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Edited by Bert Metz, Ogunlade Davidson, Peter Bosch, Rutu Dave and Leo Meyer
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**Contribution of Working Group III to the
Fourth Assessment Report of the
Intergovernmental Panel on Climate Change**

Summary for Policymakers

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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_2 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)*[1].
   - 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_2, CH_4, N_2O, HFCs, PFCs and SF_6, 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 ($GtCO_2$-eq)[2] (see Figure SPM.1). The emissions of these gases have increased at different rates. CO_2 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[3] from transport in this period was 120%, industry 65% and land use, land use change, and forestry (LULUCF)[4] 40%[5]. 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_2 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_{ppp})[6], 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[7], 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[8], 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_2-eq) is the amount of CO2 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_2, CH_4, N_2O 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 GDPppp 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_3CCl_3), carbon tetrachloride (CCl_4) and methyl bromide (CH_3Br).
8 Energy security refers to security of energy supply.

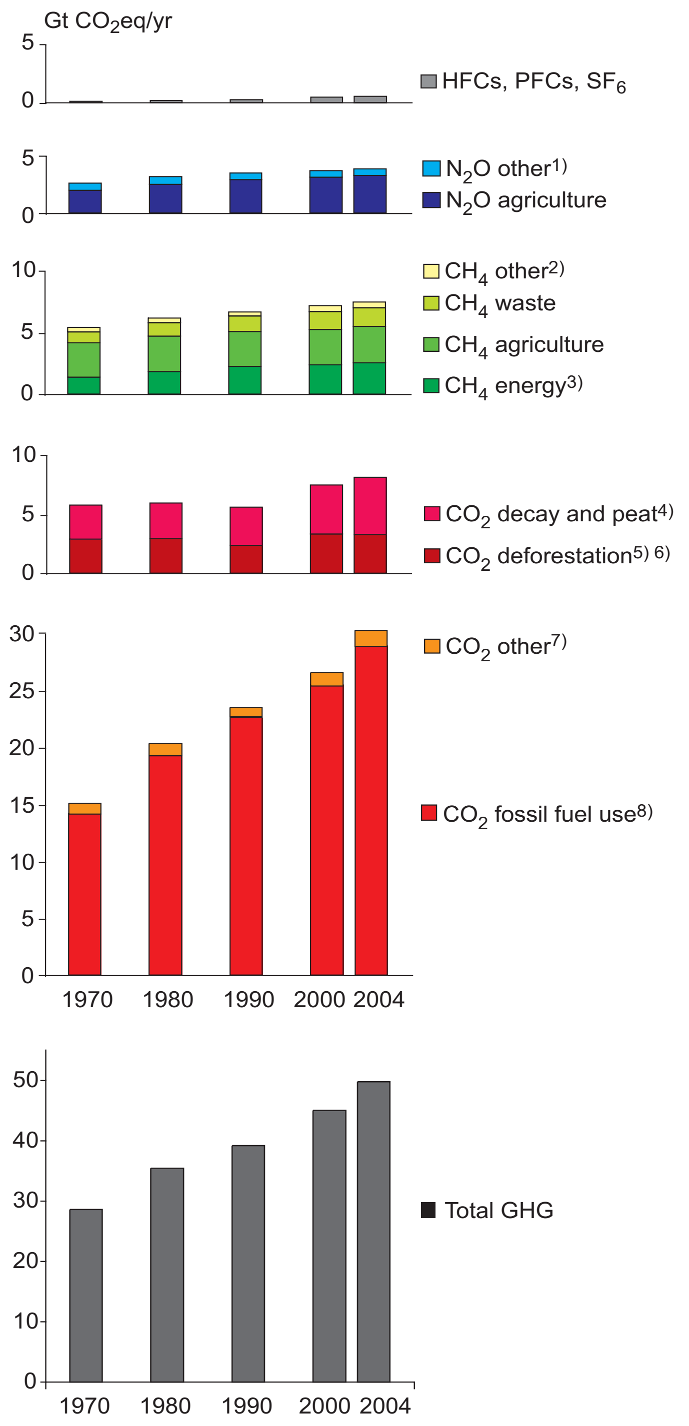

