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TECHNICAL SUMMARY

1. Introduction

1.1 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 makes the connection between climate change mitigation and sustainable development, and demonstrates where the two are mutually reinforcing. Economic development needs, resource endowments and capacities - mitigative and adaptive - differ across regions. There is no one-size fits all approach of the climate change problem and solutions needs to be regionally differentiated, reflecting primarily 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 with economic sectors, it was decided to use the economic sectors to organise 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 mitigation options.

Consequently the report has four parts. Part A (Chapters 1 and 2) includes the introduction and explains the frameworks that have been used in the literature to describe mitigation of climate change in the context of other policies and decision- making. It introduces important concepts (e.g. cost-benefit analysis and regional integration) and defines important terms used throughout the report. Part B (Chapter 3)

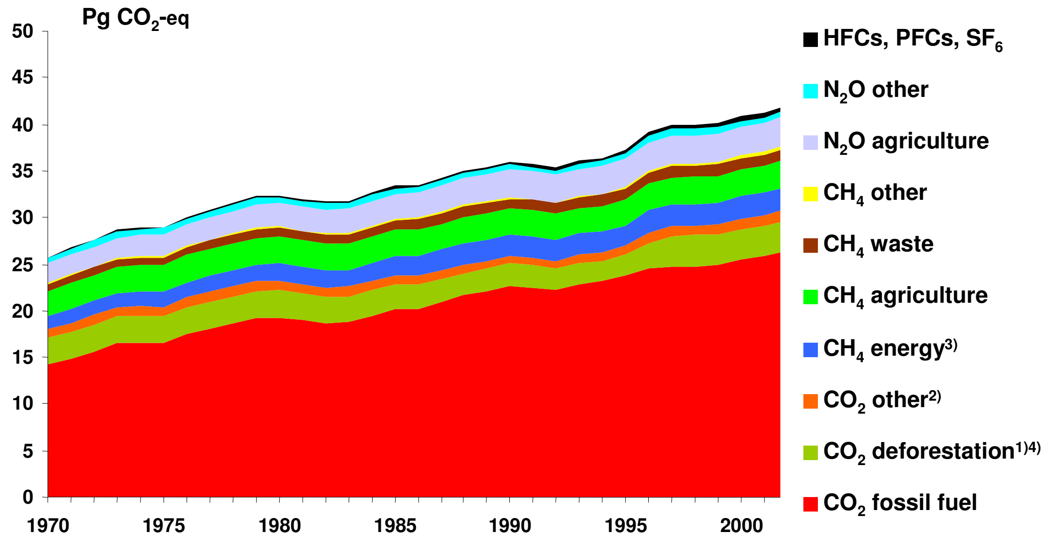
assesses how to get to long-term stabilisation of GHG concentrations in the atmosphere and what the costs are. It examines the relation between adaptation, mitigation and avoided climate change damages, in the light of decision-making regarding stabilization (Art 2 UNFCCC). Part C focuses on the detailed description of the various sectors that are responsible for GHG emissions, the short to medium term mitigation options in these sectors, the policies for achieving mitigation and the relationship with adaptation and other (sustainable development) polices that affect GHG emissions (Ch 4-10). Part D (Ch 11-13) assesses cross-sectoral, national and international aspects. Ch 11 covers the aggregated mitigation potential, macro-economic impacts, technology development and transfer, 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

1.2 Past, present, future: Emission trends

Since 1970 emissions of greenhouse gases covered by the Kyoto Protocol have increased by more than 50%, with CO_2 being the largest source, having grown by about 60% (see Figures TS.1 to TS.3). The largest growth in CO_2 emissions has come from power generation and road transport. Methane emissions rose by about 25% from 1970, with a 60% increase arising from combustion and use of fossil fuels. Agriculture is the largest source of methane emissions. Nitrous oxide emissions grew by about the same proportion as CO_2 emissions, mainly due to increased use of fertilizer and the growth of agriculture. Industrial emission of N_2O fell during this period. Considerable uncertainties still surround the estimates of anthropogenic aerosol emissions. As regards global sulfur emissions, these appear to have declined from a range of 75 ± 10 MtS in 1990 to 55 to 62 MtS in 2000. Data on non-sulfur aerosols are sparse and highly speculative.

Emissions of (ozone depleting substances) ODS gases controlled under the Montreal Protocol (CFCs, HCFCs) increased from a very low amount (1970) to about 7.5 Gt CO_2 eq in 1990 (about 20% of total GHG emissions, not shown in the Figure TS.1), however, decreased to less than 3 Gt -CO_2 eq in 2003, and are projected to further decrease due to the CFC phase-out in developing countries. Emissions of the fluorinated gases controlled under the Kyoto Protocol (HFCs, PFCs and SF6) grew rapidly over the 1990s as they replaced ODS for a substantial amount, and were estimated at about 0.7 Gt CO_2 eq in 2003 (about 1.2% of total emissions on a 100 year GW_p basis).

Global greenhouse gas emissions 1970-2004



Data sources: 1970-2000: EDGAR 3.2, EDGAR 3.2 FT 2000; 2001-2004: IEA, USGG, AFEAS, RAND, FAO, GFED

Note: 100 year GWPs from IPCC 1996 (SAR) were used to convert emissions to CO_2-eq (cf. UNFCCC reporting guidelines)

[1] Including biofuel combustion at 10% (assuming 90% sustainable production).
[2] Including natural gas venting/flaring
[3] Including biofuels
[4] For large-scale biomass burning averaged activity data for 1997-2002 were used from GFED. based on satellite data.

Figure TS.1: Global greenhouse gas emission trends 1970-2004

Translating the GHG emission of Figure TS.1 into GHG emissions by sectors as grouped in the AR4, over the period 1970 to 2004 emissions from the energy supply sector grew by 246%, from transportation by 222%, waste 179%, industry by 164%, residential and commercial buildings by 130%, and agriculture and forestry by 125% (large error margin up to ±50%).

In 2004 about 29% of GHG emissions arose from energy supply, 23% from agriculture and forestry, about 22% from industry, 14% from transport, and 12% from residential, commercial and service sectors (see Figure TS.2). These figures should be seen as indicative as some uncertainty remains, particularly with regards to CH_4 and N_2O emissions (error margin estimated to be in the order of 30% to 50%) and CO_2 emissions from agriculture (error margin up to ±50%).

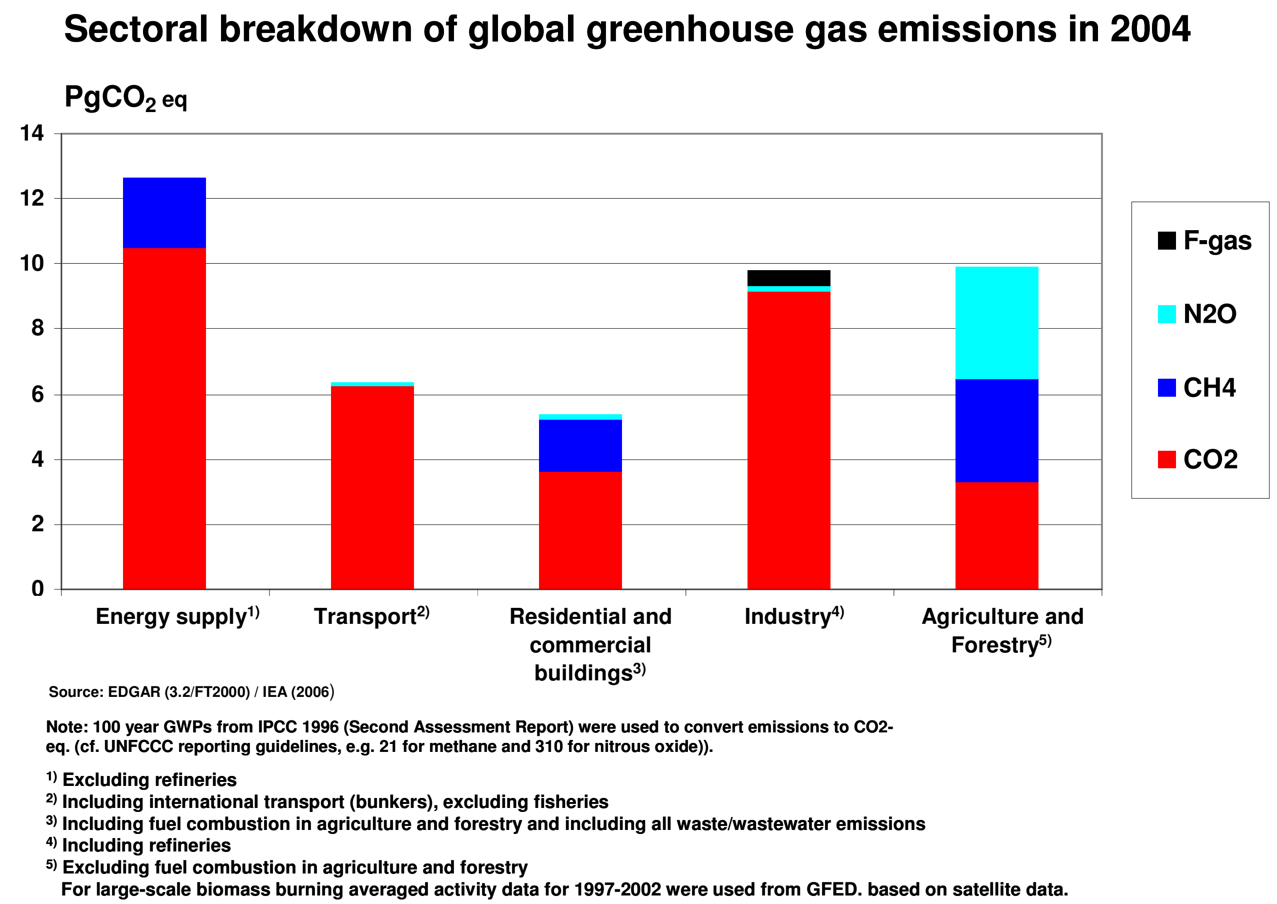


Figure TS.2: Sectoral breakdown of global greenhouse gas emissions in 2004

CO_2 emissions per unit of GDP at purchasing power parity (ppp) are 40 percent lower today than during the early 1970s and have declined faster than primary energy per unit of GDPppp or CO_2 per unit of primary energy (see Figure TS.3). As can be seen from Fig TS.4 the increase in population and GDP per capita (and therefore energy use per capita) has outweighed the decrease in energy use per unit of GDP while the carbon intensity of energy supply was more or less constant in the period 1983-2003.

