Working Group III contribution to the
Intergovernmental Panel on Climate Change
Fourth Assessment Report

Climate Change 2007: Mitigation of Climate Change

Summary for Policy Makers

Note: The content of this Draft should not be cited or quoted, and is embargoed from news coverage

Drafting Authors:
Terry Barker (UK), Igor Bashmakov (Russia), Lenny Bernstein (USA), Jean Bogner (USA),
Peter Bosch (The Netherlands), Rutu Dave (The Netherlands), Ogunlade Davidson (Sierra Leone),
Brian Fisher (Australia), Michael Grubb (UK), Sujata Gupta (India), Kirsten Halsnaes (Denmark),
Bertjan Heij (The Netherlands), Suzana Kahn Ribeiro (Brazil), Shigeki Kobayashi (Japan),
Mark Levine (USA), Daniel Martino (Uruguay), Omar Masera Cerutti (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), Priyaradshi Shukla (India), Ralph Sims (New Zealand),
Pete Smith (UK), Rob Swart (The Netherlands), Dennis Tirpak (USA),
Diana Urge-Vorsatz (Hungary), Zhou Dadi (People's Republic of China)

Contents

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_2 Capture and Storage (SRCCS) and on Safeguarding the Ozone Layer and the Global Climate System (SROC).

The following summary is organised into five sections after this introduction:
- Greenhouse gas (GHG) emission trends
- Mitigation in the short and medium term, at sector level (till 2030)
- Mitigation in the long-term context (beyond 2030)
- Policies, measures and instruments
- Sustainable development and climate change mitigation.

Standard terms used to describe the uncertainty of the statements made, according to the agreed terminology for the AR4, can be found in Annex 1. References to the corresponding chapter sections are indicated at each paragraph in square brackets. An explanation of terms and acronyms used in this SPM can be found in the glossary to the main report.

B. Greenhouse gas emission trends

2. Without additional climate mitigation and/or appropriate sustainable development policies global GHG emissions will continue to grow over the next few decades. *(high agreement, much evidence)*
- Between 1970 and 2004 global GWP weighted emissions of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 (greenhouse gases covered by the Kyoto Protocol) have increased by 70% (24% since 1990). CO_2, being by far the largest source, has grown by about 80% (28% since 1990) (Figure SPM.1). This has occurred because increases in income per capita and population have outweighed decreases in energy intensity of production and consumption (Figure SPM.2). [1.3]
- Policies, including those on climate change, energy security and supply, and sustainable development, have led to reductions of emissions compared to the baseline in some regions, but the scale is not large enough to be visible in the historic global emissions trend. [1.3, 12.2]
- In 2004 developed countries (UNFCCC Annex I countries) held a 20% share in world population and yet accounted for 46% of annual GHG emissions (Figure SPM.3a). Their economies have a lower average GHG intensity (0.68 kg CO_2-eq/US$ GDPppp) than those of non-Annex-I countries (1.06 kg CO_2-eq/US$ GDPppp) (Figure SPM.3b). [1.3]
- Without additional policies global GHG emissions are projected to increase with 25-90% by 2030 relative to 2000. Fossil fuel dominance is expected to continue to 2030 and beyond, hence CO_2 emissions from energy use are projected to grow with 40-110% over that period. (Figure SPM.4) Two thirds to three quarters of this increase is projected to come from developing countries, though their average per capita CO_2 emissions will remain substantially lower (2.8-5.1 tCO_2/cap) than those in developed country regions (9.6- 15.1 tCO_2/cap). Since 2000 carbon intensity of energy has been on the rise due to increased use of coal. [1.3]

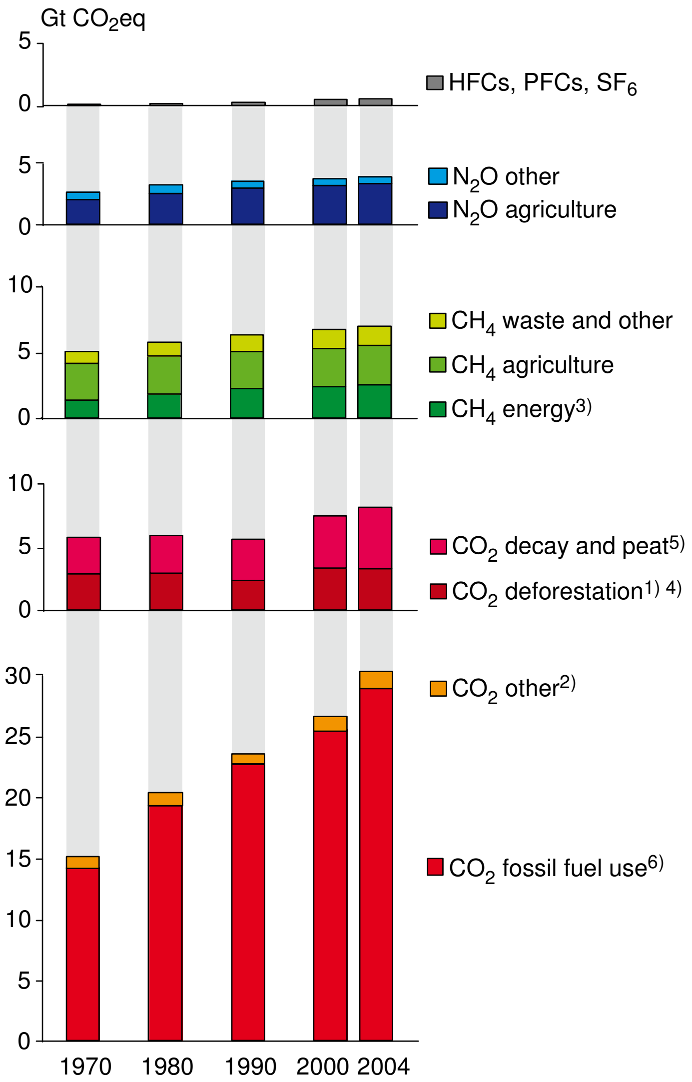


Figure SPM 1: *GWP weighted global greenhouse gas emissions 1970-2004. 100 year GWPs from IPCC 1996 (SAR) were used to convert emissions to CO_2-eq. (cf. UNFCCC reporting guidelines). CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 from all sources are included*

Sources: various, see Chapter 1, Figure 1.1.

Notes:

1. *Including traditional biomass combustion at 10% (assuming 90% sustainable production). Corrected for 10% carbon of burned biomass that remains as charcoal.*
2. *Cement production and natural gas flaring.*
3. *Including from biofuel production and biomass use.*
4. *For large-scale forest and scrubland biomass burning averaged data for 1997-2002 based on Global Fire Emissions Data base satellite data.*
5. *CO_2 emissions from decay (decomposition) of aboveground biomass that remains after logging and deforestation and CO_2 from peat fires and decay of drained peat soils (excluding fossil fuel fires).*
6. *Fossil fuel use includes emissions from feedstocks.*