Figure SPM.1: *Global Warming Potential (GWP) weighted global greenhouse gas emissions 1970-2004. 100 year GWPs from IPCC 1996 (SAR) were used to convert emissions to CO_2-eq. (cf. UNFCCC reporting guidelines). CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 from all sources are included.*
The two CO_2 emission categories reflect CO_2 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_2O includes industrial processes, deforestation/savannah burning, waste water and waste incineration.
2. Other is CH_4 from industrial processes and savannah burning.
3. Including emissions from bioenergy production and use
4. CO_2 emissions from decay (decomposition) of above ground biomass that remains after logging and deforestation and CO_2 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 $GtCO_2$-eq to 36.7 $GtCO_2$-eq (25-90%) between 2000 and 2030[9] (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_2 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_2 emissions is projected to come from non-Annex I regions, with their average per capita energy CO_2 emissions being projected to remain substantially lower (2.8-5.1 tCO_2/cap) than those in Annex I regions (9.6-15.1 tCO_2/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]

9 The SRES 2000 GHG emissions assumed here are 39.8 GtCO2-eq, i.e. lower than the emissions reported in the EDGAR database for 2000 (45 GtCO2-eq). This is mostly due to differences in LULUCF emissions.

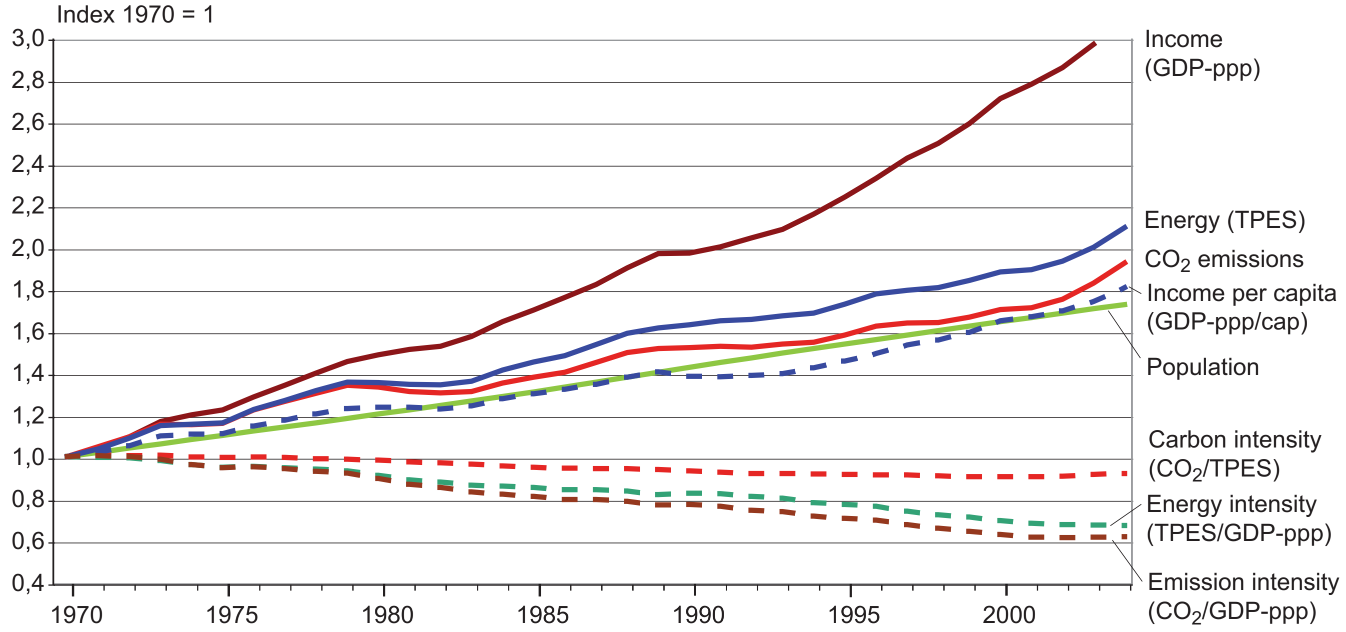

Figure SPM.2: *Relative global development of Gross Domestic Product measured in PPP (GDP_{ppp}), Total Primary Energy Supply (TPES), CO_2 emissions (from fossil fuel burning, gas flaring and cement manufacturing) and Population (Pop). In addition, in dotted lines, the figure shows Income per capita (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]*