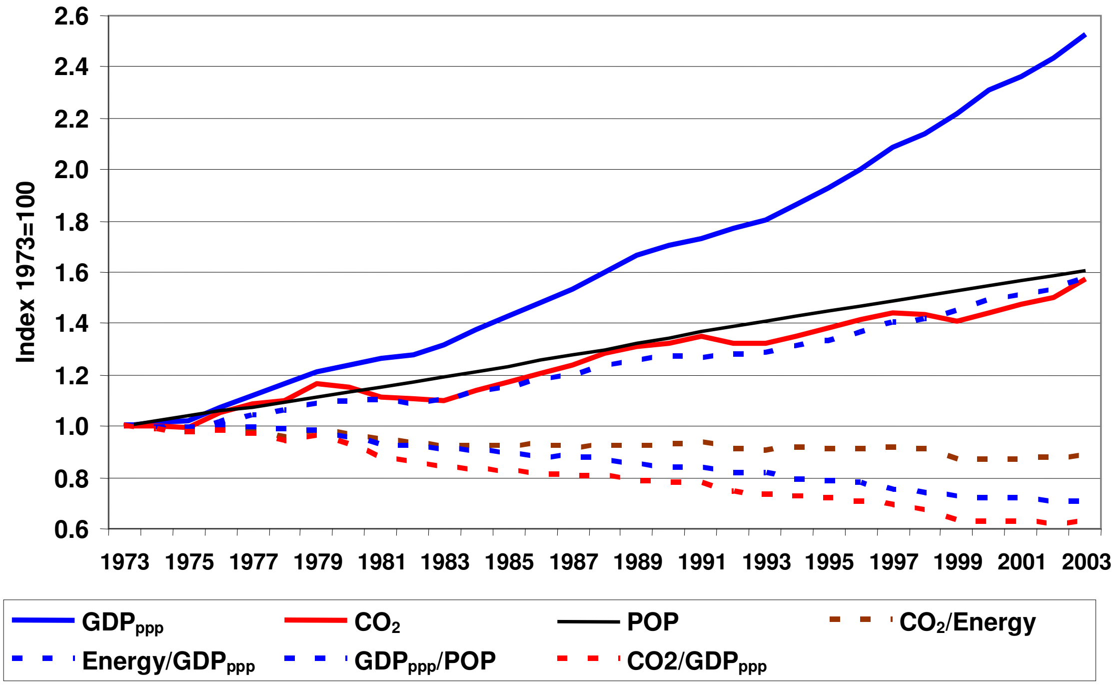


Figure TS.3 Gross Domestic Product both in terms of absolute(GDP) and per capita (GDP/POP) measured in PPP (Purchase Power Parity), Population (POP), Energy Intensity (Energy Use per GDP), Carbon Intensity (CO_2/Energy Use), and Carbon Dioxide Emissions (from fossil fuel burning, gas flaring and cement manufacturing). Sources: World Bank, 2005; Marland et.al, 2006.

Note: GDP (PPP) of 1973 and 1974 was unavailable and is therefore estimated by using the growth rate of non-PPP GDP.

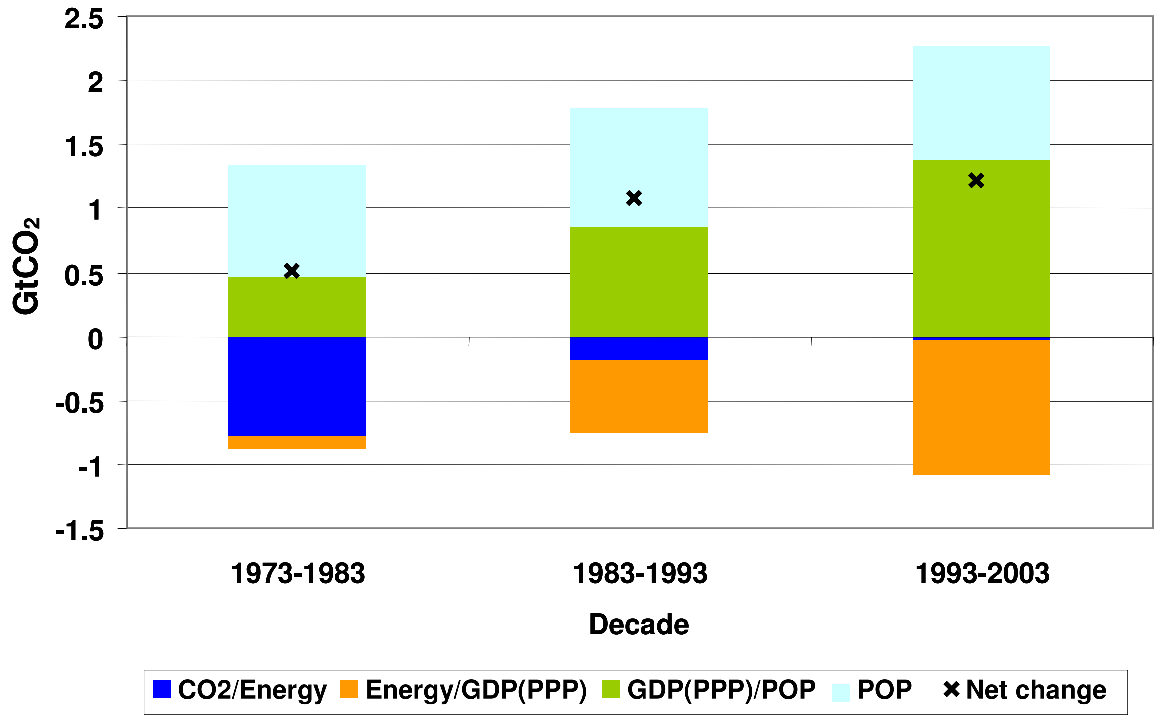


Figure TS.4: Decomposition of CO_2 emission growth at global scale, shown for three decades. Sources: World Bank, 2005; Marland et al., 2006.

Annex 1 countries hold a 20 percent share in world population but account for 46.4 percent of global GHG emissions. In contrast, the 80 percent of people living in non-Annex 1 countries account only 53.6 percent of GHG emissions. The contrast between the regions with the highest per capita GHG emissions (North America) and the lowest (Africa) is even more pronounced (see Figure TS.5) and five percent of the world population (North America) emits 20.1 percent while 30.3 percent (Other Asia) emits 13.4 percent.

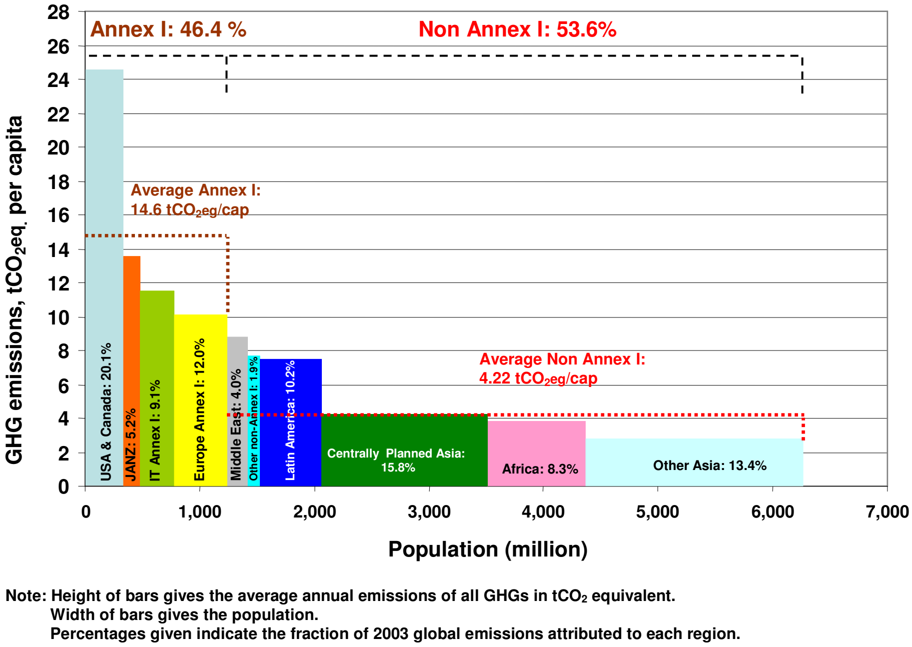


Figure TS.5: Distribution of regional per capita CO_2 emissions over different country groupings in 2003 (adapted from Bolin and Khesgi, 2001 using IEA (2005a) and EDGAR 3.0 database

Global energy use and supply - the main drivers of GHG emissions - is projected to continue to grow, especially as developing countries pursue industrialization. In most energy use and supply projections, fossil fuels will continue to provide the bulk of energy services throughout the 21st century with consequent implications for GHG emissions. Assuming current policies remain unchanged, the IEA projects 50-100% higher CO2 emissions in 2030 than in 2000 (a growth rate of 1.7% per year) with two- thirds of this increase originating in non-Annex 1 countries (see Figure TS.6), though per capita emissions in developed countries will remain substantially higher. Its alternative policy scenario targeted at achieving a more sustainable energy system results in energy-related emissions of carbon dioxide increasing by 44% in 2030 compared to 2000. The EIA/DOE international energy outlook projects almost a range of global CO_2 emissions from an 80% to 140% increase over the same period (corresponding to 2.0% to 3.0% annual growth rates), again with the largest growth projected to occur in the developing countries.

