 1990 levels by the 2008-2012 commitment period. Targets and timetables are an emissions cap on the total amount of GHG emissions that can be emitted by a country or region in a given time period.

### Tax

A **carbon tax** is a levy on the carbon content of fossil fuels. Because virtually all of the carbon in fossil fuels is ultimately emitted as CO<sub>2</sub>, a carbon tax is equivalent to an **emission tax** on each unit of CO<sub>2</sub>-equivalent emissions. An **energy tax** - a levy on the energy content of fuels - reduces demand for energy and so reduces CO<sub>2</sub> emissions from fossil fuel use. An **eco-tax** is designed to influence human behaviour (specifically economic behaviour) to follow an ecologically benign path.

An **international carbon/emission/energy tax** is a tax imposed on specified sources in participating countries by an international authority. The revenue is distributed or used as specified by this authority or by participating countries. A **harmonized tax** commits participating countries to impose a tax at a common rate on the same sources, because imposing different rates across countries would not be cost-effective. A **tax credit** is a reduction of tax in order to stimulate purchasing of or investment in a certain product, like GHG emission reducing technologies. A **carbon charge** is the same as a carbon tax. See also **Interaction effect**

### Technological change

Mostly considered as technological *improvement*, i.e., more or better goods and services can be provided from a given amount of resources (production factors). Economic models distinguish autonomous (exogenous), endogenous and induced technological change.

**Autonomous (exogenous) technological change** is imposed from outside the model, usually in the form of a time trend affecting energy demand or world output growth. **Endogenous technological change** is the outcome of economic activity *within* the model, i.e., the choice of technologies is included within the model and affects energy demand and/or economic growth. **Induced technological change** implies endogenous technological change but adds further changes *induced* by policies and measures, such as carbon taxes triggering R&D efforts.

### Technology

The practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information ('software', know-how for production and use of artefacts).

### Technology transfer

The exchange of knowledge, hardware and associated software, money and goods among stakeholders, which leads to the spreading of technology for adaptation or mitigation. The term encompasses both diffusion of technologies and technological cooperation across and within countries.

### Tolerable windows approach (TWA)

This approach seeks to identify the set of all climate-protection strategies that are simultaneously compatible with 1) prescribed long-term climate-protection goals, and 2) normative restrictions on the emissions mitigation burden. The constraints may include limits on the magnitude and rate of global mean temperature change, on the weakening of the thermohaline circulation, on ecosystem losses and on economic welfare losses resulting from selected climate damages, adaptation costs and mitigation efforts. For a given set of constraints, and given a solution exists, the TWA delineates an emission corridor of complying emission paths.

### Top-down models

Models applying macroeconomic theory, econometric and optimization techniques to aggregate economic variables. Using historical data on consumption, prices, incomes, and factor costs, top-down models assess final demand for goods and services, and supply from main sectors, such as the energy sector, transportation, agriculture, and industry. Some top-down models incorporate technology data, narrowing the gap to **bottom-up models**.

### Trace gas

A minor constituent of the atmosphere, next to nitrogen and oxygen that together make up 99% of all volume. The most important trace gases contributing to the greenhouse effect are carbon dioxide, ozone, methane, nitrous oxide, perfluorocarbons, chlorofluorocarbons, hydrofluorocarbons, sulphur hexafluoride and water vapour.

**Tradable permit.** See **emission permit**

**Tradable quota system.** See **emissions trading**.

### Uncertainty

An expression of the degree to which a value is unknown (e.g. the future state of the climate system). Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgment of a team of experts). See also **likelihood**.

### United Nations Framework Convention on Climate Change (UNFCCC)

The Convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Economic Community. Its ultimate objective is the 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. It contains commitments for all parties. Under the Convention parties included in Annex I aimed to return greenhouse gas emission not controlled by the Montreal Protocol to 1990 levels by the year 2000. The convention came into force in March 1994.

**Value added**

The net output of a sector or activity after adding up all outputs and subtracting intermediate inputs.

**Values**

Worth, desirability or utility based on individual preferences. Most social science disciplines use several definitions of value. Related to nature and environment, there is a distinction between intrinsic and instrumental values, the latter assigned by humans. Within instrumental values, there is an unsettled catalogue of different values, such as (direct and indirect) use, option, conservation, serendipity, bequest, existence, etc.

Mainstream economics define the total value of any resource as the sum of the values of the different individuals involved in the use of the resource. The economic values, which are the foundation of the estimation of costs, are measured in terms of the willingness to pay by individuals to receive the resource or by the willingness of individuals to accept payment to part with the resource. See also **contingent valuation method**.

**Voluntary action**

Informal programmes, self-commitments and declarations, where the parties (individual companies or groups of companies) entering into the action set their own targets and often do their own monitoring and reporting.

**Voluntary agreement**

An agreement between a government authority and one or more private parties to achieve environmental objectives or to improve environmental performance beyond compliance to regulated obligations. Not all voluntary agreements are truly voluntary; some include rewards and/or penalties associated with joining or achieving commitments.

## Annex II

### Abbreviations & Acronyms

A	
ADB	Asian Development Bank
AIJ	Activities Implemented Jointly
ALM	Africa, Latin America, Middle East Region (SRES and post-SRES scenarios)
A/R	Afforestation and Reforestation
B	
BAU	Business As Usual
BECS	Bioenergy with CCS
BOD	Biochemical Oxygen Demand / Biological Oxygen Demand
BRT	Bus Rapid transport
C	
CAA	Clean Air Act
CAFÉ	Corporate Average Fuel Economy
CANZ	Canada, Australia and New Zealand
CBA	Cost Benefit Analysis
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CFCs	Chlorofluorocarbons
CFL	Compact Fluorescent Lamp
CGE	Computable General Equilibrium
CHP	Combined Heat and Power
CONCAWE	European Oil Company Organisation for Environment, Health, and Safety
COD	Chemical Oxygen Demand
COP	Conference of the Parties / Coefficient of Performance
CSD	Commission for Sustainable Development
CSP	Concentrating Solar Power
D	
DAES	Domestic Alternative Energy Sources
DES	Development, Equity and Sustainability
DSM	Demand Side Management
E	
EBRD	European Bank for Reconstruction and Development
EC	European Commission
EEA	European Environmental Agency
EECCA	Countries of Eastern Europe, the Caucasus and Central Asia
EIT	Economy In Transition
EMAS	ECO-Management and Audit Scheme (EU)
EMF	Energy Modeling Forum (Stanford University)
EPR	Extended Producer Responsibility
EPRI	Electric Power Research Institute
ESCO	Energy Service Company
ETS	Emission Trading Scheme (EU)
EU	European Union
F	
FAO	Food & Agriculture Organization
FC	Fuel Cell
FCCC	Framework Convention on Climate Change (UN)
FDI	Foreign Direct Investment
FOB	Free on Board
FOD	First-Order Decay

G	
GATT	General Agreement on Trade and Tariffs
GCM	Global Climate Model
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Green House Gas
GMT	Global Mean Temperature
GNP	Gross National Product
GPP	Gross Primary Production
GWP	Global Warming Potential
H	
HDI	Human Development Index
HFC	Hydrofluorocarbons
HSS	High Strength Steels
HVAC	Heating, Ventilation and Air Conditioning
I	
IA	Integrated Assessment
IAEA	International Atomic Energy Agency
IAES	Imported Alternative Energy Sources
ICAO	International Civil Aviation Organization
ICE	Internal Combustion Engine
IDP	Integrated Design Process (for buildings)
IEA	International Energy Agency
IET	International Emission Trading
IGO	Intergovernmental Organization
IIASA	International Institute for Applied System Analysis
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Classification
ISO	International Standardization Organization
IT	Information Technology
ITC	Induced Technological Change
ITER	International Thermonuclear Experimental Reactor
IUCN	International Union for the Conservation of Nature and natural resources
J	
J	Joule = Newton x meter (International Standard unit of energy)
JI	Joint Implementation
JRC	Joint Research Centre (EU)
L	
LCA	Life Cycle Assessment
LHV	Lower Heating Value
LNG	Liquefied Natural Gas
LPG	Liquid Petroleum Gas
M	
MAC	Marginal Abatement Cost
MBT	Mechanical Biological Treatment
MDG	Millennium Development Goals
MEA	Multilateral Environmental Agreements
MOP	Meeting Of the Parties (Kyoto Protocol)
N	
NAFTA	North American Free Trade Agreement
NEDC	New European Driving Cycle
NGO	Non-Governmental Organization
NIC	Newly Industrialized Country
NMHC	Non-Methane Hydro Carbon
NMT	Non-Motorised Transport
NMVOC	Non-Methane Volatile Organic Compounds