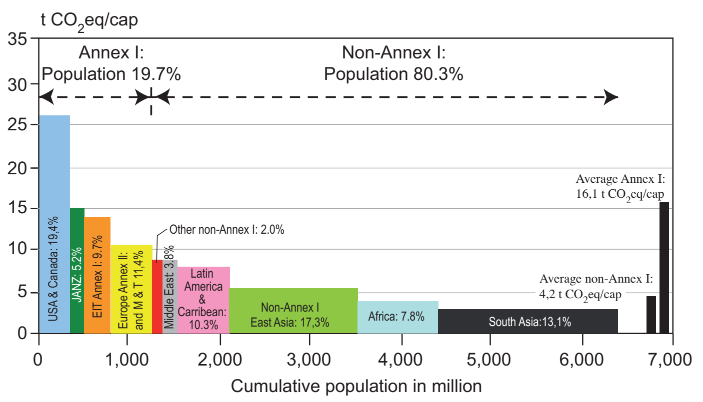

Figure SPM.3a: *Year 2004 distribution of regional per capita GHG emissions (all Kyoto gases, including those from land-use) over the population of different country groupings. The percentages in the bars indicate a regions share in global GHG emissions [Figure 1.4a].*

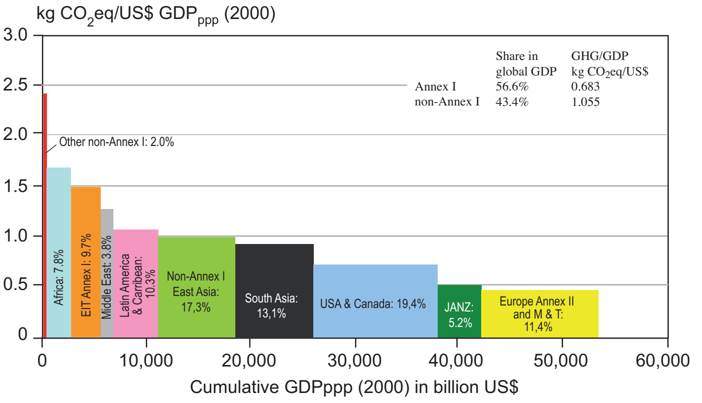

Figure SPM.3b: *Year 2004 distribution of regional GHG emissions (all Kyoto gases, including those from land-use) per US$ of GDP_{ppp} over the GDP_{ppp} of different country groupings. The percentages in the bars indicate a regions share in global GHG emissions [Figure 1.4b].*