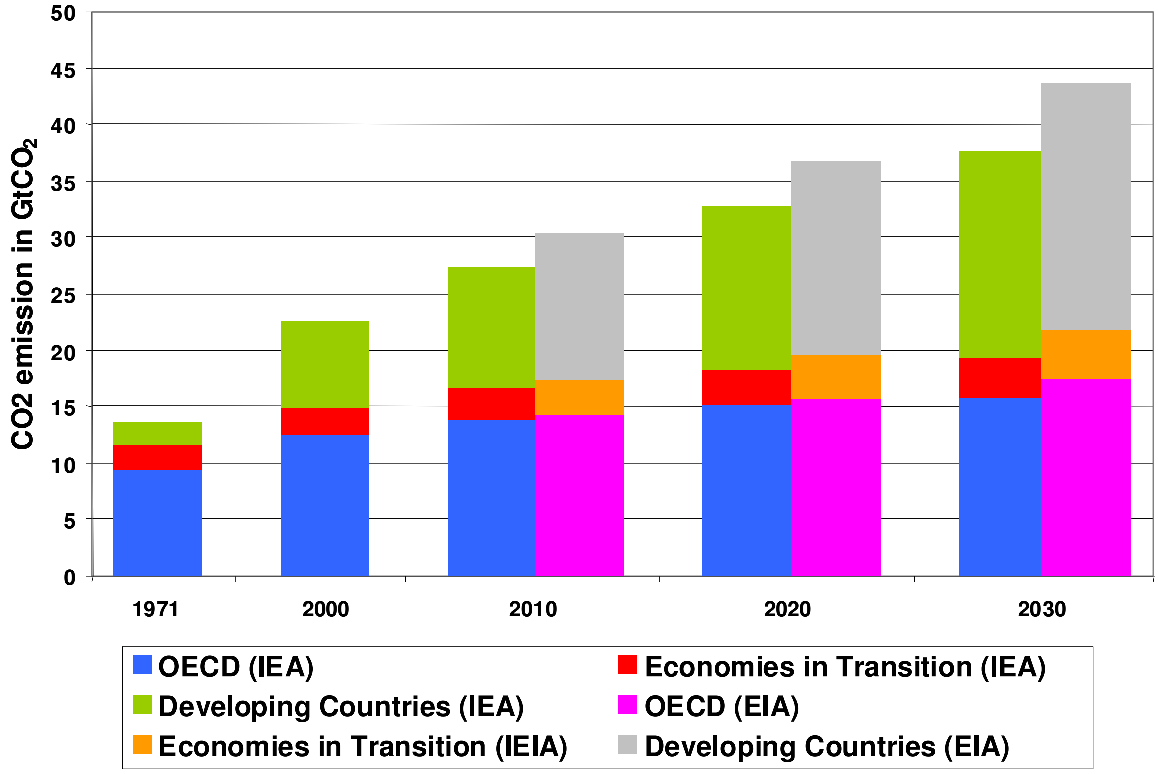


Figure TS.6: Global energy related carbon emission projections by major region. (Sources: IEA and EIA - Reference Case).

1.3 International response

The growing amount of evidence on climate change induced damages and projections of further climate change and impacts have increased the awareness of the climate change issue among the public and policy makers. The entry into force of the Kyoto Protocol in February 2005 and the subsequent formulation and partial implementation of renewables directives and emission trading schemes in many countries and regions not only further raised awareness but, more importantly, are first steps towards implementation of an international response strategy.

The United Nations Framework Convention on Climate Change (UNFCCC) is the main vehicle to promote international response to climate change. It is a "framework" document (as of July 2006, the Convention currently has received 189 instruments of ratification - 188 countries and the European Economic Community), something to be amended or augmented over time so that efforts to deal with global warming and climate change can be focused and made more effective. The first addition to the treaty, the Kyoto Protocol, was adopted in 1997. As of July 2006, 163 states and the European Economic Community have deposited instruments of ratifications, accessions, approvals or acceptances of the Protocol. These Parties agreed to take climate change into account in such matters as agriculture, industry, energy, natural resources, and activities involving sea coasts.

The entry into force of the Kyoto Protocol in February 2005 marks a first, though modest step, towards the achieving the ultimate objective of the UFCCC to avoid dangerous anthropogenic interference with the climate system, but its outcome will still be far from reversing the overall GHG emission trends. The strengths of the Kyoto Protocol are its provision for market mechanisms such as GHG emission trading and, last but not least, its institutional architecture, now solidly in place. One weakness of the Protocol, however, is its non-ratification by some significant GHG emitters.

The 2005 Montreal Meeting of the Parties adopted the implementation rules for Kyoto, and started discussions towards a Post-Kyoto regime. At that meeting, the UNFCCC Secretariat reported on GHG emissions from Annex I Parties using inventory data from national submissions. [FCCC/SBI/2005/17, 12 October 2005]. As of 2003 Annex I Parties (to UNFCCC) emissions of greenhouse gases (excluding LULUCF emissions and removals) were 5.9% below their 1990 levels. This includes Annex I Parties that are not Parties to the Kyoto Protocol. The aggregate emissions of Annex I Kyoto Parties (excluding LULUCF emissions and removals) were 12.5% below 1990 levels (or base year as agreed). Much of this reduction can be attributed to the former EIT countries that experienced prolonged economic recession. The reductions can be compared with the aim under Article 3.1 of the Kyoto Protocol "reducing their overall emissions of such gases by at least 5 percent below 1990 levels". The UNFCCC Secretariat has stated that the aggregate 5% reduction target will be reached if additional measures are adopted[1]. [http:unfccc\int, 2006] (Medium confidence).

A new working group on the commitments of Annex I countries beyond 2012 was set up at CMP-1 which met in Bonn in May 2006 and agreed to negotiate binding targets for a second commitment period. A dialogue under the guidance of the COP, and taking the form of an open and non-binding exchange of views and information in support of enhanced implementation of the Convention was set up and held its first meeting in Bonn.

Efforts undertaken by six developing countries have reduced their emissions growth over the past three decades by approximately 300 million tons a year, i.e. about 75 percent of the reductions required from developed countries from 2010 BAU emissions by the Kyoto Protocol. Many of these efforts are motivated by common drivers: economic development and poverty alleviation, energy security, and local environmental protection. The most promising policy approaches, then will be those that capitalize on natural synergies between climate protection and development priorities to simultaneously advance both. For example, Brazil achieved reductions by aggressive biofuels and energy efficiency programs aimed at reducing energy imports and diversifying energy supplies (23 $MtCO_2$ in 2000 compared with the actual emission of 91 $MtCO_2$). China has reduced its emissions growth rate through slower population growth, energy efficiency improvements, fuel switching from coal to natural gas, and afforestation (370 $MtCO_2$ compared with actual emissions of 3,110 $MtCO_2$). India's growth in energy-related carbon dioxide emissions was reduced through economic restructuring, enforcement of existing clean air laws by the courts, and renewable energy programs (by 66 $MtCO_2$ compared with the actual emission level of 1060 $MtCO_2$). Mexico has reduced deforestation rates, switched to natural gas, and efficiency improvements (37 $MtCO_2$ of reductions compared with actual emissions of 686 $MtCO_2$. South Africa is taking steps to phase out subsidies to its carbon-intensive coal liquefaction industry and to open the country to natural gas imports.

There are other voluntary international initiatives to develop and implement new technologies to reduce GHG emissions. These include for instance the Carbon sequestration Leadership Forum (promoting CO_2 capture and storage), the Hydrogen partnership, Methane to Markets 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 continuing 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, World Bank and the Renewable Energy and Energy Efficiency Partnership with

[1] http://unfccc.int/files/press/news_room/press_releases_and_advisories/application/pdf/20060215_anniversary_kp_entry_into_force.pdf

supporting their efforts. Additionally, Gleneagles created a Clean Energy, Climate Change and Sustainable Development Dialogue process for the largest emitters. The IEA and World Bank were charged with advising that dialogue process.

1. 4 Article 2 of the Convention and mitigation

Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) requires that dangerous climate change be prevented and hence the stabilization of atmospheric greenhouse gas (GHG) concentrations at levels and within a timeframe that would achieve this objective. The criteria specified in article 2 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 the balancing of the risks of climate change (risks of gradual change and of extreme events, risk of irreversible change of the climate), including risks for food security, ecosystems and sustainable development) against the risk 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, deep emission reductions are unavoidable- in order to achieve stabilization. The lower the stabilization level, the earlier these deep reductions have to be realized.