O	
O&M	Operation and Maintenance
ODA	Official Development Assistance
ODS	Ozone Depleting Substances
OECD	Organization for Economic Co-operation and Development
OPEC	Organization of Petroleum Exporting Countries
P	
PAYT	Pay As You Throw
PFC	Perfluorocarbon
ppm [v/w]	parts per million [by volume / weight]
PPP	Purchasing Power Parity
PV	Photovoltaic
Q	
QELRCs	Quantified Emission Limitation or Reduction Commitments
R	
RD&D	Research, Development and Demonstration
S	
SAR	Second Assessment Report (IPCC)
SBSTA	Subsidiary Body for Scientific and Technological Advice
SCC	Social Cost of Carbon
SD	Sustainable Development
SMEs	Small and Medium Enterprises
SPM	Summary for Policy Makers
SRCCS	Special Report on Carbon Capture and Storage (IPCC)
SRES	Special Report on Emissions Scenarios (IPCC)
SRLULUCF	Special Report on Land-Use, Land-Use Change and Forestry (IPCC)
SROC	Special Report on Ozone and Climate (IPCC)
SRTT	Special Report on methodological and technological issues in Technology Transfer (IPCC)
T	
TAR	Third Assessment Report (IPCC)
TPES	Total Primary Energy Supply
TWA	Tolerable Windows Approach
U	
UK	United Kingdom
UN	United Nations
UNCED	UN Conference on Environment and Development
UNDP	UN Development Programme
UNEP	UN Environment Programme
UNFCCC	UN Framework Convention on Climate Change
USA	United States of America
V	
VAT	Value Added Tax
VOC	Volatile organic compound
W	
W	Watt = Joule/second (International Standard unit of power)
WBCSD	World Business Council for Sustainable Development
WCED	World Commission on Environment and Development
WEC	World Energy Council
WG I	Working Group One of the IPCC
WG II	Working Group Two of the IPCC
WG III	Working Group Three of the IPCC
WHO	World Health Organization (UN)
WTO	World Trade Organization
WWF	World Wide Fund for nature

## Chemical Symbols

C	Carbon
C <sub>2</sub> F <sub>6</sub>	Perfluoroethane / Hexafluoroethane
CF <sub>4</sub>	Perfluoromethane / Tetrafluoromethane
CFCs	Chlorofluorocarbons
CH <sub>4</sub>	Methane
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
H / H <sub>2</sub>	Hydrogen (element / gas)
H <sub>2</sub> O	Water / Water vapor
HFCs	Hydrofluorocarbons
N / N <sub>2</sub>	Nitrogen (element / gas)
N <sub>2</sub> O	Nitrous Oxide
NF <sub>3</sub>	Nitrogen trifluoride
NH <sub>3</sub> / NH <sub>4</sub> <sup>+</sup>	Ammonia / Ammonium ion
NMVOOC	Non-methane Volatile Organic Compounds
NO	Nitric oxide
NO <sub>2</sub>	Nitrogen dioxide
NO <sub>x</sub>	The sum of NO and NO <sub>2</sub> expressed in NO <sub>2</sub> mass equivalent
O / O <sub>2</sub>	Oxygen (element / gas)
O <sub>3</sub>	Ozone
P	Phosphorus
SF <sub>6</sub>	Sulphur hexafluoride
SO <sub>2</sub>	Sulphur dioxide
SO <sub>x</sub>	Sulphur oxides expressed in SO <sub>2</sub> mass equivalent
VOCs	Volatile Organic Compounds

## Prefixes for basic physical units

Enlargement			Reduction		
name	symbol	factor	name	symbol	factor
deca	da	10 <sup>+1</sup>	deci	d	10 <sup>-1</sup>
hecto	h	10 <sup>+2</sup>	centi	c	10 <sup>-2</sup>
kilo	k	10 <sup>+3</sup>	milli	m	10 <sup>-3</sup>
mega	M	10 <sup>+6</sup>	micro	μ	10 <sup>-6</sup>
giga	G	10 <sup>+9</sup>	nano	n	10 <sup>-9</sup>
tera	T	10 <sup>+12</sup>	pico	p	10 <sup>-12</sup>
peta	P	10 <sup>+15</sup>	femto	f	10 <sup>-15</sup>
exa	E	10 <sup>+18</sup>	atto	a	10 <sup>-18</sup>

## Annex III

### Contributors to the IPCC WGIII Fourth Assessment Report

**ACHARD, Frédéric**  
Joint Research Centre of the EC  
Italy, France

**ADEGBULUGBE, Anthony**  
Centre for Energy Research  
and Development  
Nigeria

**AHMED, Mohammed Abdelrafie**  
University of Khartoum, Faculty  
of Engineering & Architecture  
Sudan

**AHUJA, Dilip**  
National Institute of Advanced Studies  
India

**AKUMU, Grace**  
Climate Network Africa  
Kenya

**ALFSEN, Knut H.**  
Statistics Norway  
Norway

**ALHARTHI, Awwad**  
Saudi Aramco  
Saudi Arabia

**AMANN, Marcus**  
International Institute for  
Applied Systems Analysis  
Austria

**AMBROSI, Philippe**  
World Bank  
France

**ANAYA, Carlos A.**  
Universidad Nacional Autónoma de México  
México

**ANDRASKO, Kenneth**  
USEPA  
United States of America

**APPS, Mike**  
Natural Resources Canada,  
Canadian Forest Service  
Canada

**ASMUSSEN, Arne**  
Joanneum Research, Graz  
Austria, Germany

**AWERBUCH†, Shimon**  
United States of America

**BABIKER, Mustafa**  
ARAMCO  
Saudi Arabia, Sudan

**BARKER, Terry**  
University of Cambridge, Dep.  
of Land Economy, 4CMR  
United Kingdom

**BASHMAKOV, Igor Alexeyevich**  
Center for Energy Efficiency (CENEf)  
Russia

**BEALE, Roger**  
Allen Consulting Group  
Australia

**BENITEZ, Pablo**  
British Columbia Ministry of Environment  
Canada, Equador

**BERNSTEIN, Lenny**  
L. S. Bernstein & Associates, L.L.C.  
United States of America

**BERTOLDI, Paolo**  
Joint Research Centre of the EC  
Italy

**BEUTHE, Michel**  
Facultés Universitaires Catholique de Mons  
Belgium

**BIROL, Fatih**  
International Energy Agency  
France, Turkey

**BLOK, Kornelis**  
Ecofys  
The Netherlands

**BOARDMAN, Brenda**  
Oxford ECI  
United Kingdom

**BOER, Rizaldi**  
Climatology Laboratory  
Indonesia

**BOGNER, Jean E.**  
Landfills +, Inc, and University of Illinois  
United States of America

**BOSCH, Peter**  
Ecofys  
The Netherlands

**BOSE, Ranjan**  
TERI  
India

**BOUILLE, Daniel**  
Bariiloche Foundation  
Argentina

**BRADLEY, Richard**  
International Energy Agency  
United States of America

**BRINKMAN, Sander**  
Brinkman Climate Change, Consultancy  
The Netherlands

**BROWN, Marilyn A.**  
Georgia Institute of Technology and  
Oak Ridge National Laboratory  
United States of America

**BURCH, Sarah**  
University of British Columbia  
Canada

**BURGER, Nicholas**  
University of California, Santa Barbara  
United States of America

**CAI, Zucong**  
Institute of Soil Science, Chinese  
Academy of Sciences  
P.R. China

**CALVO BUENDIA, Eduardo**  
Universidad Nacional Mayor de San Marcos  
Peru

**CHEN, Wenjun**  
Canada Centre for Remote Sensing  
Canada

**CIFUENTES, Luis**  
P. Universidad Catolica de Chile  
Chile

**CLAPP, Christa**  
U.S. Environmental Protection Agency  
United States of America

**CLARKE, Leon**  
Pacific Northwest National Laboratory  
United States of America

**COCKLIN, Christopher R**  
James Cook University  
Australia, New Zealand

**CORFEE-MORLOT, Jan**  
OECD  
France, United States of America

**CRABBÉ, Philippe J.**  
University of Ottawa  
Canada, Belgium

**DAVE, Rutu**  
Netherlands Environmental  
Assessment Agency  
The Netherlands

**DE LA CHESNAYE, Francisco**  
U.S. Environmental Protection Agency  
United States of America

*Coordinating lead authors, lead authors, contributing authors and review editors are listed alphabetically by surname; when nationality is different from country of residence it is mentioned second.*