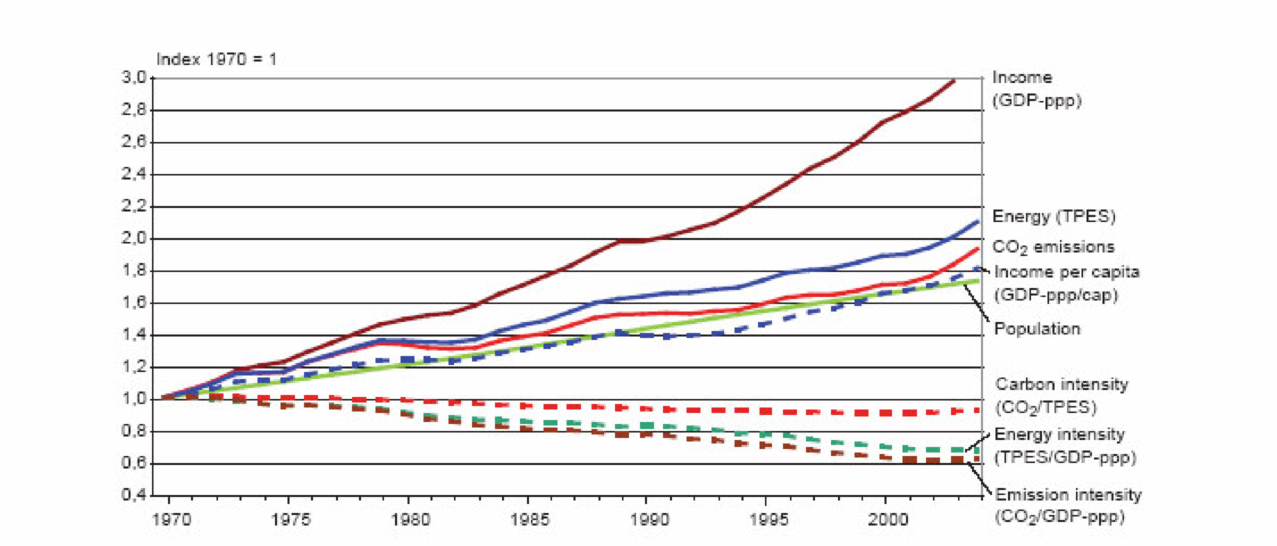
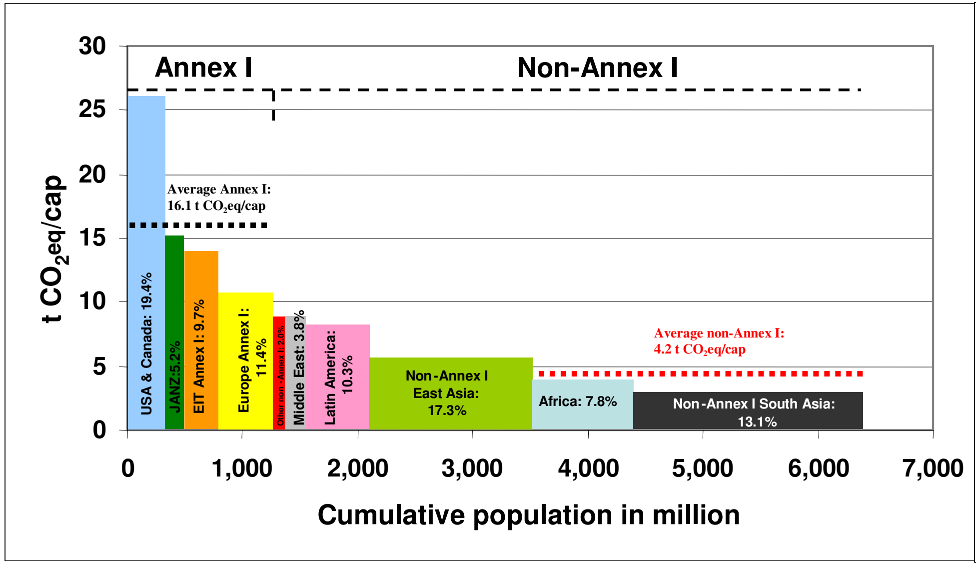


***Figure SPM 2**: Relative development of Gross Domestic Product (GDP) and GDP per capita (GDP/Pop,) measured in PPP (Purchase Power Parity), Population (Pop), Energy Intensity (energy use per GDP), Carbon Intensity (CO_2/energy use), and CO_2 emissions (from fossil fuel burning, gas flaring and cement manufacturing) for the period 1970-2004*

Sources: World Bank, 2005; Marland et al., 2006.



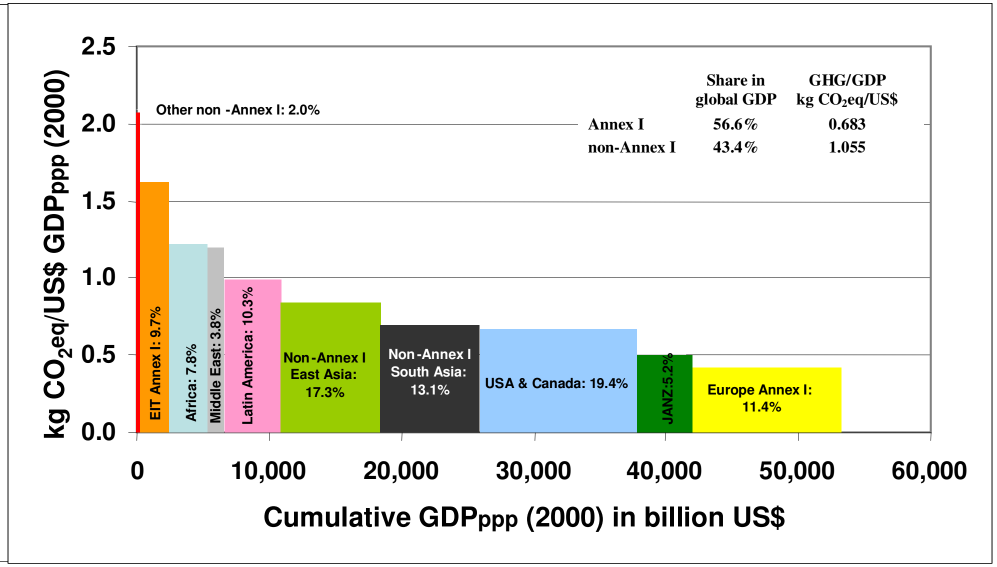


***Figure SPM 3a:** Distribution of regional per capita GHG) emissions (all Kyoto gases) over the population of different country groupings in 2004 (adapted from Bolin and Kheshgi, 2001) using IEA and EDGAR 3.2 database information. 100 year GWPs from IPCC 1996 (SAR) were used to convert emissions to CO_2-eq. (cf. UNFCCC reporting guidelines)*

***Figure SPM 3b:** Distribution of regional GHG emissions (all Kyoto gases) per US$ of GDPppp over the GDP of different country groupings in 2004 using IEA and EDGAR 3.2 database information. 100 year GWPs from IPCC 1996 (SAR) were used to convert emissions to CO_2-eq. (cf. UNFCCC reporting guidelines)*

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. The country groupings are:

- ***EIT Annex I**: Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Russian Federation, Slovakia, Slovenia, Ukraine.*
- ***Europe Annex II**: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom.*
- ***JANZ:** Australia, Japan, New Zealand.*
- ***Non-Annex I East Asia:** Cambodia, China, Hong Kong, Korea (DPR), Laos (PDR), Mongolia, Republic of Korea, Viet Nam.*
- ***Non-Annex I South Asia:** Afghanistan, Bangladesh, Bhutan, Brunei, Fiji, French Polynesia, India, Indonesia, Kiribati, Malaysia, Maldives, Myanmar, Nepal, New Caledonia, Pakistan, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Vanuatu*
- ***North America:** Canada, United States of America.*
- ***Other non-Annex I**: Albania, Armenia, Azerbaijan, Bosnia Herzegovina, Cyprus, Georgia, Gibraltar, Kazakhstan, Kyrgugyzstan, Malta, Moldova, Serbia, Montenegro, Tajikistan, Turkmenistan, Uzbekistan, Republic of Macedonia.*