- *Development and sustainable development*: The criterion that relates to enabling economic development to proceed in a sustainable manner has two sides. Projected anthropogenic climate change appears likely to adversely affect sustainable development, with adverse effects tending to increase with higher greenhouse gas concentrations (WGII AR4 Chapter 19). On the other side very costly mitigation measures could have adverse effects on economic development. This tension is what gives rise to the debate over the right scale and timing and the balance between climate policy (mitigation and adaptation) and economic growth. Projected climate changes can exacerbate poverty and hence undermine sustainable development especially in least-developed countries, which are the most dependent on natural capital. Climate change responses (including mitigation) are part and parcel of sustainable development and the two can be mutually reinforcing. Mitigation can conserve or enhance natural capital (ecosystems, environment as sources and sinks for economic activities) and prevent or avoid damages to human systems and, thereby, contribute to the overall productivity of capital needed for socio-economic development, enhancing mitigative and adaptive capacity. On the other hand sustainable development paths can reduce vulnerability to climate change and reduce GHG emissions.

- *Distributional issues* The Convention places the heaviest burden for the first steps in fighting climate change on industrialized nations, since they are the source of most past and current greenhouse gas emissions and have the technical and financial capability to act. This is enshrined in the principle of "common but differentiated responsibilities". The unequal distribution of stable climate benefits (skewed towards the least-developed countries) and of the ability to pay (skewed towards developed countries) may create tensions. Intergenerational equity issues arise because of the long time lags and inertia associated with climate change and its impacts on future generations. Important intergenerational aspects relate to the timing and degree of mitigation because benefits in terms of avoided climate change damages will only be visible much later than the costs of mitigation.

- *Timing*: Both the climate system and human socioeconomic systems exhibit considerable inertia over different time scales. The climate system response to increased GHG concentrations occurs over all time scales but is subject to substantial lags (at the scale of centuries) and inertia. Whilst a large part of the atmospheric response to forcing changes is on decadal timescales, a substantial component appears to be linked to the century time scales of the oceanic response to forcing changes, i.e., global mean temperature will not stabilise as soon as GHG concentrations are stabilized, because the earth system takes considerable time to get to equilibrium because of the oceans. This is illustrated by the fact that in case of a hypothetical drop in GHG emissions to zero now, the global mean temperature would still rise with about 0.6 ^{0}C. As a consequence of the long lead times, sea level rise would continue for many centuries after stabilization of GHG concentrations. Achieving drastic GHG emission reductions quickly (time scale of decades) requires rapid changes of both climate and non-climate relevant behaviors laden with cultural significance. It also requires rapid changes of long-lived capital stocks (energy, transportation and other infrastructure) because of the need to replace carbon emitting technologies with cleaner and climate friendly technologies (socio-economic and technological inertia). In the context of stabilization, higher inertia brings forward the date at which abatement must begin to start meeting any given stabilization constraint, and lowers the subsequent emissions trajectory.

- *Mitigation and adaptation*. Adaptation and mitigation are two sets of policy responses to climate change, which can be complementary, substitutable or independent of each other. Irrespective of the scale of mitigation measures in the next ten to twenty years, adaptation measures will be required due to the inertia in the climate system. Adaptation measures could partly prevent the impacts of climate change and are implemented at the regional level as climate change impacts and vulnerabilities tend to be regional. Adaptation measures typically have shorter timescales than the climate system or many mitigation measures. 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. Only beyond that time, will benefits from avoided climate change accrue. First, some climate change is inevitable over the next one to three decades given present levels of greenhouse gases and feasible mitigation options. Dealing with these effects of climate change is principally possible via adaptation measures. Second, over longer time frames, beyond the next few decades, mitigation investments have a greater potential to avoid climate change damages compared to unmitigated scenarios and ultimately this potential is larger than the adaptation options presently foreseeable. In the context of decisions on the level of stabilization to aim for in light of art 2 UNFCCC, adaptation can reduce some climate change risks, but not all. Adaptation can therefore only be a partial replacement of mitigation at best.

- *Global cooperation* Climate is a global public good since it is spatially indivisible, is freely available to all (non-excludability), and its consumption by one nation does not diminish its availability to others (non-rivalry). Cooperation to provide the benefit of a stable climate must overcome the national incentive to shirk its cost since an individual nation cannot be excluded from its benefits.

- *Uncertainty:* Uncertainty in knowledge is an important aspect in the implementation of art. 2 in terms of assessing the risk and severity of climate change impacts or evaluating the level of mitigation action (and its costs) needed to reduce risk. Under uncertainty, it is essential that decision making on the implementation of art.2 incorporates risk management principles. A precautionary and anticipatory risk management approach would need to incorporate adaptation and preventive mitigation based on the costs and benefits of avoided climate change damage.

2. Framing issues

2.1 Climate change mitigation and sustainable development

The chapter frames climate change mitigation policies in the context of general development issues.

There is a two-way relationship between climate change and development. On the one hand development pathways influence climate change vulnerability and emissions of greenhouse gases. Vulnerability to climate change is framed and strongly influenced by development patterns and income levels which are also major determinants for adaptive capacity. Decisions about technology, investment, trade, poverty, community rights, social policies, or governance, which may seem unrelated to climate policy, may have profound impacts upon emissions, the extent of mitigation required, and the cost and benefits that result. This is also the case with realisation of the Millenium Development Goals.

On the other hand, climate change itself and (adaptation and mitigation) response policies, could have significant impacts on development, positive, in the sense that development can be made more sustainable, but potentially also negative, if these responses compete with meeting other vital development objectives. 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”). Nevertheless, framing the debate as a sustainable development problem rather than a solely environmental one may better address the immediate goals of all countries, while acknowledging that the driving forces for emissions are linked to the underlying development path (see Figure TS.7)

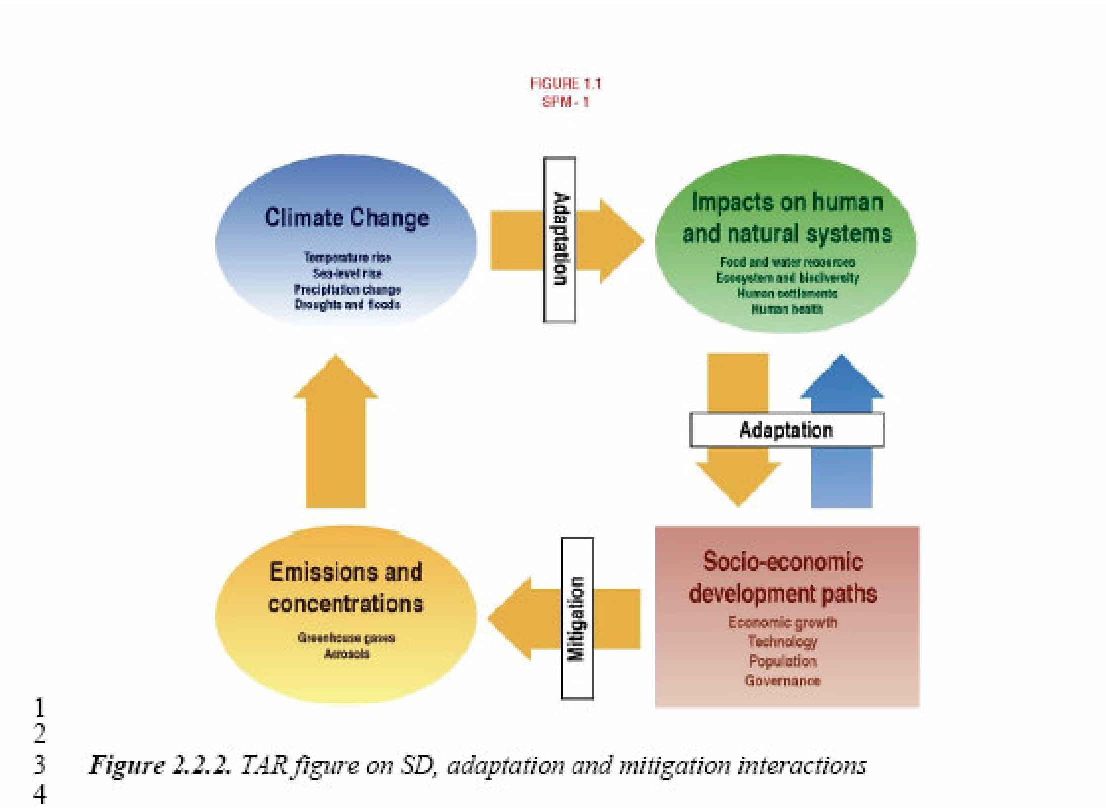


Figure TS.7: TAR figure on SD, adaptation and mitigation interactions

The strong linkages between mitigation of climate change and development apply to both developed and developing countries. The concept of sustainable development was adopted by the World Commission on Environment and Development, which defined it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." There is general agreement that sustainable development involves a comprehensive and integrated approach to economic, social and environmental processes.

This report will focus attention on how basic development goals like health, education, and energy, food and water access can be achieved in the context of good governance and without compromising the global climate.

A development path evolves as a result of many economic and social transactions that are influenced by government policies, private sector initiatives, and by the preferences and choices of consumers. They include a broad number of policies related to nature conservation, legal frameworks that support the management of common access resources, environmental 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, typically are not derived and implemented as part of a general sustainable development policy package, but are rather targeted towards more individual policy goals like air pollution standards, food security and health issues, GHG emission reduction, income generation to specific groups, or development of industries for green technologies. However, powerful impacts can arise from such policies on sustainability and greenhouse mitigation and adaptation outcomes. Chapter 12 and to some extent Chapters 4-11 address these issues in more detail.