- DE LA RUE DU CAN, Stephane**  
Lawrence Berkeley National Laboratory  
United States of America, France
- DELHOTAL, Casey**  
Research Triangle Institute  
(RTI) International  
United States of America
- DEN ELZEN, Michel**  
Netherlands Environmental  
Assessment Agency  
The Netherlands
- DIAZ, Luis F.**  
CalRecovery, Inc.  
United States of America
- DIAZ MOREJON, Cristobal Felix**  
Ministry of Science, Technology  
and the Environment  
Cuba
- DREXHAGE, John**  
International Institute for  
Sustainable Development  
Canada
- DUAN, Maosheng**  
Tsinghua University  
P.R. China
- DUTSCHKE, Michael**  
Biocarbon Consult  
Germany
- EDENHOFER, Ottmar**  
Potsdam Institute for Climate  
Impact Research  
Germany
- EDMONDS, Jae**  
Pacific Northwest National Laboratory  
United States of America
- EICKHOUT, Bas**  
Netherlands Environmental  
Assessment Agency  
The Netherlands
- ELGIZOULI, Ismail**  
High Council for Environment and  
Natural Resources (HCENR)  
Sudan
- ELSIDDIG, Elnour Abdalla**  
University of Khartoum  
Sudan
- FAAIJ, Andre P.C.**  
Copernicus Institute for Sustainable  
Development - Utrecht University  
The Netherlands
- FENHANN, Jørgen**  
Risø National Laboratory, Technical  
University of Denmark  
Denmark
- FISHER, Brian S.**  
CRA International  
Australia
- FLANNERY, Brian**  
Exxon Mobil Corporation  
United States of America
- FORD-ROBERTSON, Justin**  
Ford-Robertson Initiatives (FRI) Ltd  
New Zealand
- FRUMHOFF, Peter C.**  
Union of Concerned Scientists  
United States of America
- GAO, Qingxian**  
Chinese Research Academy of  
Environmental Science  
P.R. China
- GARG, Amit**  
Government of India/UNEP Risø Centre  
Denmark, India
- GASCA, Jorge**  
Mexican Petroleum Institute  
México
- GEHL, Stephen**  
EPRI  
United States of America
- GENG, Luis J.**  
Consultant  
Peru
- GIELEN, Dolf**  
International Energy Agency  
France, Netherlands
- GOLAY, Michael**  
Massachusetts Institute of Technology  
United States of America
- GOLLIER, Christian**  
University of Toulouse  
France, Belgium
- GREENE, David L.**  
Oak Ridge National Laboratory  
National Transport Research Center  
United States of America
- GREGORY, Robert**  
Golder Associates (UK) Ltd.  
United Kingdom
- GRUBB, Michael**  
Carbon Trust /Cambridge University/  
Imperial College London  
United Kingdom
- GRÜBLER, Arnulf**  
International Institute for Applied  
Systems Analysis/Yale University  
Austria
- GULLISON, Raymond E.**  
Hardner & Gullison Associates, LLC  
Canada
- GUPTA, Joyeeta**  
Institute for Environmental  
Studies, Free University  
The Netherlands
- GUPTA, Sujata**  
Asian Development Bank  
Philippines, India
- GWARY, Daniel**  
University of Maiduguri  
Nigeria
- HA DUONG, Minh**  
Cired, Centre National de la  
Recherche Scientifique  
France
- HAITES, Erik**  
Margaree Consultants Inc.  
Canada
- HALSNÆS, Kirsten**  
Risø National Laboratory, Technical  
University of Denmark  
Denmark
- HANAOKA, Tatsuya**  
National Institute for Environmental Studies  
Japan
- HARE, Bill**  
Potsdam Institute for Climate  
Impact Research  
Germany, Australia
- HARNISCH, Jochen**  
Ecofys  
Germany
- HARRIS, Jeffrey**  
Alliance to Save Energy  
United States of America
- HARVEY, Danny**  
University of Toronto  
Canada
- HASHIMOTO, Seiji**  
National Institute for Environmental Studies  
Japan
- HATA, Hiroshi**  
Railway Technical Research Institute  
Japan
- HAVES, Philip**  
Lawrence Berkeley National Laboratory  
United States of America, United Kingdom
- HAWKINS, David**  
Natural Resources Defence Council  
United States of America
- HAYAMI, Hitoshi**  
Keio University  
Japan
- HEGGEDAL, Tom-Reiel**  
Statistics Norway  
Norway
- HEIJ, BertJan**  
The Netherlands
- HELLER, Thomas C.**  
Stanford University  
United States of America



- HIGUCHI, Niro**  
National Institute for Research  
in the Amazon  
Brazil
- HOHMEYER, Olav**  
University of Flensburg  
Germany
- HÖHNE, Niklas**  
Ecofys  
Germany
- HOOGWIJK, Monique**  
Ecofys  
The Netherlands
- HOURCADE, Jean-Charles**  
Cired, Centre National de la  
Recherche Scientifique  
France
- HOWDEN, S. Mark**  
CSIRO Sustainable Ecosystems  
Australia
- IBITOYE, Francis I.**  
Centre for Energy Research  
and Development  
Nigeria
- IVANOVA BONCHEVA, Antonina**  
Autonomous University of  
Southern Baja California  
México
- JANZEN, H. Henry**  
Agriculture and Agri-Food Canada  
Canada
- JEPMA, Catrinus J.**  
University of Groningen  
The Netherlands
- JIANG, Kejun**  
Energy Research Institute  
P.R. China
- JOBAGY, Esteban**  
Universidad Nacional de San  
Luis & CONICET  
Argentina
- JOCHER, Eberhard**  
Fraunhofer Institute for Systems  
and Innovation Research  
Germany
- JOOSEN, Suzanne**  
Ecofys  
The Netherlands
- KAHN RIBEIRO, Suzana**  
Federal University of Rio de Janeiro  
Brazil
- KAINUMA, Mikiko**  
National Institute for Environmental Studies  
Japan
- KANOAN, Gorashi Mohammed**  
University of Nizwa  
Sultanate of Oman, Sudan
- KARJALAINEN, Timo**  
Finnish Forest Research Institute  
Finland
- KHESHGI, Haroon**  
ExxonMobil Research and  
Engineering Company  
United States of America
- KJELDSEN, Peter**  
Technical University of Denmark  
Denmark
- KOBAYASHI, Shigeki**  
Toyota Central R&D Labs, Inc  
Japan
- KOLSTAD, Charles**  
University of California, Santa Barbara,  
Dept of Economics & Bren School  
United States of America
- KONAR, Manaswita**  
Global Change Programme,  
Jadavpur University  
India
- KONSTANTINAVICIUTE, Inga**  
Lithuanian Energy Institute  
Lithuania
- KRANKINA, Olga**  
Oregon State University  
Department of Forest Science  
United States of America, Russia
- KRUGER, Joseph A.**  
National Commission on Energy Policy  
United States of America
- KUIJPERS, Lambert**  
Technical University Eindhoven  
The Netherlands
- KUMAR, Pushpam**  
University of Liverpool  
UK, India
- KURZ, Werner A.**  
Natural Resources Canada,  
Canadian Forest Service  
Canada
- KVERNDOKK, Snorre**  
Ragnar Frisch Centre for  
Economic Research  
Norway
- LA ROVERE, Emilio Lèbre**  
Federal University of Rio de Janeiro  
Brazil
- LANG, Siwei**  
China Academy of Building Research  
P.R. China
- LARSEN, Hans**  
Risø National Laboratory, Technical  
University of Denmark  
Denmark
- LATHAM, John**  
University Corporation for  
Atmospheric Research  
United States of America
- LECOCQ, Franck**  
Laboratory of Forestry Economics,  
INRA-AgroParisTech (ENGREF)  
France
- LEE, David S.**  
Manchester Metropolitan University  
United Kingdom
- LEE, Hoesung**  
Council on Energy and Environment  
Korea/Keimyung University  
Korea
- LEFEVRE, Nicolas**  
International Energy Agency  
France, United States of America
- LEVERMORE, Geoffrey J.**  
The University of Manchester  
United Kingdom
- LEVINE, Mark D.**  
Lawrence Berkeley National Laboratory  
United States of America
- LLANES-REGUEIRO, Juan F.**  
Havana University, Centre for  
Environmental Studies  
Cuba
- MALONE, Elizabeth L.**  
Joint Global Change Research Institute  
United States of America
- MARECKOVA, Katarina**  
Umweltbundesamt  
Austria, Slovakia
- MARKANDYA, Anil**  
University of Bath/FEEM  
Italy, United Kingdom
- MARTINO, Daniel L.**  
Carbosur  
Uruguay
- MARTINOT, Eric**  
Tsinghua University  
P.R. China, United States of America
- MASERA, Omar**  
Centro de Investigaciones en  
Ecosistemas, UNAM  
México, Argentina
- MASTRANDREA, Michael D.**  
Stanford University  
United States of America
- MATSUHASI, Ryuji**  
Tokyo University  
Japan
- MATSUMOTO, Mitsuo**  
Forestry and Forest Products  
Research Institute  
Japan
- MATSUOKA, Yuzuru**  
Kyoto University  
Japan
- MATYSEK, Anna**  
CRA International  
Australia