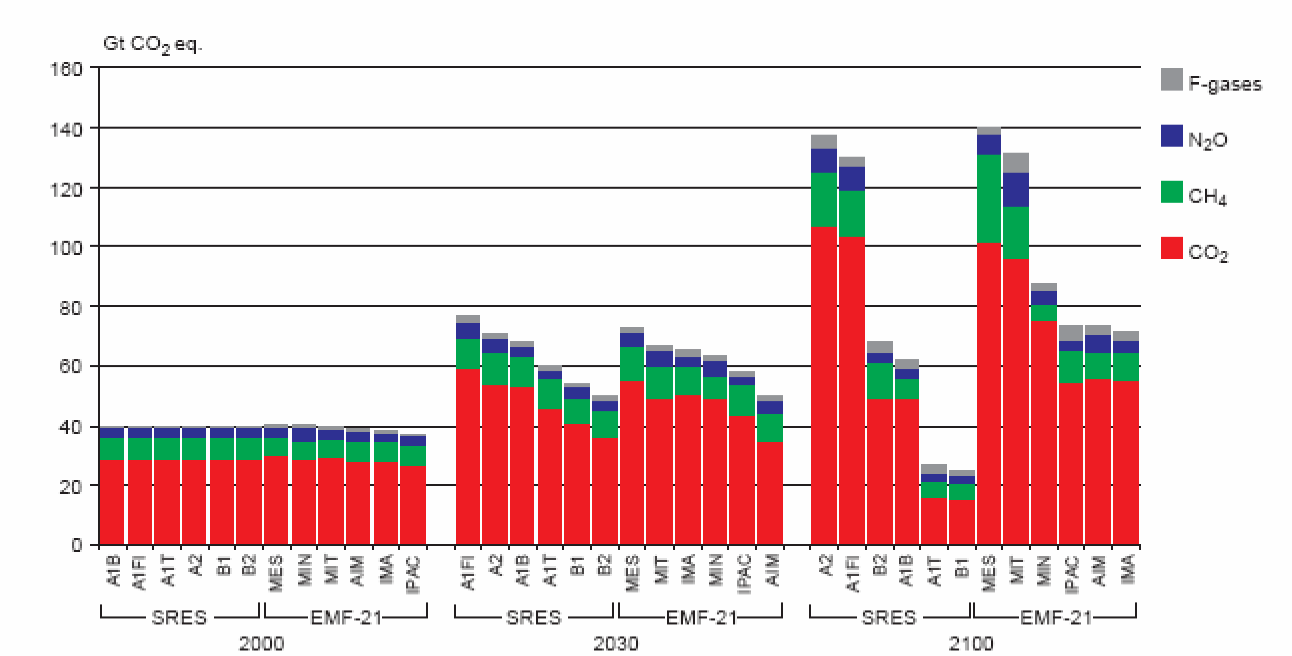


Figure SPM 4: *GHG emission projections 2000-2100 from IPCC SRES and EMF 21. This figure does not show the full range of scenario results since SRES that is covered in chapter 3.2. F-gases include HFCs, PFCs and SF6.*
Source: IPCC, 2000 and Weyant et al., 200.6

3. **GHG emissions ranges derived from long-term baseline scenarios[1] have not changed appreciably compared with the Special Report on Emission Scenarios (SRES) (25- 135 Gt CO_2-eq/yr in 2100, see Figure SPM.4).** *(high agreement, much evidence)*
   - Studies since TAR 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 scenarios are lower than in SRES, but this has only minor effects on global economic growth and overall emissions. [3.2]
   - Aerosol and aerosol precursor emissions, which have a net cooling effect, are projected to be lower than reported in SRES. [3.2]
   - Evidence from the limited number of new Purchasing Power Parity (PPP) based studies indicates that the choice of metric for GDP (Market exchange rates or PPP) does not appreciably affect the projected emissions, when metrics are used consistently. The differences, if any, are small compared to the uncertainties caused by assumptions on other parameters, e.g. technological change. [3.2]

[1] Baselines do not include additional climate policies above current ones.

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

Box SPM 1: *Mitigation potential*

Economic potential, as used in most studies, is 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. [2.5]

Market potential, as used in most studies, is the actual potential with current conditions and barriers, based on private cost pricing and discount rates, including energy savings, but with barriers limiting actual uptake. [2.5]

Estimates for the economic potential can be derived from bottom-up studies or top-down studies. ***Bottom-up studies*** are based on assessment of specific mitigation options, covering all sectors, but corrected to avoid double-counting. Non-technical mitigation options, such as life style changes are not included. The aggregation of bottom-up analyses at sectoral and global level is hindered by the lack of harmonization and the lack of full geographic coverage. ***Top-down studies*** have limited sectoral and technological detail, but do include the macro economic and systems feedbacks that bottom-up studies lack. Aggregate economic potential estimates from bottom-up and top down are similar, but sector estimates show differences. [3.6, 11.3]

4. There is a significant economic potential for the mitigation of greenhouse gas emissions from all sectors over the coming decades, sufficient to offset growth of global emissions or to reduce emissions below current levels. *(high agreement, medium evidence)*

- In 2030 the economic potential ranges from 9-18 Gt CO_2-eq/yr[2] relative to a medium emission baseline[3] at carbon prices lower than 20 US$/t CO_2-eq (15-30% below baseline) to 16-30 Gt CO_2-eq/yr at carbon prices lower than 100 US$/t$CO_2$-eq (30-50% below baseline) (see figure SPM.5). [11.3]
- The most important mitigation technologies for the respective sectors are shown in table SPM.1. Sector contributions and the regional distribution of mitigation potential, as derived from bottom-up studies, are given in figure SPM 6. [4.3, 4.4, 5.4, 6.5, 7.5, 8.4, 9.4, 10.4, 11.3]
- From bottom-up studies a range of around 6 Gt CO_2-eq/yr at net negative costs has been identified. [11.3]
- The economic potential up to 50 US$/t$CO_2$ is consistent with emission trajectories for stabilisation around 550 ppmv CO_2-eq and that up to US$ 100/tCO_2-eq for stabilisation between 450 and 550 ppmv CO_2-eq. [3.3, 3.6, 11.3]
- The market potential is much smaller than the economic potential. A mix of policy instruments (see section E) can bridge the gap between market and economic potential. [2.5, 11.3]

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[2] This range represents the results from bottom-up and top-down studies

[3] For the assessment of mitigation potential each sector assessment used a mixture of baselines. For comparison with the mitigation potential the sum of the respective baselines is shown in figure SPM.5.For details see TS 11 and chapter 11.3.Top-down models generally used medium baselines The average for those baselines in shown in Figure SPM.5.

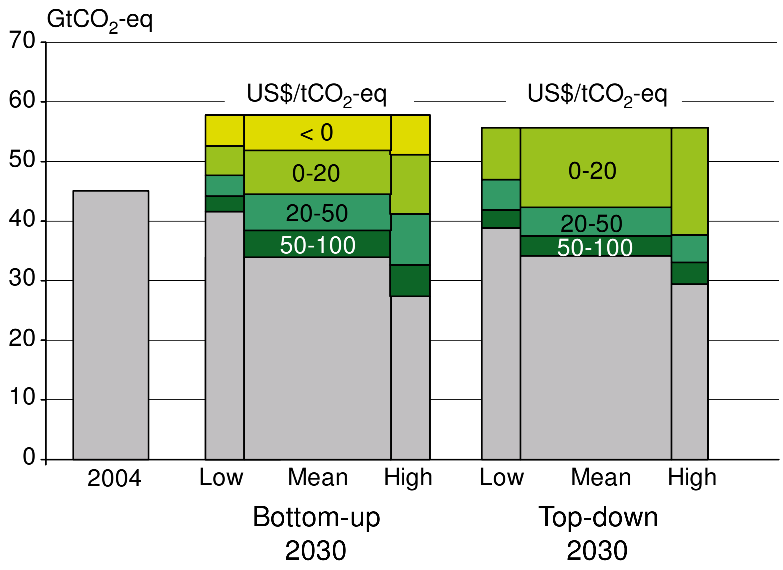

Figure SPM 5: *Economic mitigation potential in different cost categories as compared to the baseline. For the 2030 bottom-up results the sum of the respective sector baselines, assumed in the calculation of the mitigation potential, was used for comparison. For the top-down studies the average of the baselines reported in Tables 3.13 and 3.14 was used for comparison. The 2004 emissions are from chapter 11.3*

Note: "Mean", "high" and "low" refer to the mean, high and low end of the economic potential range reported.