Institutional capacity at the national and international level is essential for creating the conditions for integrated climate mitigation and sustainable development policies.

(see Chapter 12 for more information).

As far as international governance is concerned, a wider spectrum of stakeholders is beginning to be engaged. These stakeholders include international agencies, global forums like the WSSD, private companies, and NGO's. The participation of a broader set of stakeholders creates a new potential for linking formal international agreements and commitments with voluntary actions, and market driven processes.

An emerging literature has identified methodological approaches to characterise and analyse 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 SD impacts of policies including both quantitative and qualitative measurement standards.

2.2 Mitigation, vulnerability and adaptation relationships

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

Both adaptation and mitigation make demands on the capacity of societies. These capacities are intimately connected to social and economic development. The responses to climate change depend on society's productive base including natural and man made capital assets, human capital and institutions as well as income and exposure to climate risk. Together these will define its adaptive and mitigative capacities. Policies that enhance the society's productive base 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 at times difficult trade offs might have to be made. It is important that where possible these are carefully assessed. Adaptation and mitigation policies can be understood as more specific policy efforts that directly addresses climate change and indirectly influence society's productive base. The outcome of implementing specific mitigation and adaptation policies is influenced by many of the same drivers that influence socio-economic development (investments, consumption, technology, population, governance, and environmental priorities). Key factors determining individual stakeholders' and society's capacity to implement climate change mitigation and adaptation include: access to resources, markets, finance, information, and a number of governance issues. See Chapters 2 and 11 for more information.

Key factors determining individual stakeholders' and society's capacity to implement climate change mitigation and adaptation include: access to resources, markets, finance, information, and a number of governance issues.

2.3 Risk and uncertainty

Risk is defined as a combination of the probability of an outcome and its consequences or impacts. Uncertainty is understood as all forms of ignorance associated with risk. Uncertainty can apply both to probabilities as well as to consequences. Causes of uncertainty include insufficient or contradictory evidence as well as human behavior (see TS Table.1). The human dimensions of uncertainty, especially coordination and strategic behavior issues, explain a major share of uncertainties related to climate change mitigation.

Structural uncertainty (not having probabilities) does not preclude quantified or model-based analysis. The literature has effectively used uncertainty frameworks dealing with incomplete or imprecise data.

Risk management is not limited to the consequences of global climate change, but also encompasses the uncertainties of climate policy itself and technology development.

Table TS.1 Types of uncertainty

Type	Indicative examples of sources	Typical approaches and considerations
Unpredictability	Projections of human behaviour not easily amenable to prediction (e.g. evolution of political systems). Chaotic components of complex systems.	Use of scenarios spanning a plausible range, clearly stating assumptions, limits considered, and subjective judgments. Ranges from ensembles of model runs.
Structural uncertainty	Inadequate models, incomplete or competing conceptual frameworks, lack of agreement on model structure, ambiguous system boundaries or definitions, significant processes or relationships wrongly specified or not considered.	Specify assumptions and system definitions clearly, compare models with observations for a range of conditions, assess maturity of the underlying science and degree to which understanding is based on fundamental concepts tested in other areas.
Value uncertainty	Missing, inaccurate or non-representative data, inappropriate spatial or temporal resolution, poorly known or changing model parameters.	Analysis of statistical properties of sets of values (observations, model ensemble results, etc); bootstrap and hierarchical statistical tests;comparison of models with observations.

Source: reproduced from Table 2 in IPCC Guidance Notes (2005).

The vocabulary described in Table TS.1 is used to summarize the scientific understanding relevant to an issue, or to express uncertainty in a finding where there is no basis for making a more quantitative statement. This table is based on two dimensions of uncertainy presented above, the amount of evidence and the level of agreement.

Where the level of confidence is “high agreement, much evidence”, or where otherwise appropriate, uncertainties are described using Table TS.2 for levels of confidence or likelihood.

Table TS.2 Characterising uncertainty

Consensus → agreement or Level of			
	High agreement limited evidence	....	High agreement much evidence
	....	....	....
	Low agreement limited evidence	....	Low agreement much evidence

Amount of evidence (theory, observations, models) →

Terminology	Likelihood of the occurrence/outcome
Virtually certain	> 99% probability of occurrence
Very likely	> 90% probability
Likely	> 66% probability
About as likely as no	33 to 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Exceptionally unlikely	< 1% probability

Source: reproduced from Table 4 in IPCC Guidance Notes (2005)

2.4 Decision making and implementation

Decision support analysis can assist decision makers even if there is no optimum policy that everybody can agree upon. There are significant problems in identifying, measuring and quantifying many variables which are important inputs to any decision support analysis frameworks - particularly impacts on natural systems and human health which do not have a market value. With these caveats many analytical and ethical approaches can be used to support decision making, including:

- *formalised optimisation approaches* such as cost-benefit analysis, cost-effectiveness analysis and guardrail/safe landing/ tolerable windows analysis (feasible mitigation paths in agreement with their explicitly expressed constraints on risks and costs),
- *quantified hedging analysis*: factoring in the (subjective) uncertainty about certain policy choices in the future
- *approaches that mix quantitative and qualitative data* including some applications of multicriteria analysis
- *cooperative and non-cooperative gaming analysis and other analytic approaches to understanding the dynamics of complex decision making and the conditions under which effective agreements are more or less likely*
- *structured policy-science dialogues*.

These approaches all have their strengths and weaknesses and all represent considerable simplifications of reality and assumptions about values. However applied with these caveats in mind they may help 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.

Decision making approaches cannot escape dealing with values (essentially whose interests and preferences and what moral judgements underpin the analysis) either explicitly or implicitly. There is no single decision maker in climate change, and because of differences in values and objectives, parties participating in a collective decision-making process do not apply the same criteria to the choice of alternatives. When many decision makers with different values are involved in a decision, it is helpful to be as clear as possible about the value judgements underpinning any analytic support work they are expected to draw on. This can be particularly difficult and subtle where analysis is aiming to illuminate choices associated with high levels of uncertainty and risk.

2.5 Distributional and equity aspects

Climate change and climate change mitigation 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 for the distribution of costs and benefits of climate policies.

Table TS.3 Impacts of climate change on different dimensions of equity

Table 2.7.3. Impacts of Climate Change on Different Dimensions of Equity

Dimension of Equity	Effect of Climate Change	
	Within a Country	Across Countries
Economic	Increased vulnerability of agricultural practices that are undertaken by poor people will increase inequality	With greater negative impacts in developing countries, inequality will increase
Health	Poorer people suffer from lower general health standard and less access to health services and can therefore be more impacted, although some impacts will affect all sections	Major impacts of flooding, vector borne diseases etc. will be in developing countries

Economic and Social Security	Probably affects all sections, but those more dependent on natural resources will be hurt more.	Bigger effects will be in developing countries
Gender	As major users of natural resources e. g firewood for wood fuel and as contributors to subsistence agriculture, women will be severely affected by climate change	Economic disparity along gender lines will increase
Access to Public Goods	Cuts in government expenditure to cope with climate change will affect all, but could fall disproportionately on the poor.	Costs of adaptation will be greater in poor countries, making them less able to maintain provision of other public goods.
Political and Social Freedoms	With possible social disruptions, freedoms could be eroded.	Effects of migration and could be felt in all countries, including the more well-to-do ones, affecting traditional liberties.

Different approaches to social justice can be applied to the evaluation of equity consequences of climate change policies. As the 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 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 a certain amount of emissions per capita allowed for all countries, irrespective of the costs of mitigation or the mitigative capacity. The literature also includes the capability approach that puts the emphasis on capacity to mitigate, but can also be can be interpreted as ensuring that opportunities and freedom are maintained.

2.6 Costs, benefits and potentials

The calculation of costs and benefits of climate change mitigation policies, as presented in this report, is very sensitive to the definitions and assumptions used. As part of the information for making choices involving efficiency and equity considerations, this report contains information on costs and impacts (benefits and side-effects) of climate mitigation policies and measures. The calculation of costs and impacts of climate change mitigation policies is very sensitive to the definitions and assumptions used. The following issues are of critical importance:

- scale: is the cost calculated at project, firm, technology, sectoral, community, regional, national or multi-national level?.
- *cost to whom?:* is the cost calculated from a private and financial perspective, or from a social perspective?
- *discount rate:* one major determinant of the present value of costs and benefits is the discount rate since climate change, and mitigation and adaptation measures all involve impacts spread over very long time periods. Much of the literature use constant discount rates at a level estimated to reflect time preference rates as used in assessment of typical large investments but recent literature suggests to use time decreasing discount rates for long-term issues like climate change, in order to reflect uncertainties about future economic growth, fairness and intra generational distribution. Such discount rates have been adopted by some government including the UK, France and USA.

- *implementation and transaction costs*: In practice, the implementation of climate change mitigation policies requires some transaction and implementation cost, but many studies due to methodological complexities do not take these costs fully into account.
- no regret options, ancillary impacts (benefits), and double dividends
  - *No-Regrets* Many project level and sectoral mitigation costing studies have identified a potential of GHG reduction options with a negative cost implying that the benefits, including co-benefits, of implementing the options are greater than the costs. Such negative cost options are commonly referred to as no regret options. They depend strongly on assumptions regarding market efficiency..
  - *Ancillary or co-impacts* Policies aimed at mitigating GHGs, as stated earlier, can yield other indirect social benefits and costs (herein called ancillary benefits and costs); other policies can equally yield some benefits and cost for GHG mitigation (ancillary from the other perspective); in many cases policies have multiple objectives and then we speak about co-benefits and co-impacts..
  - *Double dividend.* Instruments (such as taxes or auctioned permits) provide revenues to the government. If used to finance reductions in existing distortionary taxes (“revenue recycling”), these revenues reduce the economic cost of achieving greenhouse gas reductions.