- McALLISTER, Tim**  
Agriculture and Agri-Food Canada  
Canada
- McCARL, Bruce**  
Texas A&M University  
United States of America
- McFARLAND, Mack**  
DuPont Fluoroproducts  
United States of America
- MEHLWANA, Monga**  
CSIR, Natural Resources  
and the Environment  
South Africa
- METZ, Bert**  
Netherlands Environmental  
Assessment Agency  
The Netherlands
- MEYER, Leo**  
Netherlands Environmental  
Assessment Agency  
The Netherlands
- MICHALOWA, Axel**  
University of Zurich  
Switzerland, Germany
- MINER, Reid**  
NCASI  
United States of America
- MIRASGEDIS, Sevastian**  
National Observatory of Athens  
Greece
- MOEZZI, Mithra**  
HELIO International  
United States of America
- MONNI, Suvi**  
Benviroc Ltd  
Finland
- MOOMAW, William**  
US The Fletcher School of Law and  
Diplomacy Tufts University  
United States of America
- MOREIRA, Jose Roberto**  
National Reference Center on  
Biomass, Institute of Electr.&  
Energy, Univ. of Sao Paulo  
Brazil
- MUNASINGHE, Mohan**  
Munasinghe Institute for Development  
Sri Lanka
- MURASE, Shinya**  
Faculty of Law, Sophia University, Tokyo  
Japan
- MUROMACHI, Yasunori**  
Tokyo Institute of Technology  
Japan
- NABUURS, Gert-Jan**  
Alterra  
The Netherlands
- NAJAM, Adil**  
Boston University Center for Energy  
and Environmental Studies  
United States of America, Pakistan
- NAKICENOVIC, Nebojsa**  
International Institute for Applied Systems  
Analysis/Vienna University of Technology  
Austria, Montenegro
- NEWTON, Peter J.**  
Dept. for Business, Enterprise  
and Regulatory Reform  
United Kingdom
- NIKITINA, Elena**  
Russian Academy of Science Inst.of  
World Economy and Int. Relations  
Russia
- NIMIR, Hassan B.**  
University of Khartoum, Dept.  
of Petroleum Engineering  
Sudan
- NOVIKOVA, Aleksandra**  
Central European University  
Hungary, Russia
- ODINGO, Richard**  
University of Nairobi  
Kenya
- OGLE, Stephen**  
Colorado State University  
United States of America
- OKAZAKI, Teruo**  
Nippon Steel Corporation  
Japan
- OLIVIER, Jos G.J.**  
Netherlands Environmental  
Assessment Agency  
The Netherlands
- O'MARA, Frank P.**  
University College Dublin  
Ireland
- O'NEILL, Brian**  
International Institute for  
Applied Systems Analysis  
Austria, United States of America
- OPSCHOOR, Hans (J.B.)**  
Insitute of Social Studies/Free University  
The Netherlands
- OYHANTÇABAL, Walter**  
Minstry of Livestock, Agriculture  
and Fisheries. Uruguay  
Uruguay
- PAN, Genxing**  
Nanjing Agricultural University  
P.R. China
- PAN, Jiahua**  
USDA Forest Service  
P.R. China
- PERSHING, Jonathan**  
World Resources Institute  
United States of America
- PETSCHEL-HELDT, Gerhard**  
Germany
- PICHS, Ramon**  
CIEM  
Cuba
- PIPATTI, Riitta**  
Statistics Finland  
Finland
- PITCHER, Hugh M.**  
Joint Global Change Research Institute  
United States of America
- PIZER, William A.**  
Resources for the Future  
United States of America
- PLOTKIN, Steven**  
Argonne National Laboratory  
United States of America
- POPP, David**  
The Maxwell School, Syracuse University  
United States of America
- PRICE, Lynn K.**  
Lawrence Berkeley National Laboratory  
United States of America
- RANA, Ashish**  
Reliance Industries Ltd.  
India
- RAO, Shilpa**  
International Institute of  
Applied Systems Analysis  
Austria, India
- RAVINDRANATH, N. H.**  
Indian Institute of Science  
India
- RAYNER, Steve**  
James Martin Institute,  
University of Oxford  
United Kingdom, United States of America
- READ, Peter**  
Massey University  
New Zealand
- RIAHI, Keywan**  
International Institute for  
Applied Systems Analysis  
Austria
- RICE, Charles**  
Kansas State University  
United States of America
- RICHELS, Richard G.**  
Electric Power Research Institute  
United States of America
- RILLING, Jacques**  
CSTB Building Research Center  
France
- ROBINSON, John**  
UBC  
Canada
- ROGNER, H-Holger**  
International Atomic Energy Agency  
Austria, Germany

**ROMANENKOV, Vladimir**

All-Russian Institute of Agrochemistry  
named after D.Pryanishnikov  
Russia

**ROSE, Steven K.**

United States Environmental  
Protection Agency  
United States of America

**ROY, Joyashree**

Jadavpur University  
India

**RYPDAL, Kirstin**

CICERO  
Norway

**SAIJO, Tatsuyoshi**

Osaka University  
Japan

**SANDERS, Johan**

Wageningen University and Research Centre  
The Netherlands,

**SÁNZ SÁNCHEZ, María José**

Fundación CEAM  
Spain

**SARI, Agus**

PT Ecoscurities  
Indonesia

**SATHAYE, Jayant**

Lawrence Berkeley National Laboratory  
United States of America

**SCHAEFFER, Roberto**

Federal University of Rio de Janeiro  
Brazil

**SCHLAMADINGER, Bernhard**

Joanneum Research, Graz  
Austria

**SCHLEICHER, Stefan P.**

University of Graz  
Austria

**SCHNEIDER, Uwe A.**

Hamburg University  
Germany

**SCHOCK, Robert**

Lawrence Livermore National  
Laboratory/World Energy Council  
United States of America/United  
Kingdom, United States of America

**SCHOLES, Robert (Bob) J.**

Council for Scientific and  
Industrial Research  
South Africa

**SEKI, Shigetaka**

Ministry of Economy Trade and Industry  
Japan

**SHEINBAUM PARDO, Claudia**

Universidad Nacional Autónoma de México  
México

**SHUKLA, Priyadarshi**

Indian Institute of Management, Ahmedabad  
India

**SILVEIRA SOARES FILHO, Britaldo**

Centro de Sensoriamento Remoto  
Brazil

**SIMS, Ralph E. H.**

Massey University/International  
Energy Agency  
New Zealand

**SIROTENKO, Oleg D.**

All-Russian Research Ins. For  
Agricultural Meteorology  
Russia

**SKJOLSVIK, Kjell Olav**

Marintek  
Norway

**SMITH, Kirk R.**

University of California / Woods  
Hole Research Center  
United States of America

**SMITH, Michael H.**

University of Leeds  
United Kingdom

**SMITH, Peter**

University of Aberdeen  
United Kingdom

**SOHNGEN, Brent**

The Ohio State University  
United States of America

**SOKONA, Youba**

Sahara and Sahel Observatory (OSS) Tunis  
Tunisia, Mali

**SPEHLING, Daniel**

University of California, Davis  
United States of America

**STRENGERS, Bart**

Netherlands Environmental  
Assessment Agency  
The Netherlands

**SUGIYAMA, Taishi**

Central Research Institute of  
Electric Power Industry  
Japan

**SUTAMIHARDJA, R.T.M.**

Ministry of Environment  
Indonesia

**SWART, Rob J.**

Netherlands Environmental  
Assessment Agency  
The Netherlands

**TANAKA, Kanako**

International Energy Agency  
France, Japan

**TIRPAK, Dennis A.**

UNFCCC Secretariat  
France, United States of America

**TORRES-MARTÍNEZ, Julio**

Cuban Observatory for  
Science and Technology  
Cuba

**TOTH, Ferenc L.**

International Atomic Energy Agency/  
Corvinus University of Budapest  
Austria, Hungary