***Table SPM 1:** Estimated global mitigation potential in 2030 compared to SRES B2 or World Energy Outlook (2004) Baselines and mitigation technologies with significant reduction potential for each sector. Total economic potential for costs <100 US$/t*$CO_2$*-eq is given for end-use sector allocation of emissions*

Sector	**2030 economic potential at carbon prices < US$ 100/t CO_2-eq (Gt CO_2-eq/yr)**	**Mitigation technologies with significant reduction potential currently on the market**	**Mitigation technologies with significant mitigation potential projected to be commercialised before 2030**
Energy Supply [4.3, 4.4, 11.3]	2.4- 4.7	Improved supply and distribution efficiency, combined heat and power, fuel switching from coal to gas, nuclear power, renewable heat and power (hydropower, solar, wind, geothermal and bio energy), early applications of CCS (e.g. natural gas processing).	CCS for gas, biomass or coal-fired electricitygenerating facilities, advanced nuclear power, advanced renewables
Transport [5.4]	1.6- 2.5	More fuel efficient vehicles, hybrid vehicles, cleaner diesel, bio-fuels, rapid public transport systems, non-motorised transport	Hydrogen powered fuel cell vehicles, second generation biofuels, more efficient aircraft, advanced electric and hybrid vehicles with more powerful and reliable batteries.
Buildings [6.5]	5.7- 6.0	Efficient lighting, more effective insulation and ventilation, passive solar design for heating, cooling and ventilation, more efficient electrical appliances and heating and cooling devices, alternative refrigeration fluids, recovery and recycle of fluorinated gases from appliances and insulation	Integrated solar PV electricity, smart metering, intelligent controls
Industry [7.5]	2.5- 5.5	More efficient end-use electrical equipment, heat and power recovery, material recycling and substitution, control of non-CO_2 gas emissions, and a wide array of process-specific technologies	Advanced energy efficiency, CCS for cement, ammonia, fertilizer and steel manufacture, inert electrodes for aluminium manufacture,
Agriculture [8.4]	2.3- 6.4	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_4 emissions; improved nitrogen fertilizer application techniques to reduce N_2O emissions; dedicated bio-energy crops to replace fossil fuel use; improved energy efficiency	Genetic technologies to improve energy crops
Forestry [9.4]	1.3- 4.2	Afforestation, reforestation, forest management, reduced deforestation and degradation, harvested wood product management, use of forestry products for bio-energy to replace fossil fuel use	
Waste [10.4]	0.4-1.0	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_4 oxidation
Total	16.2- 30.3		

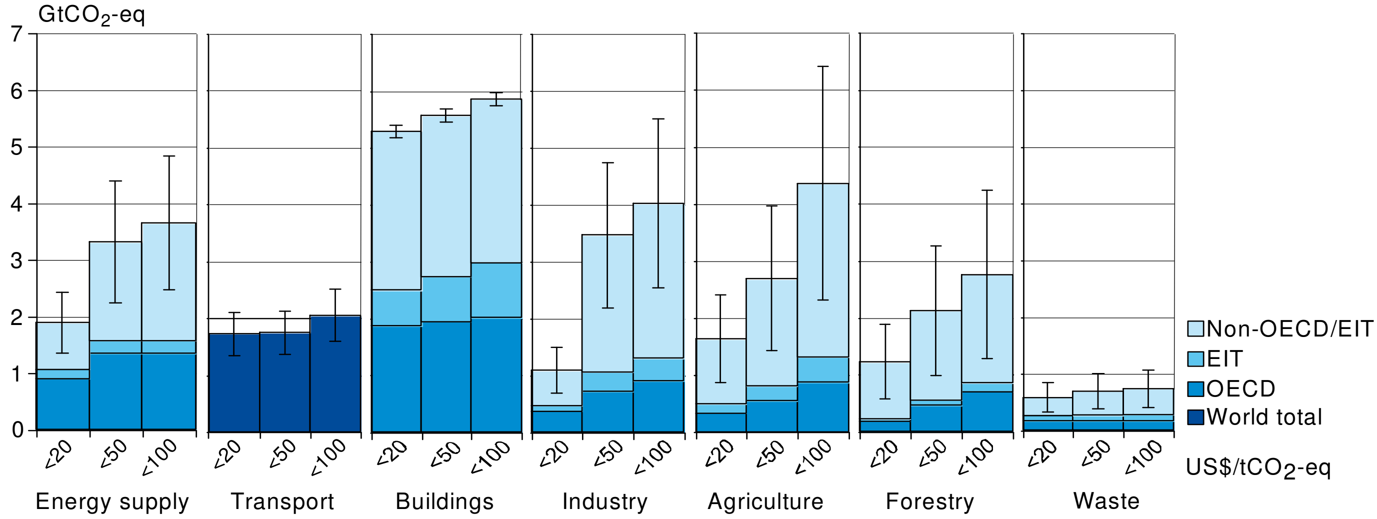

Figure SPM 6: *Estimated mitigation potential at sectoral level in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments (see notes)*

Notes:

1. *Mitigation potentials are calculated for a baseline scenario that is for most sectors close to the SRES B2 baseline. For Industry, the SRES B2 baseline was taken; for Energy supply and Transport the WEO 2004 baseline was used; the building sector constructed a separate baseline in between SRES B2 and A1b;for waste SRES A1bdrivers were used; agriculture and forestry used baselines that mostly used SRES B2 drivers.*
2. *Total figures include only the categories for which data were available. Categories excluded are: non-CO_2 emissions in buildings; part of material efficiency options; heat production and cogeneration in energy supply; heavy duty vehicles, shipping and public transport; most high-cost options for buildings; wastewater treatment. The underestimation of the economic potential due to these omissions is in the order of 10-15% (not included in uncertainty bars).*

5. **In 2030 macro-economic costs for mitigation in the medium term, consistent with emissions trajectories towards stabilisation around 650 ppmv CO_2-eq are 0.2 (-0.6 to 1.2)[4]% global GDP loss[5] compared to the baseline (reduction of the average annual GDP growth rate less than 0.06 percentage points). For trajectories towards 550 ppmv CO_2-eq these costs are 0.6 (0-2.5)% GDP loss in 2030 (reduction of the average annual GDP growth rate less than 0.1 percentage points).** (*high agreement, much evidence)* **(see Box SPM.2 for the caveats of these results)**
   - For trajectories towards stabilisation levels between 445 and 535 ppmv CO_2-eq costs are lower than 3% global GDP loss, but the number of studies is relatively small and they generally use low baselines. [3.3]
   - Costs are lower if revenues from carbon taxes or auctioned permits are used to promote low-carbon technologies or reform of existing taxes. Studies that assume the possibility that climate change policy induces enhanced technological change also give lower costs. [3.3, 11.4, 11.5, 11.6]
   - Some models give positive GDP gains (or negative GDP losses), because they assume that baselines are economically not optimal and that climate change mitigation policies steer economies towards reducing imperfections. [3.3, 11.4]
   - Regional abatement costs are dependent on the assumed emission allowances to regions. However, the assumed stabilisation level and baseline scenario are more important in determining regional costs.[11.4, 13.3]

[4] The median and the 10th to 90th percentile range of the analysed data are given.
[5] This is global GDP based on market exchange rates.