There are different ways to define the potential for mitigation options and it is therefore important to specify what potential is meant. The measure “potential” is used to report the quantity of GHG mitigation compared with a baseline or reference case that can be achieved by a mitigation option with a given cost per tonne of carbon avoided over a given period. The measure is usually expressed in million tonnes carbon- or CO_2 equivalent emissions avoided compared with baseline emissions.
“Market potential” is the conventional assessment of the mitigation potential at current market price, with all barriers, hidden costs, etc in place. 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 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 in $/t$CO_2$ and $/t C eq. (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 and ancillary benefits.
“Technical potential” is the amount by which it is possible to reduce greenhouse gas emissions or improve energy efficiency by implementing a technology or practice that has already been demonstrated. There is no specific reference to costs here, only to “practical constraints” although in some cases implicit economic considerations are taken into account. Finally the “**physical potential”** is the theoretical (thermodynamic) and sometimes in practice rather uncertain upper limit to mitigation.

2.7 Technology research, development, deployment, diffusion and transfer

The cost and pace of any response to climate change concerns will depend critically on the cost, performance, and availability of technologies that can lower emissions in the future.
Technology simultaneously determines the size of the climate change problem and the cost of its solution. Technology is the broad set of processes covering know-how, experience and equipment, used by humans to produce services and transform resources. The principal role of technology in mitigating greenhouse gas emissions is in controlling the social cost of limiting greenhouse gas emissions. Numerous studies show significant economic value to the improvement of emissions mitigating technologies that are currently in use and the development and deployment of advanced emissions mitigation tech-

nologies.

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 deep emission reductions, the large variation in national circumstances and the uncertainty about performance of individual options. Uncertainties on pace and technology deployment rates (so called, 'baseline uncertainty') dominates over uncertainty in deployment of climate policy related technology ("stabilisation uncertainty").
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 for long-lived energy capital stock and infrastructures.

There are numerous paradigms used to separate the process of technological change into distinct phases. One approach is to consider technological change as roughly a two-part process which includes: (1) the process of conceiving, creating, and developing new technologies or enhancing existing technologies-the process of advancing the "technological frontier"- and (2) the process of diffusion or deployment of these technologies. Our understanding of technology and technology's role in addressing climate change continues to improve. Yet, the processes by which technologies are created, developed, deploy and are eventually replaced is complex and no simple description of these processes exist. Technology development and deployment is characterized by two public goods problems: the level of R&D is suboptimal because private decision makers cannot capture the full value of private investments that create new technologies, and an environmental externality problem, markets for greenhouse gas emissions mitigation are only primitively formed and do not reflect the long time scales and massive emissions mitigation that are ultimately required to address climate change. (see Figure TS.8)

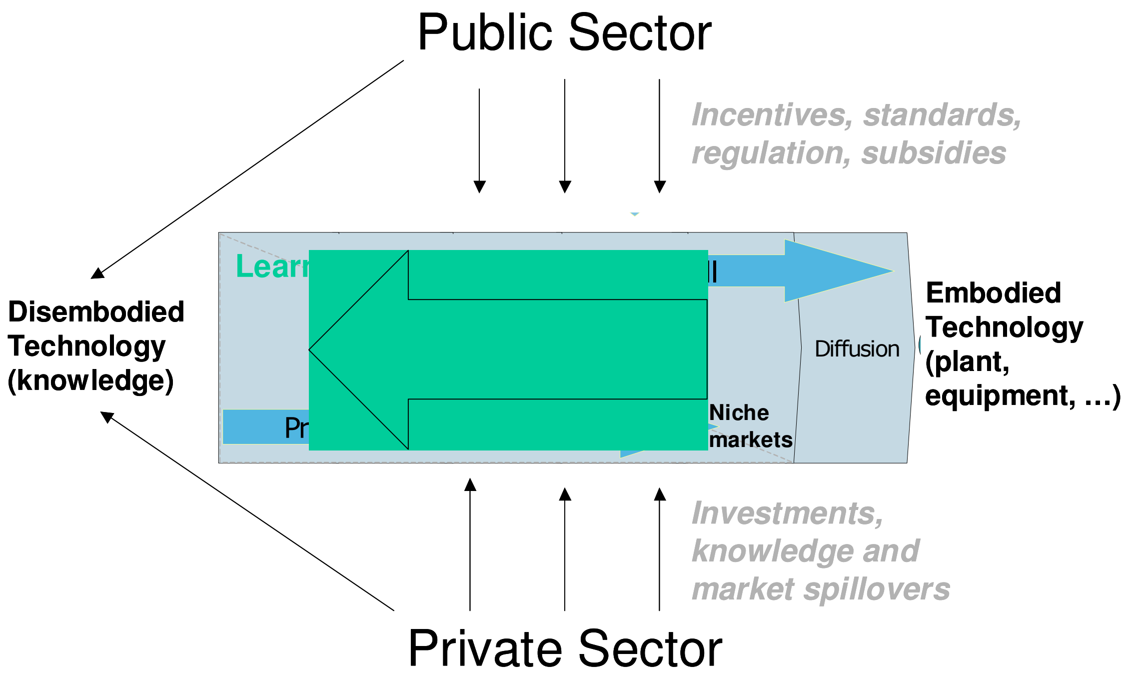


Figure TS.8 Describing the technology development cycle and its main driving forces. Note that important overlaps and feedbacks exist between the stylized technology life-cycle phases illustrated here and therefore the Figure does not suggest a "linear" model of innovation. It is important to recognize the need for finer terminological distinction of "technology", particularly when discussion different mitigation and adaptation options. Source: Adapted from Foxon (2003) and Grubb (2005).

These two processes are inextricably tied and both contribute to lowering costs. The set of available technology defines what might be deployed, and use of technology affords learning that can guide R&D programs or directly improve technology through learning-by-doing. The two processes are also linked temporally. The set of technologies that find their way into use necessarily lags the technological frontier. The useful life of technologies-their natural turnover rate-helps to drive the time relationship.

Three important drivers of new technology employment are: R&D, learning by doing and spillovers (transfer of knowledge or economic benefits of innovation from one entity to another).

- *R&D*: R&D encompasses a broad set of activities in which firms, governments, or other entities expend resources specifically to improve technology or gain new knowledge.
- *Learning by doing*: Learning-by-doing refers to the technology-advancing benefits that arise through the use or production of technology.
- *Spillovers*: Spillovers refer to the transfer of the knowledge or the economic benefits of innovation from one individual, firm, industry, or other entity to another.
- On the whole, the evidence strongly suggests that all three of the sources highlighted above - R&D, learning-by-doing, and spillovers - play important roles in technological advance and there is no compelling reason to believe that one is broadly more important than the others. The evidence also suggests that these sources are not simply substitutes, but may have highly complementary interactions.

Economic benefits from improved technology can be significant. They will be higher with a larger distance between current and future technology, with a lower stabilisation target and a more comprehensive suite of technologies. The literature strongly suggests substantial returns from R&D, social rates well above private rates in the case of private R&D (implying that firms are unable to fully appropriate the benefits of their R&D), and large spillover benefits. The literature also shows an irrefutable relationship between technological advance (typically measured in per-unit costs) and cumulative production volume over time (the learning effect).

The literature indicates an important relationship between environmental regulation and innovative activity on environmental technologies, implying that market forces stimulate private innovative activity (so called induced technological change). On the other hand, this work also indicates that not all technological advance can be attributed to the response to environmental regulation.

A consensus has emerged in the literature that the relative relevance of 'technology push' versus 'market pull' in delivering new products and processes cannot be determined; both are important. Technology-push emphasizes the role of policies that stimulate research and development especially those aimed to lower the costs of meeting long-term objectives with technology that today are very far from economic in existing markets. Demand-pull emphasizes the use of instruments to enhance the demand for lower-emissions technologies, thereby increasing private incentives to improve these technologies and inducing any learning-by-doing effects.

On technology transfer the main findings of the IPCC Special Report on the need to create the right enabling environment in host and recipient countries, remain valid (see Figure TS.9).

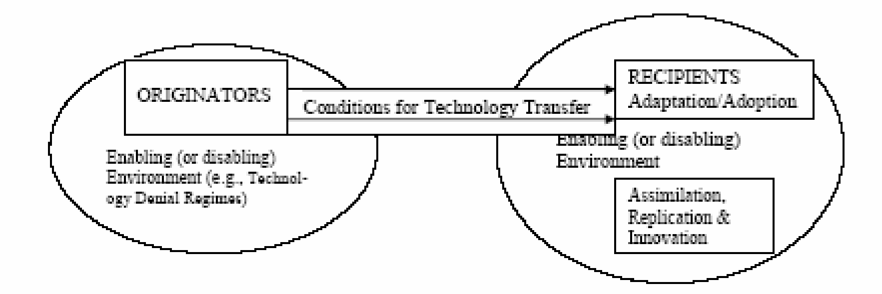


Figure TS.9 A general framework for technology transfer

3. Issues related to mitigation in the long term context

3.1 Emissions scenarios

The evolution of future greenhouse gas emissions and their underlying driving forces is highly uncertain. This is reflected in the very wide range of future emissions pathways across (more than 750 emissions) scenarios in the literature. The main finding from the comparison of older IPCC SRES and the new scenarios in the literature is that the uncertainties as represented by the ranges of main driving forces and emissions have not changed very much. Population projections are now generally lower, but they have not been implemented so far in many of the new emissions scenarios in the literature. Economic growth perspectives have not changed much even though they are among the most intensely debated aspects of the SRES scenarios. There have been some changes in the distribution of the carbon dioxide emissions. There are many more new (multigas) scenarios that include emissions of all greenhouse gases.