**TOWPRAYOON, Sirintornthep**

KM University  
Thailand

**TRINES, Eveline**

Treeness Consult  
The Netherlands

**TURNER, Clive**

Eskom  
South Africa

**UCHIYAMA, Yohji**

The University of Tsukuba  
Japan

**URGE-VORSATZ, Diana**

Central European University, Dept. of  
Environmental Sciences and Policy  
Hungary

**VAN KOOTEN, G. Cornelis**

University of Victoria  
Canada

**VAN VUUREN, Detlef P.**

Netherlands Environmental  
Assessment Agency  
The Netherlands

**VERBRUGGEN, Aviel**

University of Antwerp  
Belgium

**VILLAVICENCIO, Arturo**

Equador

**VUORI, Seppo**

Technical Research Centre of Finland  
Finland

**WA GITHENDU, Mukiri**

Ministry of Science and Technology  
Kenya

**WAMUKONYA, Njeri**

Division of Policy Development and Law  
Kenya

**WARREN, Rachel**

Tyndall Centre for Climate Change  
Research, School of Environmental  
Sciences, University of East Anglia  
United Kingdom

**WATTENBACH, Martin**

University of Aberdeen  
United Kingdom, Germany

**WEYANT, John**

Stanford University  
United States of America

**WINKLER, Harald**

University of Cape Town  
South Africa

**WIT, Ron**

Stichting Natuur en Milieu/CE  
The Netherlands

**WORRELL, Ernst**

Lawrence Berkeley National  
Laboratory/Ecofys  
The Netherlands

**WYATT, Andrew B.**

University of Sydney  
Australia

**XU, Huaging**

Chinese Academy of Sciences  
P.R. China

**YAMAGUCHI, Mitsune**

The University of Tokyo  
Japan

**YAMAJI, Kenji**

The University of Tokyo  
Japan

**YAMBA, Francis**

University of Zambia  
Zambia

**YANG, Hongwei**

Energy Research Institute  
P.R. China

**YOSHINO, Hiroshi**

Tohoku University  
Japan

**ZHANG, Tianzhu**

Dept. of Environmental Science and  
Engineering, Tsinghua University  
P.R. China

**ZHANG, Xiaoquan**

Chinese Academy of Forestry  
P.R. China

**ZHANG, Xiliang**

Tsinghua University  
P.R. China

**ZHOU, Dadi**

Energy Research Institute  
P.R. China

**ZHOU, Fengqi**

Energy Research Institute of NDRC  
P.R. China

**ZHOU, Peter P.**

EECG Consultants (Pty) Ltd.  
Botswana, Zimbabwe

**ZOU, Ji**

Renmin University of China  
P.R. China

# Annex IV

## Reviewers of the IPCC WGIII Fourth Assessment Report

### Argentina

**Ginzo, Hector**

Ministerio de Relaciones Exteriores,  
Comercio Internacional y Culto

**Pedace, Alberto**

Buenos Aires University

**Taboada, Miguel Angel**

Facultad de Agronomía

### Australia

**Betz, Regina Annette**

University of New South Wales (UNSW)

**Denniss, Tom**

Energetech Australia Pty Ltd

**Edwards, Spencer**

Australian Greenhouse Office

**Enting, Ian**

MASCOS

**Gifford, Roger**

CSIRO

**Jotzo, Frank**

Australian National University

**MacGill, Iain**

University of NSW

**Pezzey, Jack**

Australian National University

**Quiggin, John**

University of Queensland

**Raupach, Michael**

CSIRO Marine and Atmospheric Research

**Trewin, Dennis**

Australian Bureau of Statistics

**Uddin, NOIM**

Macquarie University, Sydney

### Austria

**Amon, Barbara**

Institute of Agricultural Engineering

**Clemens, Torsten**

OMV E&P

**Furukawa, Michinobu**

International Institute for  
Applied Systems Analysis

**Hojesky, Helmut****Klaus, Radunsky**

Umweltbundesamt

**Kolp, Peter**

IIASA

**Ma, Tiejun**

International Institute for  
Applied Systems Analysis

**Manfred, Lexer**

University of Natural Resources and  
Applied Life Sciences, Vienna

**Miketa, Asami**

International Atomic Energy Agency

**Rogner, H-Holger**

IAEA

**Schrattenholzer, Leo**

IIASA

**Shihab-Eldin, Adnan**

OPEC

### Belgium

**Botschek, Peter**

European Chemical Industry Council (Cefic)

**Claude, Lorea**

CEMBUREAU

**Debruxelles, Jean-Pierre**

EUROFER

**Friberg, Lars**

Climate Action Network (CAN) Europe

**Herbst, Stephan**

Toyota Motor Europe

**Kjaer, Christian**

European Wind Energy Association

**Kris, Piessens**

Royal Belgian Institute of Natural Sciences

**Lorea, Claude**

CEMBUREAU, The European  
Cement Industry

**Macey, Kirsten**

Climate Action Network Europe

**Martchek, Kenneth**

Alcoa

**Tulkens, Henry**

Center for Operations Research  
and Econometrics (CORE)

**Van Houte, Frédéric**

Comité Permanent des Industries  
du Verre Européennes

**Van Wesemael, Bas**

Université catholique de Louvain

**Van Ypersele, Jean-Pascal**

Université catholique de Louvain (Belgium)