Box SPM 2: 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 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 stabilisation 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.

6. **While studies use different methodologies, in all analyzed world regions near-term health benefits from reduced air pollution as a result of GHG reductions 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 employment, would further enhance cost savings. [11.8]
   - Integrating air pollution abatement and climate change mitigation policies offers potentially large cost reductions compared to treating the policies in isolation. [11.8]

7. **Recent literature confirms the conclusions in TAR on spill over and carbon leakage** *(medium agreement, medium evidence).*
   - Fossil fuel exporting nations (in both Annex I and non-Annex I) may expect, as indicated in TAR, lower demand and prices and lower GDP growth in case of emission abatement policies. The extent of this spill over depends strongly on assumptions related to Annex I policy decisions and oil market conditions. [11.7]
   - Critical uncertainties remain in the assessment of carbon leakage. Most equilibrium modelling support the conclusion in the TAR of economy wide leakage in the order of 5-20%, which would be less if low-emissions technologies are effectively diffused. Findings from sectoral analysis of the effects of the EU Emissions Trading Scheme indicate lower levels of economy wide leakage. [11.7]

8. **New energy supply investments in developing countries, upgrades of energy infrastructure in developed countries, and policies that promote energy security, create opportunities to achieve GHG emission reductions[6], and to provide co-benefits such as air pollution abatement, balance of trade improvement, wealth creation and employment** *(high agreement, much evidence).*
   - Future energy infrastructure investment decisions (projected investment till 2030 is at least 20 trillion US$[7]) will have long term impacts on GHG emissions, because long life-times of energy and other infrastructure capital stock means that widespread diffusion of low-carbon technologies may take many decades. Initial estimates for lower carbon scenarios show a large redirection of investment, with net additional investments ranging from negligible to less than 5%. [4.1, 4.4, 11.6]
   - It is often cheaper to invest in end-use energy efficiency improvement than in increasing energy supply to satisfy energy demand. Efficiency improvement has a positive effect on energy security and employment. [4.2, 4.3, 6.5, 7.7, 11.3, 11.8]
   - Renewable energy can have a positive effect on energy security, employment and on air quality. Given costs relative to other supply options, renewable electricity can have a 30-

[6] See Table SPM.1 and Figure SPM.6.
[7] 20 trillion = 20000 billion= 10^{12}.

35% share of the total electricity supply in 2030 at carbon prices of US$ 20-100/tCO_2-eq. [4.3, 4.4, 11.3, 11.6, 11.8]

- 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. It depends on economic and technical assumptions whether building "CCS ready" plants is more cost-effective than retrofitting plants or building a new plant integrated with CCS. [4.2, 4.3, 4.4]

9. **The higher the prices of fossil fuels, the more low-carbon alternatives will be competitive, although price volatility will be a disincentive for investors. On the other hand, oil sands, oil shales, heavy oils, and synthetic fuels from coal and gas will also become more competitive as transportation fuels, leading to increasing GHG emissions, unless production plants are equipped with CCS** *(high agreement, much evidence).* [4.2, 4.3, 4.4, 4.5]

10. **The growth of transportation emissions is among the highest of all end-use sectors. Mitigation options are faced with many barriers.** *(medium agreement, medium evidence).*

- Improved vehicle efficiency measures to a large extent have net negative costs[8] due to fuel savings (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. Market forces alone, including fuel costs, are therefore not expected to lead to significant emission reductions. [5.3, 5.4]
- Biofuels as gasoline and diesel fuel additives/substitutes are projected to grow to 3% of total transport fuel in the baseline in 2030. For carbon prices of 25 US$/t$CO_2$-eq this could increase to about 10%, which includes only a small contribution by biofuels from cellulosic biomass. [5.3, 5.4]
- Public transport systems and non-motorised transport offer opportunities for greenhouse gas mitigation, depending on local conditions. [5.3, 5.5]
- Without policy intervention, CO_2 emissions from global aviation are expected to rise at around 3-4% per year. Mitigation potential in the medium term is limited to efficiency improvements, which will be insufficient to halt emission growth. [5.3, 5.4]
- Realising emissions reductions in the transport sector will often be a co-benefit of addressing traffic congestion, air quality and energy security. [5.5]

11. Energy efficiency options for new and existing buildings could significantly reduce CO_2 emissions at net negative cost[6]. Many barriers exist against tapping this potential, but there are also large co-benefits. *(high agreement, much evidence)*

- By 2020, about 30% of the projected GHG emissions in the building sector can be avoided at net negative cost. More than half of this potential is in developing countries. [6.4, 6.5]
- Energy efficient buildings, while limiting the growth of CO_2 emissions, can reduce mortality in developing countries, improve social welfare and enhance energy security. [6.6, 6.7]
- Overcoming the many barriers to realise the economic mitigation potential in the building sector, requires a broad and stronger portfolio of policies; instruments encouraging private initiatives can limit public expenditures. [6.7, 6.8]

12. The mitigation potential in the industry sector[6] is dominated by energy intensive industries, of which more than 50% is located in developing countries. International competi-

8 Net costs are defined as the mitigation costs minus the saved energy costs; net negative costs means benefits.

tion means that costs are very important for mitigation decisions. (*high agreement, much evidence*)

- Many industrial facilities in developing countries are new and include the latest technology with the lowest specific energy use. 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]
- 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 these SMEs provide the bulk of employment and manufacturing capacity in many developing countries. [7.1, 7.3, 7.4]

13. **Agricultural practices can make a significant contribution to increasing soil sinks at low costs[6] and to bioenergy.** *(high agreement, much evidence)*
    - About 90% of the mitigation potential arises from soil carbon management, which has strong synergies with sustainable agriculture and generally reduces vulnerability to climate change. [8.4, 8.5, 8.8]
    - The net impact of climate change on soil carbon stocks, and hence its impact on long-term mitigation potentials, is uncertain due to several different complex processes with opposing effects. [8.4, 8.5]
    - There is a substantial potential to produce biomass for energy from crop residues and dedicated crops, but the size of its contribution to mitigation depends on how much bio energy could be used in transport and energy supply and on requirements of land for food production. [8.4]

14. **Forest sector activities can make a significant contribution to both reducing emissions and to increasing removals by sinks at low costs[6], while providing synergies with adaptation and sustainable development**. *(high agreement, much evidence)*
    - Over 65% of the total mitigation potential is located in the tropics and 50% of the total could be achieved by reducing deforestation and forest degradation. [9.4]
    - Climate change will influence carbon mitigation in the forest sector but the magnitude and direction of this impact cannot yet be predicted with confidence. [9.5]
    - Properly designed and implemented forestry mitigation options will have substantial co-benefits in terms of employment, income generation, renewable energy supply and poverty alleviation. This provides opportunities for expanding forestry projects under the Clean Development Mechanism (CDM). [9.6, 9.7]

15. **Post-consumer waste[9] is a small contributor to global GHG emissions (<5%), but the waste sector can positively contribute to GHG mitigation at low cost[6] and promote sustainable development** *(high agreement, much evidence).*
    - Improved public health and safety, pollution prevention, local energy supply (from landfill gas and incineration), and mitigation of GHG emissions are all important co-benefits of sustainable waste and wastewater management, but financial obstacles exist in many developing countries. [10.3, 10.4, 10.5]

16. **Geo-engineering options, such as ocean fertilisation to remove CO_2 directly from the air, or blocking sunlight by bringing material into the upper atmosphere, remain largely**

[9] Industrial waste is covered in the industry sector.

speculative 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)