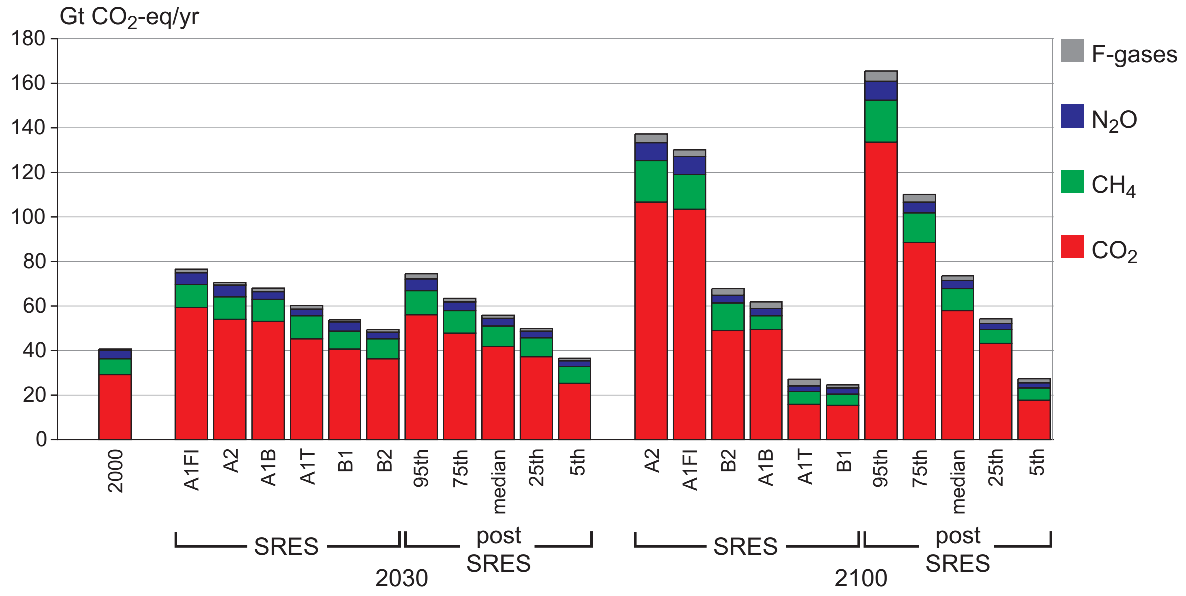

Figure SPM.4: *Global GHG emissions for 2000 and projected baseline emissions[10] for 2030 and 2100 from IPCC SRES and the post-SRES literature. The figure provides the emissions from the six illustrative SRES scenarios. It also provides the frequency distribution of the emissions in the post-SRES scenarios (5th, 25th, median, 75th, 95th percentile), as covered in Chapter 3. F-gases cover HFCs, PFCs and SF_6 [1.3, 3.2, Figure 1.7].*

4. **Baseline emissions scenarios published since SRES[10], are comparable in range to those presented in the IPCC Special Report on Emission Scenarios (SRES) (25- 135 $GtCO_2$-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[11] 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[12]. 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].

10 Baseline scenarios do not include additional climate policy above current ones; more recent studies differ with respect to UNFCCC and Kyoto Protocol inclusion.
11 See AR4 WG I report, Chapter 10.2.
12 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_{ppp}.

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[13], 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].

13 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[14], 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 21st 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.

14 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.

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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 $GtCO_2$-eq. [11.3]:
- Studies suggest that mitigation opportunities with net negative costs[15] have the potential to reduce emissions by around 6 $GtCO_2$-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_2$-eq)	**Economic potential** ($GtCO_2$-eq/yr)	**Reduction relative to SRES A1 B** (68 $GtCO_2$-eq/yr) (%)	**Reduction relative to SRES B2** (49 $GtCO_2$-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_2$-eq)	**Economic potential** ($GtCO_2$-eq/yr)	**Reduction relative to SRES A1 B** (68 $GtCO_2$-eq/yr) (%)	**Reduction relative to SRES B2** (49 $GtCO_2$-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).

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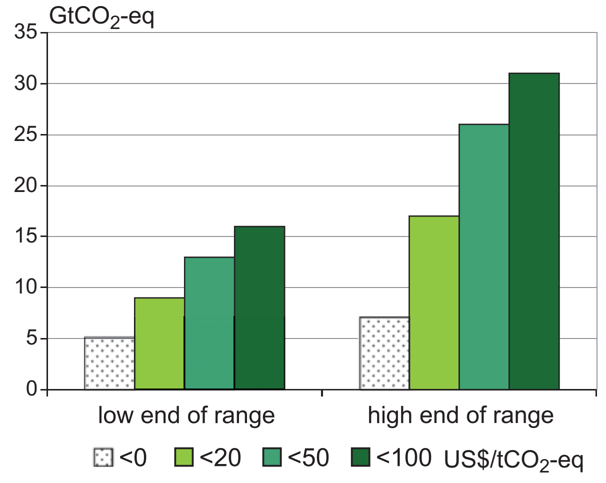

Figure SPM.5A: *Global economic mitigation potential in 2030 estimated from bottom-up studies (data from Table SPM.1)*

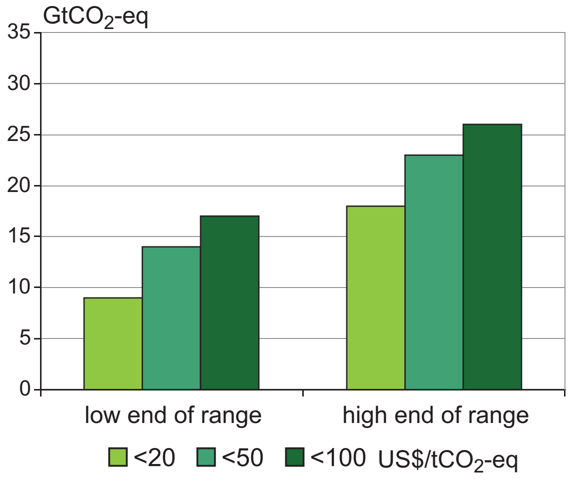

Figure SPM.5B: *Global economic mitigation potential in 2030 estimated from top-down studies (data from Table SPM.2)*

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_2 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_2 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_4 emissions; improved nitrogen fertilizer application techniques to reduce N_2O 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_4 oxidation.