**Vanderstraeten, Martine****Verbruggen, Aviel**

University of Antwerp

**Wittoeck, Peter**

Belgian Federal Administration

### Bénin

**Guendehou, G. H. Sabin**

Benin Centre for Scientific  
and Technical Research

**Ibouraïma, Yabi**

LECREDE/DGAT/UAC

**Vissin, Expédit Wilfrid**

FLASH/Abomey-Calavi University

### Bolivia

**Halloy, Stephan**

Universidad Mayor de San Andrés

**Trujillo Blanco, Ramiro Juan**

National Programme on Climate Changes

### Brazil

**Barbosa da Silva, Demóstenes**

AES Brazil

**Lima, Magda Aparecida**

Brazilian Agricultural Research  
Corporation - Embrapa

**Machado, Pedro**

Embrapa Rice and Beans

**Moreira, Jose Roberto**

Institute of Electrotechnology and Energy,  
University of Sao Paulo-IEE-USP

**Volpi, Giulio**

WWF International

### Canada

**Drexhage, John**

International Institute for  
Sustainable Development

**Edwards, Patti**  
Environment Canada

**Etcheverry, Jose**  
David Suzuki Foundation

**Gagnon, Luc**  
Hydro-Quebec

**Gilbert, Richard**  
Centre for Sustainable Transportation

**Green, Christopher**  
McGill University

**Harvey, Danny**  
University of Toronto

**Hupe, Jane**  
ICAO - International Civil  
Aviation Organization (UN)

**Hyndman, Richard**  
Canadian Association of  
Petroleum Producers

**Jackson, David**  
McMaster University

**Meadowcroft, James**  
Carleton University

**Mirza, Monirul**  
Adaptation and Impacts Research  
Division (AIRD), Environment Canada

**Nyboer, John**  
Simon Fraser University

**Sheppard, Stephen**  
University of British Columbia

**Stewart, Cohen**  
Environment Canada

**Turk, Eli**  
Canadian Electricity Association (CEA)

## Chile

**Fernando, Farias**  
CONAMA (IPCC Chilean focal point)

**Meza, Francisco**  
Facultad de Agronomia. Pontificia  
Universidad Catolica de Chile

## Costa Rica

**Locatelli, Bruno**  
CIRAD-CATIE

## Cuba

**Diaz Morejon, Cristobal Felix**  
Ministry of Science, Technology  
and the Environment

**Hernández, Gladys Cecilia**  
Centre for World Economy Research

**Llanes-Regueiro, Juan F.**  
Havana University

**Somoza, José**  
National Institute of Economic Research

**Torres-Martinez, Julio**  
Cuban Observatory for  
Science and Technology

## Czech Republic

**Jan, Pretel**  
Climate Change

**Novotny, Vladimir**  
International Lime Association ILA

## Denmark

**Fenhann, Jørgen**  
Risø

**Jesper, Jensen**  
J-Consulting ApS

**Juhler-Kristoffersen, Helle**  
Confederation of Danish Industries

## Estonia

**Ahas, Rein**  
University of Tartu

## European Community

**Lars, Müller**  
Directorate General Environment

## Finland

**Hamalainen, Raimo**  
Helsinki University of Technology

**Käyhkö, Jukka**  
University of Turku

**Melanen, Matti**  
Finnish Environment Institute

**Saari, Mikko**  
Technical Research Centre of Finland VTT

**Savolainen, Ilkka**  
Technical Research Centre of Finland VTT

**Syri, Sanna**  
VTT

## France

**Birol, Fatih**  
International Energy Agency

**Bonduelle, Antoine**  
E&E\_Consultant

**Braathen, Nils-Axel**  
OECD

**Campbell, Nick**  
ARKEMA SA

**Caneill, Jean-Yves**  
Electricité de France

**Cazzola, Pierpaolo**  
IEA

**Ceron, Jean-Paul**  
CRIDEAU/Université de Limoges

**Corfee-Morlot, Jan**  
University College London / OECD

**Czernichowski-Lauriol, Isabelle**  
BRGM

**De T'Serclaes, Philippine**  
International Energy Agency

**Dellero, Nicole**  
Corporate Strategy AREVA

**Gherssi, Frédéric**  
CNRS

**Gielen, Dolf**  
International Energy Agency

**Gordelier, Stanley**  
Nuclear Energy Agency of the OECD

**Gundogdu, Niyazi**  
La Farge Group

**Hallegatte, Stephane**  
Météo-France

**Jacques, Leonardi**  
Institut National de Recherche sur  
les Transports et leur Sécurité

**Karousakis, Katia**  
OECD

**Ladoux, Norbert**  
University of Toulouse and IDEI

**Leonardi, Jacques**  
INRETS - Institut National de Recherche  
sur les Transports et leur Sécurité

**Levina, Ellina**  
OECD

**Marc, Gillet**  
ONERC

**Mocilnikar, Antoine-Tristan**  
Délégué Interministériel au  
Développement Durable

**Muirheid, Ben**  
International Fertilizer Industry  
Association (IFA)

**Paillard, Michel**  
IFREMER

**Perkins, Stephen**  
European Conference of Ministers  
of Transport (ECMT)

**Petit, Michel**  
CGTI

**Philibert, Cédric**  
International Energy Agency

**Poot, Brigitte**  
Total s.a.

**Puig, Daniel**  
United Nations Environment Programme

**Ricketts, Brian**  
International Energy Agency

**Riedacker, Arthur**  
INRA

**Rilling, Jacques**  
CSTB Building Research Center

**Ruffing, Kenneth**  
Non-affiliated

**Sinton, Jonathan**  
International Energy Agency

**Stevens, Candice**  
OECD

**Sukalac, Kristen Elizabeth**  
International Fertilizer Industry  
Association (IFA)

**Taylor, Michael**  
International Energy Agency

**Taylor, Peter**  
International Energy Agency

**Varet, Jacques**  
BRGM-French Geological Survey

**Wickstrom, Johanna**  
World LP Gas Association

## Germany

**Brockhagen, Dietrich**  
Atmosfair gGmbH

**Bruckner, Thomas**  
Technical University of Berlin

**Fuentes, Ursula**  
German Federal Environment Ministry

**Glauner, Reinhold**  
Institute for World Forestry

**Grassl, Hartmut**  
Max Planck Institute for Meteorology

**Hartmut, Grassl**  
Max Planck Institute for Meteorology

**Hein, Joachim**  
BDI - Federation of German Industries

**Jung, Martina**  
Ecofys

**Kemfert, Claudia**  
German Institute for Economic Research

**Kohlhaas, Michael**  
German Institute for Economic Research

**Kriegler, Elmar**  
Potsdam Institute for Climate  
Impact Research

**Kuckshinrichs, Wilhelm**  
Forschungszentrum Juelich GmbH

**Kulesa, Margareta**  
Mainz University of Applied Sciences

**Martin, Janicke**  
Forschungsstelle für Umweltpolitik

**Meyer, Bernd**  
University of Osnabrueck and GWS mbH

**Ott, Hermann E.**  
Wuppertal Institute for Climate,  
Environment and Energy

**Peterson, Sonja**  
Kiel Institute for World Economics

**Pitz-Paal, Robert**  
German Aerospace Centre (DLR)

**Plöger, Friedrich**  
Siemens AG

**Renn, Ortwin Wolfgang**  
Institute for Social Science,  
University of Stuttgart

**Reusswig, Fritz**  
Potsdam Institute for Climate  
Impact Research

**Rothermel, Joerg**  
German Chemical Industry Association

**Schleich, Joachim**  
Fraunhofer Institute Systems  
and Innovation Research

**Schwarze, Reimund**  
DIW Berlin

**Supersberger, Nikolaus**  
Wuppertal Institute for Climate  
Environment and Energy

**Tol, Richard**  
Hamburg University

**Treber, Manfred**  
Germanwatch

**Von Goerne, Gabriela**  
Greenpeace

**Walz, Rainer**  
Fraunhofer Institute Systems  
and Innovation Research

**Weimer-Jehle,**  
Institute for Social Science,  
University of Stuttgart

## Greece

**Georgopoulou, Elena**  
National Observatory of Athens

## Hungary

**Urge-Vorsatz, Diana**  
Central European University

**Zoltán, Somogyi**  
Forest Research Institute

## India

**Chatterjee, Anish**  
Development Alternatives

**Grover, Ravi B**  
Department of Atomic Energy

**Roy, Joyashree**  
Jadavpur University

**Tulkens, Philippe**  
TERI School of Advanced Studies

**Subodh, Sharma**  
Ministry of Environment and Forests

## Ireland

**Finnegan, Pat**  
Grian