17. Global emissions must peak and decline thereafter to meet any long-term GHG concentration stabilisation level. The lower the stabilisation level, the more quickly this peak and decline must occur. Mitigation efforts over the next two to three decades will determine to a large extent the long-term global mean temperature increase and the corresponding climate change impacts that can be avoided. (see Figure SPM.7 and 8) (*high agreement, much evidence*)

- Recent studies using multi-gas reduction have explored lower stabilisation levels than reported in TAR. Studies on stabilisation around or below 450 ppmv CO_2-eq assume a temporary increase of concentrations above the stabilisation level (so called overshoot scenarios). [3.3]
- Using the 'best estimate' of climate sensitivity, the most stringent scenarios assessed (stabilising at 445- 490 ppmv CO_2-eq) could limit global mean temperature increases to 2-2.4°C above pre-industrial, at equilibrium, requiring emissions to peak within 15 years and to be around 50% of current levels by 2050. Scenarios stabilising at 535-590 ppmv CO_2-eq could limit the increase to 2.8-3.2°C above pre-industrial and those at 590-710 CO_2-eq to 3.2- 4°C, requiring emissions to peak within the next 25 and 55 years respectively (see fig SPM.8). Results from studies exploring the effect of carbon cycle and climate feedbacks indicate that the above mentioned temperature ranges might be an underestimate.[3.3, 3.5]

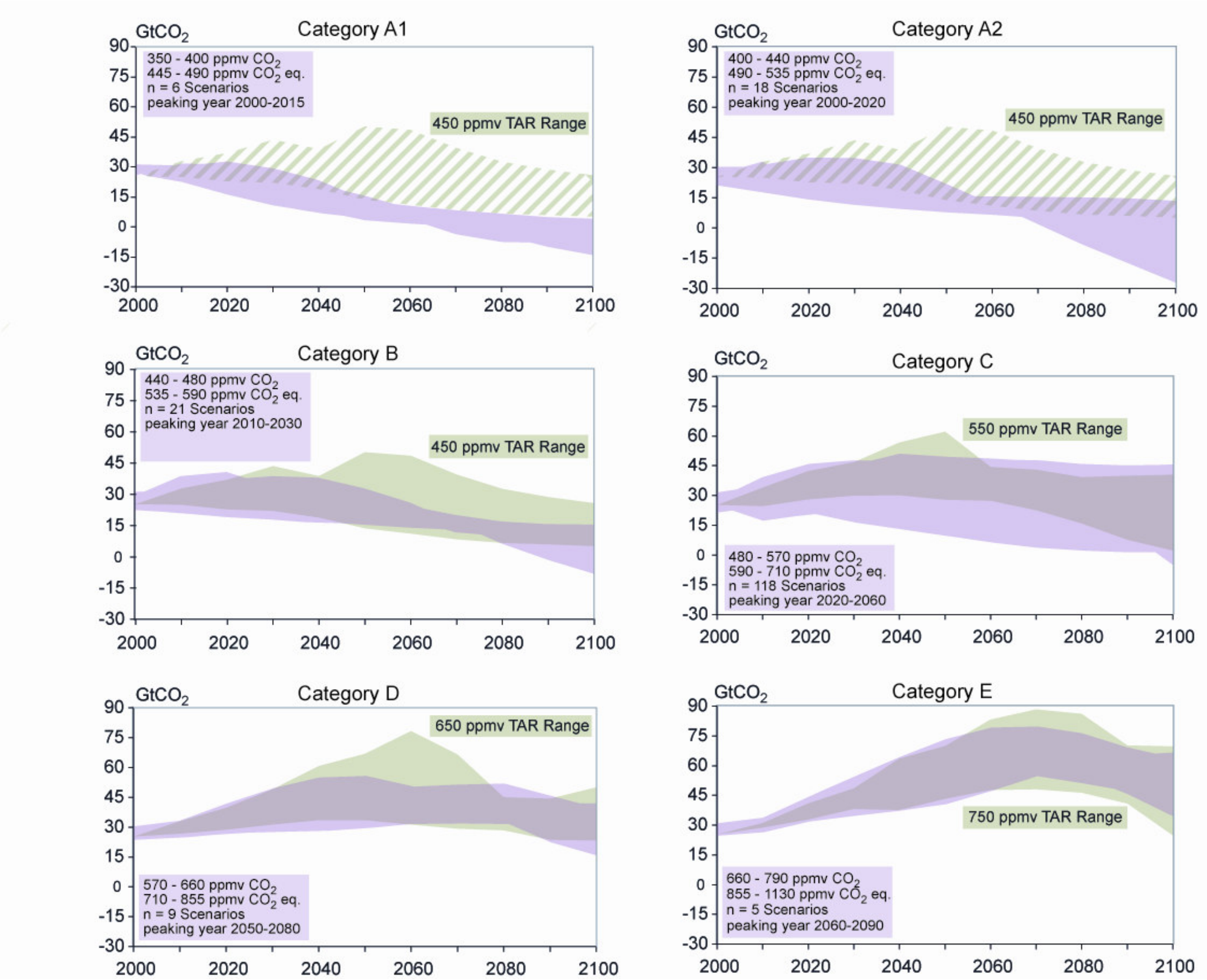

Figure SPM 7: *Emissions pathways of mitigation scenarios for alternative categories of stabilisation targets (Category A1 to E). Pink shaded (dark) give the CO_2 emissions for the recent mitigation scenarios developed post TAR. Green shaded (light) areas depict the range of more than 80 TAR stabilisation scenarios (Morita et al., 2001). Category A1 and A2 scenarios explore stabilisation targets below the lowest of TAR. Therefore green striped areas show the TAR range closest to these stabilisation categories.*
Source: Nakicenovic *et al.*, 2006, and Hanaoka *et al.,* 2006).

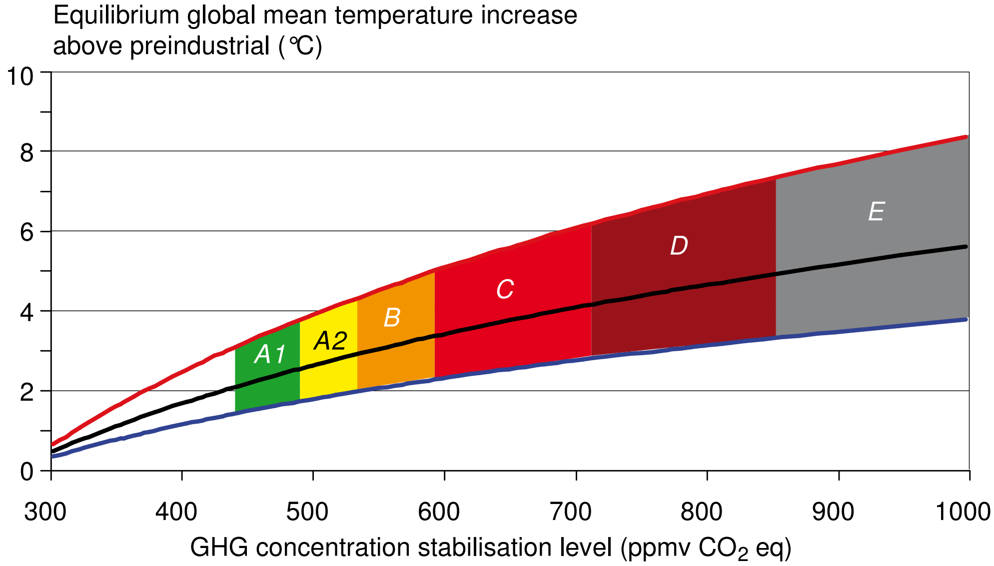

***Figure SPM 8**: Stabilisation scenario categories as reported in fig SPM.7 (coloured bands) and their relationship to equilibrium global mean temperature change above pre-industrial, using (i) "best estimate" climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of likely 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 stabilisation of greenhouse gases in the atmosphere corresponding to the stabilisation scenario categories A1 to E as indicated in Figure SPM 7.*