Climate change intervention or mitigation scenarios include measures and policies for reducing GHG emissions with respect to some baseline (or reference) scenario. Examples of policy intervention and mitigation scenarios are the 80 IPCC TAR scenarios and of reference and baseline scenarios are the 40 SRES scenarios. Stabilization scenarios are mitigation scenarios that aim at a pre-specified GHG reduction target or pathway. Usually the target is the concentration of CO_2, the CO_2 equivalent concentration of a 'basket' of gases (thus the name multigas), radiative forcing or temperature by 2100 or at some later date when atmospheric stabilization is actually reached.

3.2 Baseline scenarios

Demographers have revised their outlook on future population downward, based mainly on new data indicating that birth rates in many parts of the world have fallen sharply. Figure TS.10 demonstrates that the range of population projections has changed since the TAR. Recent projections indicate a small downward revision to the median outlook and to the high end of the uncertainty range, and a larger downward revision to the low end of the uncertainty range.

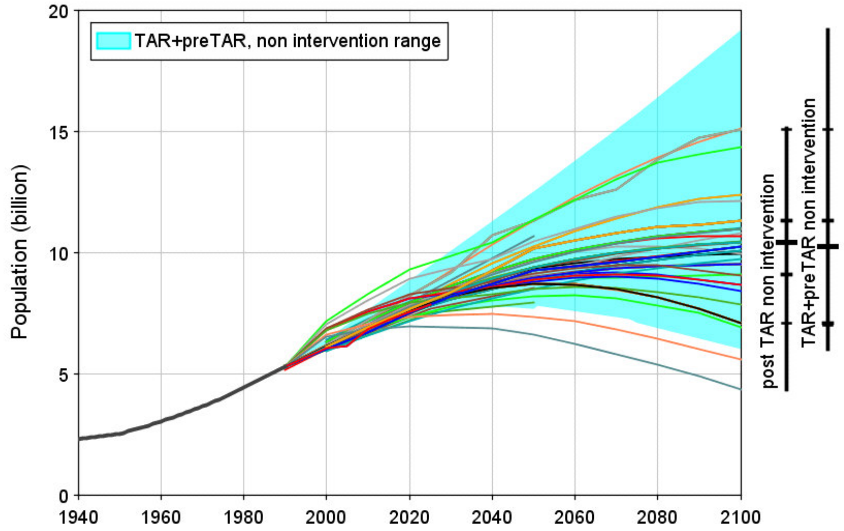


Figure TS.10: *Comparison of population assumptions in recent (post-TAR) emissions scenarios with those used in previous scenarios. Blue shaded areas spans range of 132 population scenarios used in TAR or pre-TAR emissions scenarios; individual curves show population assumptions in 85 emissions scenarios in the literature since 2001. Two vertical bars on the right extend from the minimum to maximum of the distribution of scenarios by 2100. The horizontal bars indicate the 5th, 25th, 50th, 75th and the 95th percentiles of the distributions. Data source: Nakicenovic et al., 2006.*

For long-term scenarios, economic growth is usually reported in the form of growth of gross domestic product (GDP) or gross national product (GNP). To get a meaningful comparison over time of the real size of economic activities, GDP is reported in constant prices taken from a base year. There are two main alternatives how to convert from one monetary unit to another: using the observed market exchange rate (MER) in a fixed year, or using a purchasing power parity (PPP) index (see Box TS.1).

Box TS.1 Market exchange rates and purchasing power parities

For international comparisons, GDP data must be converted into a common unit. The conversion can be based on observed market exchange rates (MER) or purchasing power parity estimates (PPP), in which a correction is made for differences in price levels for various goods among countries. PPP is currently considered the better alternative if data are used for welfare or income comparisons across regions. Usually, market exchange rates under value the purchasing power of currencies in developing countries.

Scenarios expressed in PPP are relatively few. Derivation of PPP exchange rates requires analysis of a relatively large amount of data. Hence, methods have been devised to derive PPP rates for new years based on price indices. Unfortunately, there is currently no single method or price index favoured for doing this, resulting in different sets of PPP rates (e.g. from the OECD, Eurostat, World Bank and Penn World Tables) although the differences tend to be small. This creates some practical difficulties in reporting economic scenarios based on PPP exchange rates and is one reason why economic scenario data are generally reported on the basis of MER - although for some models PPP values are also given.

GDP trajectories in the large majority of scenarios in the literature are calibrated in MER. A few dozen scenarios exist in the literature that use PPP exchange rates, but most of them are shorter-term, generally running out to 2030, such as the G-Cubed model, the IEA World Energy Outlook and the POLES model used by the European Commission. Some exceptions exist, more recent scenarios with the MERGE model.

Recently, the uses of MER-based economic projections have been criticized. A team of researchers responded to this criticism, indicating that the use of MER or PPP data does not in itself lead to different emission projections outside the range of the literature. The reason is that the choice of metric for economic activity clearly will also influence the numerical values of the emission coefficients. If a consistent set of metrics is employed, it is difficult to see why the choice of metric should affect the final emission level substantially, unless the share of the non tradable sector of the economy is very different in PPP based scenarios compared to MER based scenarios.
Also a growing number other researchers have indicated their different opinions on this issue or explored it in a more quantitative sense.

Figure TS.11 compares the income range of the 195 scenarios from the pre-TAR and TAR literature with the 121 new scenarios developed post-TAR. While there is a considerable overlap in the GDP numbers published, the median of the new scenarios is about the half of the median in the pre-TAR scenario literature because there are now many more scenarios with lower-growth assumptions. The data suggest that the upper as well as the lower bounds of the range of economic growth has remained unchanged in the current projections.

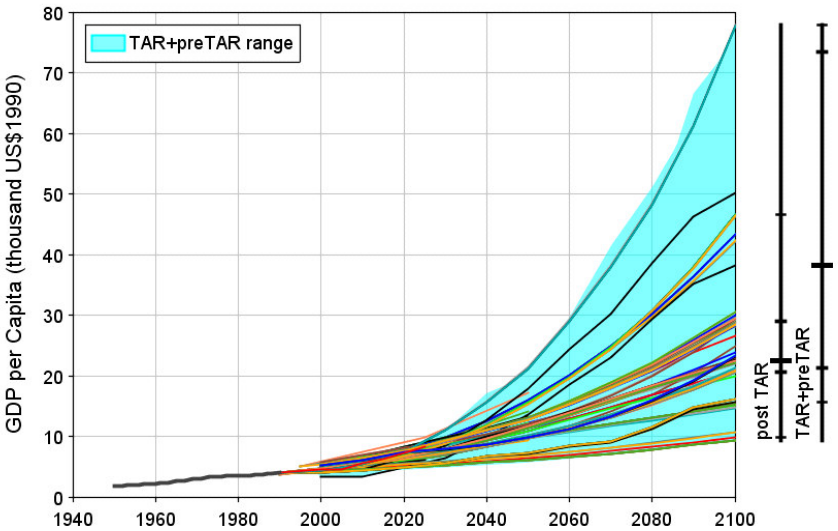


Figure TS.11: *More recent scenarios in the literature since the publication of TAR (post TAR) suggest that the upper as well as the lower bounds of the range of economic growth has remained unchanged. The median of the new scenarios is about the half of the median of the in the pre-SRES and TAR scenario literature. Two vertical bars on the right extend from the minimum to maximum of the distribution of scenarios by 2100. The horizontal bars indicate the 5th, 25th, 50th, 75th and the 95th percentiles of the distributions. Data source: Nakicenovic et al., 2006.*

The span of CO2 emissions across baseline scenarios in the literature is very large from 9.9 to around 132 GtCO2 eq (2.7-36 GtC). Figure TS.12 shows that the scenario range has declined since the TAR. In particular, there seems to have been a downward shift on the high end, but this difference is due to only eight high-emissions scenarios in the pre-TAR literature that extend beyond 40 GtC by 2100. Such high-emissions scenarios still exist but are not reported din the peer-reviewed literature since TAR. This new range is consistent with the SRES both in the short and long term. The majority of scenarios, both pre- and post-TAR indicate an increase of emissions across most of the century. However, there are some baseline (reference) scenarios both in the new and older literature where emissions peak and decline.