**McGovern, Frank**  
Environmental Protection Agency

## Israel

**Deutscher, Guy**  
Tel Aviv University

## Italy

**Caserini, Stefano**  
Politecnico di Milano

**Dragoni, Walter**  
Perugia University

**Romeri, Mario Valentino**  
none - private Italian citizen

## Japan

**Akimoto, Keigo**  
Research Institute of Innovative  
Technology for the Earth (RITE)

**Amano, Akihiro**  
University of Hyogo

**Chiba, Yukihiko**  
Forestry and Forest Products  
Research Institute

**Fujino, Junichi**  
National Institute for Environmental Studies

**Hashimoto, Seiji**  
National Institute for Environmental Studies

**Hirata, Kimiko**  
Kiko Network  
**Hori, Masahiko**  
Japan Automobile Research Institute

**Ichinose, Toshiaki**  
National Institute for Environmental Studies

**Inoue, Takashi**  
Tokyo University of Science

**Ishii, Atsushi**  
Tohoku University

**Itoh, Kiminori**  
Yokohama National University

**Izumi, Yoshito**  
Taiheiyo Cement Corporation

**Kadono, Koji**  
Global Industrial and Social  
Progress Research Institute

**Kaibara, Makoto**  
Matsushita Electric Industrial Co., Ltd.

**Kainuma, Mikiko**  
National Institute for Environmental Studies

**Kanie, Norichika**  
Tokyo Institute of Technology

**Kawase, Reina**  
Kyoto University

**Kiyono, Yoshiyuki**  
Forestry and Forest Products  
Research Institute

**Kobayashi, Noriyuki**  
Nihon University

**Koide, Hitoshi**  
Waseda University

**Komiyama, Ryoichi**  
The Institute of Energy  
Economics, Japan (IEEJ)

**Kosugi, Takanobu**  
Ritsumeikan University

**Maeda, Akira**  
Kyoto University

**Masui, Toshihiko**  
National Institute for Environmental Studies

**Miura, Shuichi**  
Tohoku university of art & design

**Mizuno, Koichi**  
National Institute of Advanced  
Industrial Science and Technology

**Mori, Shunsuke**  
Tokyo University of Science

**Murayama, Shigeo**  
The Federation of Electric  
Power Companies

**Nakakuki, Shinichi**  
Tokyo Electric Power Company

**Nakamaru, Susumu**  
Sun Management Institute

**Nakamura, Takuya**  
Mizuho Information & Research Institute

**Naoto, Hisajima**  
Climate Change Division,  
International Cooperation Bureau

**Nishio, Masahiro**  
Ministry of Economy, Trade and Industry

**Nishioka, Shuzo**  
National Institute for Environmental Studies

**Noriyuki, Kobayashi**

**Okayama, Takayuki**  
Tokyo University of Agriculture  
and Technology

**Omori, Ryota**  
Japan Science and Technology Agency

**Onuma, Eiichi**

**Oshima, Kenichi**  
Ritsumeikan University

**Sano, Fuminori**  
Research Institute of Innovative  
Technology for the Earth

**Seki, Shigetaka**  
METI

**Shimoda, Yoshiyuki**  
Osaka University

**Shirato, Yasuhito**  
Agriculture, Forestry and  
Fisheries Research Council

**Sugiyama, Taishi**  
CRIEPI

**Takenaka**  
Japan Gas Association

**Takeshita, Takayuki**  
The University of Tokyo

**Tonooka, Yutaka**  
Saitama University

**Tonosaki, Mario**  
Forestry and Forest Products  
Research Institute

**Uezono, Masatake**  
Citizens' Alliance for saving the  
Atmosphere and the Earth

**Xue, Ziqiu**  
Research Institute of Innovative  
Technology for the Earth

**Yagi, Kazuyuki**  
National Institute for Agro-  
Environmental Sciences

**Yamaguchi, Mitsutsune**  
Teikyo University

**Yanagisawa, Yukio**  
The University of Tokyo

**Yaoita, Yasuhisa**  
Global Industrial and Social  
Progress Research Institute

**Yoshida, Satoshi**  
Tokyo Gas Company

## Kenya

**Demkine, Volodymyr**  
UNEP

## Korea

**Kang, Yoon-Young**  
Korea Energy Economics Institute

**Noh, Dong-Woon**  
Korea Energy Economics Institute

## Malawi

**Donald Reuben, Kamdonyo**  
Meteorological Services

**Kainja, Samuel**  
Malawi Water Partnership

## Malaysia

**Chow, Kok Kee**  
Malaysian Meteorological Department

## México

**Aguayo, Francisco**  
El Colegio de México

**Gasca, Jorge**  
Mexican Petroleum Institute

**Romero Lankao, Patricia**  
Metropolitan Autonomous  
University, campus Xochimilco

## Morocco

**Senhaji, Fauzi**  
I.A.V. Hassan II (GERERE)

## New Zealand

**Baisden, W. Troy**  
Landcare Research

**Beard, Catherine**  
Greenhouse Policy Coalition (NGO  
representing energy intensive sector)

**Becken, Susanne**  
Landcare Research

**Chapman, Ralph**  
Victoria University of Wellington

**Gray, Vincent**  
Climate Consultant

**Isaacs, Nigel**  
Brnz Ltd



**Law, Cliff**

National Institute of Water and Atmospheric Research

**Maclaren, Piers**

Piers Maclaren & Associates

**Read, Peter**

Massey University

**Walton, Darren**

Opus Central Laboratories

**Nicaragua****Ebinger, Michael**

Atmosphere, Climate, & Environmental Dynamics (EES-2)

**Norway****Aunan, Kristin**

Center for International Climate and Environmental Research-Oslo

**Berntsen, Terje**

CICERO

**Fuglestvedt, Jan**

CICERO

**Gerlagh, Reyer**

Centre for Advanced Study

**Jenssen, Tore**

Yara Hesq

**Kjell, Oren**

Norsk Hydro ASA

**Oren, Kjell**

Norsk Hydro ASA

**Øyvind, Christophersen**

Norwegian Pollution Control Authority

**Schei, Tormod André**

Statkraft AS

**Torvanger, Asbjørn**

CICERO

**Vennemo, Haakon**

ECON

**P. R. China****Chen, Wenying**

Tsinghua University

**Dahe, Qin**

China Meteorological Administration

**Guo, Yuan**

Energy Research Institute, National Development and Reform Commission

**Hongfa, Di**

Tsinghua University

**Junfeng, Li**

Energy Research Institute of National Development and Reform Committee and Secretary General of China Renewable Energy Industry Association.

**Wang, Yanjia**

Tsinghua University

**Wu, Shaohong**

Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences

**Zhao, Yong**

China Huaneng Technical and Economic Research Institute

**Pakistan****Athar, Ghulam Rasul**

Pakistan Atomic Energy Commission

**Latif, Muhammad**

Pakistan Atomic Energy Commission

**Shahzad, Iqbal**

National Conservation Strategy (NCS) Unit

**Peru****Bartra, Valentin**

Instituto Andino y Amazónico de Derecho Ambiental

**Philippines****Guha, Ajay**

Asian Development Bank

**Poland****Zyrina, Olga**

MCPFE, LU Warsaw

**Russia****Shmakin, Andrey**

Institute of Geography, Russian Academy of Sciences.

**Saudi Arabia****Al-Fehaid, Mohammed**

Ministry of Petroleum

**Senegal****Thiam, Nogoye**

ENDA-TM

**South Africa****Asamoah, Joe**

International Energy Foundation

**Winkler, Harald**

University of Cape Town

**Spain****Abanades-García, Juan Carlos**

Instituto Nacional del Carbon-CSIC

**Catalan, Jordi****Ciscar, Juan Carlos**

IPTS, European Commission

**Hernández, Félix**

Economía y Geografía. Consejo Superior de Investigaciones Científicas (IEG-CSIC)

**Löschel, Andreas**

European Commission, DG Joint Research Centre, Institute for Prospective Technological Studies

**Pardo Buendía, Mercedes**

Political Science and Sociology Department

**Pedro, Fernández**

Ordenación del Territorio, Urbanismo y Medio Ambiente. ETSI Caminos, Canales y Puertos

**Rafael, Martínez Carrasco**

Instituto de Recursos Naturales y Agrobiología de Salamanca

**Russ, Peter**

IPTS, Joint Research Centre, European Commission

**Sanz Sanchez, M.J.**

Fundación CEAM

**Yábar Sterling, Ana**

Institute of Environmental Studies

**Sri Lanka****Munasinghe, Mohan**

Munasinghe Institute for Development (MIND)