18. The range of stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are commercially available today and those that are expected to be commercialised in coming decades, provided appropriate incentives are in place for investments, cost reduction and further development and deployment of a wide portfolio of technologies. *(high agreement, much evidence)*

- The contribution of different technologies to emission reductions required for stabilisation will vary over time, region and stabilisation level. Energy efficiency plays a key role across many scenarios for most regions and timescales. For lower stabilisation 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_2 capture and storage (CCS). In these scenarios improvements of carbon intensity need to be much faster than in the past. Including non-CO_2 and CO_2 land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Modern bio energy could contribute substantially to the share of renewable energy in the mitigation portfolio. For illustrative examples see figure SPM.9. Note that the share of low carbon energy options in total energy supply is also determined by inclusion of these options in the baseline. [3.3, 3.4]
- Investments in and world-wide deployment of low-carbon technologies as well as technology improvements through public and private RD&D are needed for achieving stabilisation targets as well as cost reduction. The lower the stabilisation levels, especially those of 550 ppmv CO_2-eq or lower, the larger the numbers of new low-emission equipment and the more RD&D would be needed in the next few decades. [2.9, 3.3, 3.4, 3.6, 4.3, 4.4,4.6]

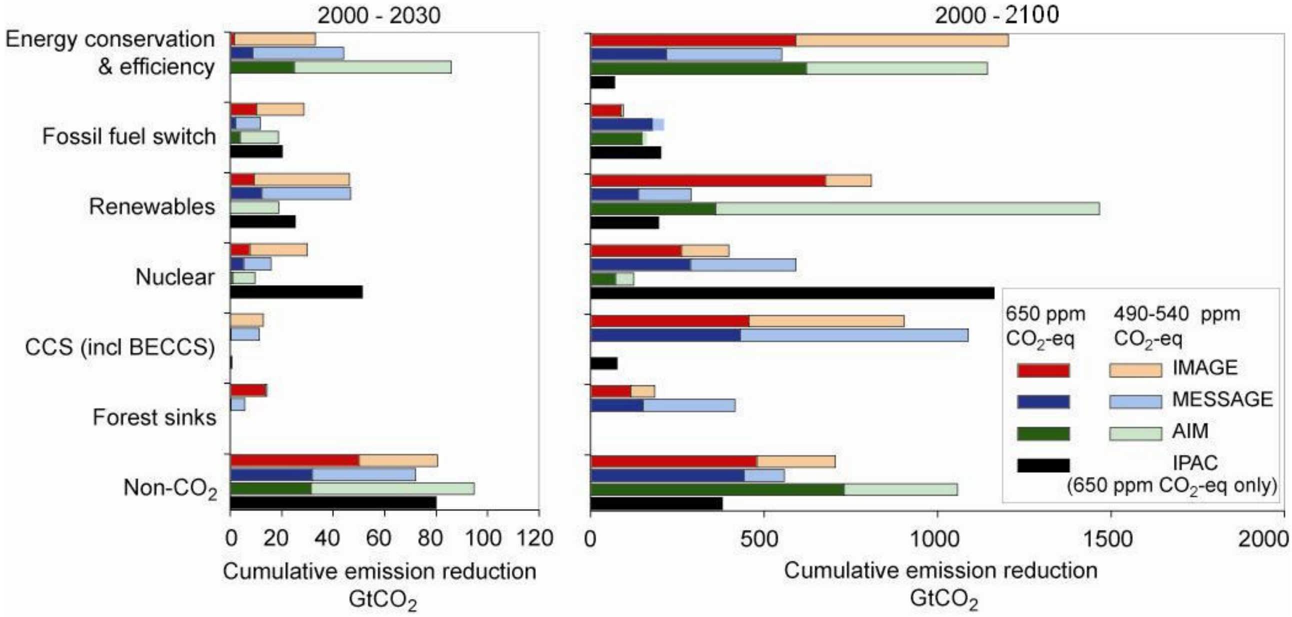

***Figure SPM 9:** Cumulative emissions reductions for alternative mitigation measures for 2000 to 2030 (left-hand panel) and for 2000-2100 (right-hand panel). The figure shows illustrative scenarios from four models (AIM, IMAGE, IPAC and MESSAGE) aiming at the stabilisation at low (490-540 ppmv CO_2-eq) and intermediate levels (650 ppmv CO_2-eq) respectively. Dark bars denote reductions for a target of 650 ppmv CO_2-eq and light bars the additional reductions to achieve 490-540 ppmv CO_2-eq. Note that some models do not consider mitigation through forest sink enhancement (AIM and IPAC) or CCS (AIM). BECS stands for "bio energy with CCS.*

Data source: Van Vuuren *et al.* (2006); Riahi *et al.* (2006); Hijioka, *et al.* (2006); Masui *et al.* (2006); Jiang *et al.* (2006).

19. In 2050[10] global average macro-economic costs for multigas stabilisation at 650 ppmv CO_2-eq are 0.5 (-1 to 2)%[11] loss of global GDP compared to the baseline (reduction of annual GDP growth rate of less than 0.05 percentage points). For 550ppmv CO_2-eq these costs are 1.3 (slightly negative to 4)% (reduction of annual GDP growth rate less than 0.1 percentage points) (See Box SPM.2 for the caveats and paragraph 5 for explanation of negative costs). *(high agreement, medium evidence).*

- For stabilisation levels between 445 and 535 ppmv CO_2-eq costs are lower than 5.5% GDP loss, but the number of studies is limited and they generally use low baselines. [3.3]
- For some countries, sectors, or shorter time periods costs could vary considerably from the global and long-term average. [3.3, 13.3]

20. Decision making about the appropriate level of mitigation is part of an iterative risk management process. Cost-benefit comparison (implicit or explicit, and preferably incorporating risk analysis) is one possible tool that considers investment in mitigation and adaptation, the co-benefits of undertaking climate change mitigation and the damages due to climate change. *(high agreement, limited evidence)*

- Although there are large uncertainties that make such a comparison incomplete and assumption dependent, estimates of (marginal) carbon prices for even the most stringent of stabilisation pathways assessed (i.e. 550 ppmv CO_2-eq and below) indicate that carbon

[10] Cost estimates for 2030 are presented in paragraph 5.
[11] The median and the 10^{th} to 90^{th} percentile range of the analysed data are given.

prices are comparable to or lower than the social costs of carbon (or marginal damage costs)[12]. [1.4, 3.3, 3.5]

E. Policies, measures and instruments

21. A positive 'price of carbon' would create incentives for producers and consumers to significantly invest in lower carbon products, technologies and processes. However, additional incentives related to direct government funding and regulations are also important. *(high agreement, much evidence)*

- Both sectoral bottom-up and top-down assessments suggest that carbon prices of US$ 20 to 50 per tCO_2-eq, sustained or increased over decades, could largely decarbonise power generation and make many mitigation options in the end-use sectors attractive. Reaching such carbon prices by 2020-2030 would be consistent with stabilisation at around 550 ppmv CO_2-eq. [3.6, 11.6]
- Applying an environmentally effective and cost effective instrument mix requires a good understanding of the environmental issue to be addressed, the links with other policy areas and the interactions between the different instruments in the mix. [13.2]
- Barriers to implementation of mitigation options are manifold and vary by region and sector. They can be related to financial, technical, information and behavioural aspects. [4.5, 5.5, 6.7, 7.6, 8.6, 9.6, 10.5]

22. A wide variety of national policies and instruments are available to governments to create the incentives for mitigation action. Experience from implementation in various countries and sectors shows there are advantages and disadvantages for any given instrument *(high agreement, much evidence)*

- Stringency and implementation practices may affect all instruments. General findings about the performance of policies are: [12.2,13.2]
  - *Integrating climate policies in broader development policies* makes it easier to implement them and to overcome barriers
  - *Regulatory measures 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.
  - *Taxes and charges* are generally cost effective, but cannot guarantee a particular level of emissions and may be politically difficult to implement.
  - *Tradable permits* will establish a carbon price. The volume of allowed emissions determines their environmental effectiveness, while the distribution of allowances has implications for competitiveness. Fluctuation in the price of carbon makes it difficult to estimate the total cost of complying with emission allowances.
  - *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 have accelerated the application of best available technology and led to measurable reductions of emissions compared to the baseline, particularly in countries with traditions of close cooperation between government and industry. Success factors include: clear targets, a base-

[12] Costs of adaptation and co-benefits of mitigation other than energy savings are not considered for this statement; nor are impacts that have not yet been expressed in monetary terms [WG II, ch 20.6]

line scenario, third party involvement in design and review and formal provisions of monitoring.