**Sweden****Berndes, Göran**

Chalmers University of Technology

**Berntsson, Thore**

Chalmers

**Mattias, Lundblad**

Climate Unit

**Möllersten, Kenneth**

Swedish Energy Agency

**Sterner, Thomas**

Univ of Göteborg

**Switzerland****Aebischer, Bernard**

CEPE/ETHZ

**Baranzini, Andrea**  
Geneva School of Business Administration

**Barreto, Leonardo**  
Paul Scherrer Institute

**Hardeman, Andreas**  
International Air Transport Association

**Koch, Lorenz**  
World Business Council for Sustainable  
Development (WBCSD)

**Kreuzer, Michael**  
Institute of Animal Science, Swiss  
Federal Institute of Technology (ETH)

**Marcu, Andrei**  
IETA

**Mazzotti, Marco**  
Institute of Process Engineering

**Michael, Kreuzer**  
Institute of Animal Science

**Romero, Jose**  
Federal Office for the Environment

## The Netherlands

**Annema, Jan-Anne**  
Ministerie V & W

**Beerkens, Ruud**  
TNO Science & Industry

**Berk, Marcel**  
Netherlands Environmental  
Assessment Agency

**Bosch, Peter**  
IPCC TSU WGIII

**Brinkman, Sander**  
TSU WG III / Brinkman Climate Change

**Brok, Paul**  
National Aerospace Laboratory NLR

**Bruggink, Jos J.C.**  
Energy Research Centre of  
the Netherlands ECN

**Dave, Rutu**  
IPCC WGIII TSU

**De Coninck, Heleen**  
Energy Research Centre of  
the Netherlands ECN

**De Gans, Gert**  
Kerkinactie

**De Lange, Theo J.**  
Energy Research Centre of  
the Netherlands ECN

**De Wilde, Hein**  
Energy Research Centre of  
the Netherlands ECN

**Den Elzen, Michel**  
Netherlands Environmental  
Assessment Agency

**Eerens, Hans**  
Netherlands Environmental  
Assessment Agency

**Elbersen, Berien**  
WUR-Alterra

**Elbersen, Wolter**  
Agrotechnology and Food  
Sciences Groep of WUR

**Faber, Albert**  
Netherlands Environmental  
Assessment Agency

**Fiechter, Wilco**  
Nederlandse Spoorwegen (Dutch Railways)

**Groenenberg, Heleen**  
Energy Research Centre of  
the Netherlands ECN

**Gunning, Jan Willem**  
Free University, Amsterdam

**Hoogwijk, Monique**  
Ecofys

**Hutjes, Ronald**  
Alterra

**Jansen, Daniel**  
Energy Research Institute of  
the Netherlands ECN

**Jeeninga, Harm**  
Energy Research Institute of  
the Netherlands ECN

**Kemp, Rene**  
Erasmus University

**Kessels, John**  
Energy Research Institute of  
the Netherlands ECN

**Kok, Marcel T.J.**  
Netherlands Environmental  
Assessment Agency

**Kornelis, Blok**  
Ecofys

**Kram, Tom**  
Netherlands Environmental  
Assessment Agency

**Kruijt, Bart**  
Alterra

**Kuikman, Peter**  
Alterra

**Labohm, Hans H.J.**  
Consultant

**Metz, Bert**  
IPCC WGIII

**Misdorp, Robbert**  
Ministry of Transport and Public Works

**Olivier, Jos**  
Netherlands Environmental  
Assessment Agency

**Oonk, Hans**  
TNO

**Pols, Donald**  
Friends of the Earth Netherlands/  
Milieudefensie

**Ren, Tao**  
Utrecht University

**Ronald, Flipphi**  
Dutch Ministry of the  
Environment (VROM)

**Rothman, Jan**  
Erasmus University

**Ruijgrok, Walter**  
EnergieNed

**Sawyer, Steve**  
Greenpeace International

**Schyns, Vianney**  
DSM and SABIC

**Seebregts, Ad**  
Energy Research Institute of  
the Netherlands ECN

**Sijm, Jos**  
Energy Research Institute of  
the Netherlands ECN

**Sinke, Wim**  
Energy Research Institute of  
the Netherlands ECN

**Skutsch, Margaret**  
University of Twente

**Smulders, Sjak**  
Tilburg University

**Stead, Dominic**  
Delft University of Technology

**Stevens, Arjette**  
Natuur en Milieu

**Storm van Leeuwen, Jan Willem**  
Ceedata Consultants

**Swart, Rob**  
Netherlands Environmental  
Assessment Agency

**Teske, Sven**  
Greenpeace International

**Trines, Eveline**  
Treeness Consult

**Van Bussel, Gerard**  
Section Wind Energy, Faculty LR, TU Delft.

**Van der Meer, Peter**  
Alterra

**Van der Schoor, Tineke**  
Sustainability Centre Lauwersoog/  
RUG-Bedrijfskunde

**van der Zwaan, Bob**  
Energy Research Institute of  
the Netherlands ECN

**Van Soest, Jan Paul**

Advies voor Duurzaamheid on request  
of International Gas Union

**Van Wee, Bert**

Delft University of Technology

**Verhagen, Jan**

Plant Research International,  
Wageningen UR

**Tunisia****Osman, Néjib**

CIEDE/Agence Nationale pour  
la Maîtrise de l'Énergie

**United Kingdom****Ashford, Paul**

Calebgroup

**Awerbuch, Shimon**

SPRU - University of Sussex

**Barker, Terry**

4CMR Centre for Climate  
Change Mitigation Research,  
University of Cambridge

**Chase, Robert**

International Aluminium Institute

**Cinzia, Losenzo**

Global Atmosphere Division

**Cobb, Jonathan**

World Nuclear Association

**Cook, Ian**

United Kingdom Atomic Energy Authority

**Copley, Christine**

World Coal Institute

**Curran, James**

Scottish Environmental Protection Agency

**Dlugolecki, Andrew**

University of East Anglia

**Gardiner, Ann**

AEA Technology

**Green, Richard**

University of Birmingham

**Grubb, Michael**

Carbon Trust/Cambridge University/  
Imperial College London

**Hamilton, Kirsty**

Chatham House/UK Business  
Council for Sustainable Energy

**Hedger, Merylyn**

Environment Agency

**Jefferson, Michael**

World Renewable Energy  
Network & Congresses

**Köhler, Jonathan**

Tyndall Centre, University of Cambridge

**Lawrence, Martin**

Earth & Ocean Carbon Ltd

**McCulloch, Archie**

Marbury Technical Consulting

**Mottershead, Chris**

BP

**Parker, Claire**

Environmental Policy Consultant

**Pearce, Catherine**

Friends of the Earth International

**Phylipsen, Dian**

Ecofys

**Reisinger, Andy**

TSU IPCC Synthesis Report

**Tanner, Thomas**

Institute of Development Studies

**Viner, David**

University of East Anglia

**Warren, Luke**

IPIECA

**Warren, Rachel**

University of East Anglia

**United States of America****Ackerman, Frank**

Global Development and Environment  
Institute, Tufts University

**Anderson, Peter**

Center for a Competitive Waste Industry  
/ RecycleWorlds Consulting Corp

**Arquit Niederberger, Anne**

Policy Solutions

**Baer, Paul**

Stanford University

**Bahor, Brian**

Covanta Energy Corporation

**Baughcum, Steven**

Boeing Company

**Bernstein, Lenny**

L. S. Bernstein & Associates, L.L.C.

**Bero, James**

BASF Corporation

**Blanford, Geoffrey**

Stanford University

**Bogner, Jean**

Landfills +, Inc.

**Bowman, Michael**

GE Global Research

**Boyden, James**

Vulcan Inc.

**Brieno Rankin, Veronica**

CH2M HILL

**Brown, Donald**

Pennsylvania Consortium for  
Interdisciplinary Environmental Policy

**Brown, Sandra**

Winrock International

**Bull, Stan**

National Renewable Energy Laboratory

**Clemmer, Steve**

Union of Concerned Scientists

**Cointreau, Sandra**

World Bank

**Crawford, James**

Trane/American Standard

**Danilin, Michael**

The Boeing Company

**De la Chesnaye, Francisco**

USEPA

**Delhotel, Katherine Casey**

Research Triangle Institute

**Diaz, Luis**

CalRecovery, Inc.

**Doctor, Richard**

Argonne National Laboratory

**Dooley, James**

Battelle

**Emerson, Sarah**

Energy Security Analysis, Inc

**Epstein, Paul**

Harvard Medical School

**Freedman, Steven**

Energy Consultant

**Fuessel, Hans-Martin**

Stanford University

**Gallagher, Kelly Sims**

Harvard University

**Ghosh, Debyani**

Global Energy Partners, LLC

**Golay, Michael**

MIT

**Goldston, Robert**

Princeton Plasma Physics Laboratory

**Golub, Alexander**

Environmental Defense

**Heil, Mark**

U.S. Environmental Protection Agency

**John Oliver, Niles**

Tropical Forest Group

**Jones, Russell**

American Petroleum Institute

**Kheshgi, Haroon**

ExxonMobil Research and  
Engineering Company

**Kirilenko, Andrei**

University of North Dakota

**Klages-Buechner, Sabine**

E.I. du Pont de Nemours and Company

**Kruger, Dina**

Environmental Protection Agency

**Larson, Robert**

US Environmental Protection Agency

**Lee, Arthur**

Chevron Corporation

**Lewis, Joanna**

Pew Center on Global Climate Change

**Lynd, Lee**

Dartmouth College

**Malone, Elizabeth L**

Pacific Northwest National Laboratory

**Mark, Jason**

Union of Concerned Scientists

**Marks, Jerry**

International Aluminium Institute/J  
Marks & Associates

**Maurice, Lourdes**

US Government

**Michaels, Patrick**

University of Virginia and Cato Insitute

**Miller, Alan**

International Finance Corporation

**Miner, Reid**

NCASI

**Montgomery, David**

CRA International

**Murray, Brian**

Center for Regulatory Economics  
and Policy Research

**Niles, John**

Coalition for Rainforest Nations

**Nissen, David**

Columbia University

**Park, Jacob**

Green Mountain College

**Pizer, William**

Resources for the Future

**Price, Jeff**

California State University, Chico

**Price, Lynn**

Lawrence Berkeley National Laboratory

**Ragland, Jim**

Aramco Services Company

**Raskin, Paul**

Tellus Institute

**Rose, Steven**

US-EPA

**Rosenberg, Norman**

**Rubin, Edward**

Carnegie Mellon University

**Sprinz, Detlef**

The University of Michigan

**Trigg, Talley**

U.S. Department of State

**Widge, Vikram**

International Finance Corporation

**Zambia**

**Yamba, Francis**

University of Zambia

**Zimbabwe**

**Nziramasanga, Norbert**

Southern centre for Energy and Environment