- *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.
- *Financial incentives* are frequently used by governments to stimulate the diffusion of new technologies. While economic costs are generally higher than for other instruments, they are often critical to overcome barriers to the penetration of new technologies.

- Selection of policies is often based on consideration of environmental effectiveness, cost effectiveness, distributional effects (including equity) and institutional feasibility. [13.2]
- Lessons learned from specific sector application are shown in Table SPM.2

Table SPM 2: *Most important sectoral policies, measures and instruments that have proven to be environmentally effective in the respective sector in at least a number of national cases*

Sector	Policies and measures proven to be environmentally effective	Key constraints or opportunities
Energy supply [4.5]	Reduction of fossil fuel subsidies	Resistance by vested interests may make them difficult to implement
	Taxes or carbon charges on fossil fuels	
	Feed-in tariffs for selected technologies	May be appropriate to create markets for low emissions technologies
	Renewable energy obligations	
	Producer subsidies	
Transport [5.5]	Mandatory fuel economy and CO_2 standards	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	Particularly appropriate for countries that are building up their transportation systems.
	Investment in attractive public transport facilities and non-motorised forms of transport	
Buildings [6.8]	Appliance standards and labeling	Regular evaluation and updating may enhance effectiveness
	Building codes and certification	
	Demand side management programmes	
	Public sector leadership programmes, including procurement	
	Incentives for energy service companies (ESCOs)	
Industry [7.9]	Provision of benchmark information	May be appropriate to stimulate technology uptake. Stability of national policy important in view of international competitiveness
	Performance standards	
	Subsidies, tax credits	
	Tradable permits	Predictable allocation mechanisms and stable price signals important for investments
Agriculture [8.6, 8.7, 8.8]	Financial incentives for improved land management, maintaining soil carbon content, efficiency in irrigation and use of fertilizers	May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation
Forestry [9.6]	Financial incentives to maintain and manage forests (national and international)	Effectiveness depends on investment capital, regulatory and financial incentives, and international cooperation
	Land use regulation and enforcement	
Waste management [10.5]	Financial incentives for improved waste and wastewater management, including the CDM	May be appropriate for to stimulate technology uptake
	Renewable energy incentives or obligations	
	Regulations	

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

- Public benefits of RD&D investments are much bigger than the benefits captured by the private sector, justifying government support of RD&D. Government funding in 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, 4.6, 11.5, 13.2]

- Effective technology transfer requires enabling conditions for investments and technology uptake. Mobilising financing of incremental costs of low carbon technologies is important. International technology agreements could strengthen the knowledge infrastructure. [13.3]
- Financial flows to developing countries through CDM projects are reaching levels of the order of several billion US$ per year[13]. This is higher than the flows through the Global Environment Facility, comparable to the energy oriented development assistance flows, but at least an order of magnitude lower than total foreign direct investment (FDI) flows. The role of CDM, GEF and development assistance in technology transfer is therefore limited. [13.3]

24. The most notable achievements of the UNFCCC and its Kyoto protocol are the stimulation of an array of national policies, the creation of a global 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 its current commitment period relative to global emissions is likely to be limited. Its economic impacts on participating countries are likely to be smaller than presented in TAR, that showed 0.2- 2% lower GDP in 2012 without emissions trading, 0.1-1.1% lower GDP with full emissions trading. [1.4,11.4,13.3]

25. The literature identifies many options for achieving reductions both under and outside the UNFCCC and the Kyoto Protocol. Future international agreements would have stronger support, if they are environmentally effective, cost-effective, incorporate distributional considerations and equity, and are institutionally feasible. *(high agreement, much evidence)*

- Since climate change is a global problem, approaches that do not include a larger share of global emissions will have higher global costs or be less environmentally effective. [13.3]
- Expanding the scope of market mechanisms (emission trading, Joint Implementation and CDM) could reduce overall mitigation costs. [13.3]
- Different approaches to global agreements (targets, sectoral or sub-national agreements, adopting common policies, international technology R,D&D programmes, implementing development oriented actions or expanding financing instruments) can be integrated within an agreement, but comparing such efforts quantitatively would be complex and resource intensive. [13.3]
- Actions to 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. Decisions on how to allocate states to tiers can be based on formalized quantitative or qualitative criteria, or be “ad hoc”.[13.3]

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[13] Depends strongly on the market price that has fluctuated between 5 and 25 US$/t$CO_2$-eq.

F. Sustainable development and climate change mitigation

26. Making development more sustainable by changing development paths can make a major contribution to climate change mitigation. At the same time there is a growing understanding of the possibilities to choose and implement mitigation options to realise synergies and avoid conflicts with other dimensions of sustainable development. *(high agreement, much evidence)*

- 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 processes are coordinated. [2.2, 3.3, 12.2]
- There is growing evidence that decisions about macroeconomic policy, multilateral development bank lending, insurance practices, electricity market reform, energy security and forest conservation, for example, which may seem unrelated to 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 related policies such as energy efficiency are often economically beneficial, improve energy security and reduce local pollutant emissions. Other energy supply mitigation options can be designed to achieve also other sustainable development benefits such as avoided displacement of local populations, job creation, and rationalized human settlements design. [4.5,12.3]
- Reducing deforestation can have significant biodiversity, soil and water conservation benefits, but may result in loss of economic welfare for some stakeholders. Appropriately designed forestation and bio energy plantations can lead to reclamation of degraded land, manage water runoff, retain soil carbon and benefit rural economies, but could compete with land for agriculture and may be negative for biodiversity. [9.7, 12.3]
- There are good possibilities for reinforcing sustainable development though 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 adaptive and mitigative capacity and reduce both vulnerability to climate change and emission levels. Synergies between mitigation and adaptation can be identified, such as biomass production, 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].

ANNEX 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 reports make a common approach impractical. The “likelihood” approach applied in "Climate change 2007, the physical science basis" and the “confidence” approach used in "Climate change, impacts adaptation, and vulnerability" are less appropriate in this volume as human choices are concerned, while each of the other approaches was also considered to provide insufficient characterization of the specific uncertainties involved in mitigation.

In this report a two-dimensional scale noting the relative level of expert agreement on the respective statements in light of the underlying literature (in rows) and the amount of scientific/technical evidence (in columns) on which the findings are based, are used (see Table SPM.A.1).

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

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 statement)

Amount of evidence (theory, observations, models) →

Because the future is inherently unpredictable and this report tries to assess mitigation potential and costs for 30 to 100 years ahead, scenarios, i.e., internally consistent images of different futures - not prediction of the future to come, have been used extensively in this report to handle this unpredictability.