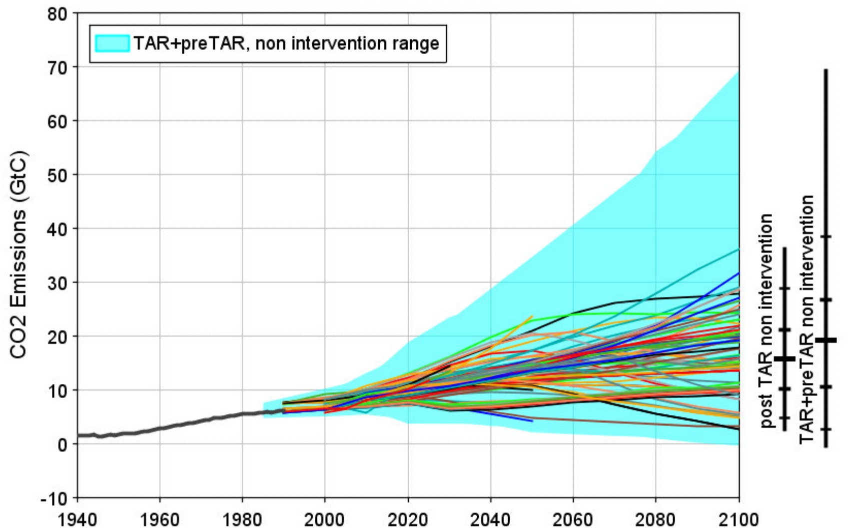


Figure TS.12: *Comparison of the TAR and pre-TAR energy-related and industrial CO_2 emissions scenarios in the literature with the post-TAR, scenarios. Two vertical bars on the right extend from the minimum to maximum of the distribution of scenarios by 2100. (Nakicenovic et al. 2006) Notes: Blue shaded areas spans range of 132 TAR or pre-TAR emission scenarios, individual curves show the results of 85 emissions scenarios in the literature since 2001. Vertical bars on the right extend from the minimum to maximum of the distribution of scenarios by 2100. The horizontal bars indicate the 5th, 25th, 50th, 75th and the 95th percentiles of the distributions. Source: Nakicenovic et al. 2006.*

Land-use change carbon emissions are projected to increase in the near future and decline over time (see Ch 3, Figure 3.2-11), leading to net sequestration by the end of the century in some scenarios. The recent scenarios suggest a greater degree of expert agreement than in the past. The baseline emissions scenarios are driven by projected increases in cropland requirements at the expense of forest area due to global food demand, which grows at a decreasing rate, and shifts in dietary preferences towards meat consumption. Long-run conversions to agricultural land are projected to slow, or reverse, as population levels off and improved crop productivity reduces deforestation pressure. Non-CO_2 GHG emissions from land-use are projected to increase throughout the century, potentially doubling.

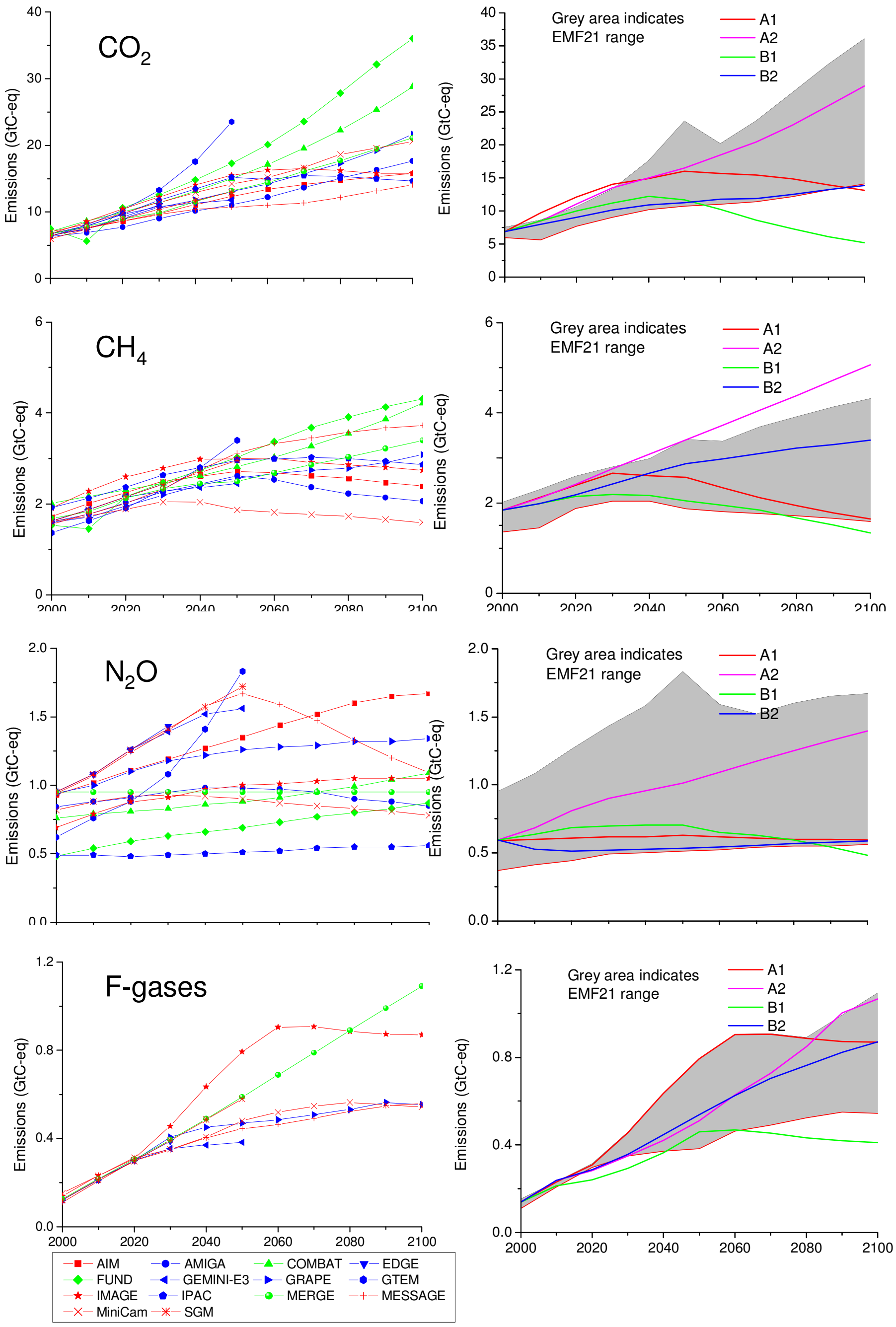


Figure TS.13: *Development of baseline emission in the EMF-21 scenarios (left) and comparison between EMF21 and SRES scenarios (right).*

Emissions of non-CO2 GHG as a group are projected to increase, but somewhat less rapidly as CO2 emissions, because the most important sources of CH_4 and N_2O are agricultural activities growing less than energy use. Including the F-gases gives a total of non-CO_2 emissions in 2100 in the range from 9.9 to 33.6 MtCO_2 eq (2.7-9.2 Mt Ce).

Figure TS.13 compares the EMF-21 baseline scenario emissions with those of SRES including energy as well as non-energy emissions of CO_2, CH_4, N_2O and F-gases. For most other drivers, scenarios published since TAR show a similar range as those published before TAR (and in SRES). A major exception are emissions of SO_2 and NO_x. As short-term emissions of these pollutants have decreased, the range of projections for both are currently lower than the range published before TAR.A small number of new scenarios have begun to explore emission pathways for black and organic carbon.

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

3.3 Stabilization scenarios

A commonly used target in mitigation literature is stabilization of CO_2 concentrations in the atmosphere. If more than one GHG is studied, a useful alternative is to formulate a GHG concentration targets in terms of radiative forcing, thereby weighting the concentrations of the different gases by their radiative properties. Another option is to stabilise 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 risks or probability of exceeding particular values of global annual mean temperature rise since pre-industrial times looking across various stabilization or radiative forcing targets.

Box TS.2 Comparison of different GHGs

In a multi-gas studies, a method is needed to compare different greenhouse gases with different atmospheric lifetimes and different radiative properties. Ideally, the method would allow for substitution between gases (in order to achieve cost effective reductions) but ensure equivalence in climate impact. One of these methods, CO_2 equivalent emissions based on Global Warming Potentials (GW_p), has been adopted by current climate policies, such as the Kyoto Protocol and the United States climate policy. Despite the continuing scientific debate on the use of GWPs (that is, they are not based on economic considerations and use an arbitrary time horizon) the concept is regarded as convenient and is widely used. Having an exchange metric to facilitate emissions trading between gasses broadens the set of abatement alternatives, creating the potential opportunity for cost savings through ‘what flexibility’ (i.e. substitution among gases) in reduction strategies. Therefore, it is appropriate to ask what are the costs of using GWPs versus not using them; and, whether other ‘real world’ metrics exist that could perform better. It has been found that the cost of using GWPs compared with optimal weights depends on the ambition of climate policies. GWPs have the advantage of not needing a particular target (e.g., long term stabilization).

A large number of studies focusing on climate stabilization have been published since TAR. Several model comparison projects contributed to the new literature, including the Energy Modelling Forum’s EMF19 and EMF21 studies that focused on technology change and multigas studies respectively, the IMCP (International Model Comparison Project) that focused on technological change, and other modelling work.

The new multigas literature shows that multigas reduction strategies give substantially lower costs than CO2-only strategies, where the timing of mitigation of the short-lived gases is determined by how the substitution of gases is defined (see Box TS.2). If global warming in future decades is viewed as less critical then it would be economically more efficient to trigger abatement of short lived gases only after more information on climate change risks has become available to facilitate switching to possibly very tight concentration constraints.

There is a clear and strong correlation between the radiative forcing and the CO_2 concentrations by 2100 because CO_2 is the most important contributor to radiative forcing. Based on this relationship, to facilitate scenario comparison and assessment, we have classified stabilization scenarios into five different categories that vary in the stringency of the climate targets. The most stringent is category A. It groups (multi-gas) scenarios that stabilize radiative forcing below 3.25 W/m^2 and CO_2-only scenarios that stabilise CO_2 concentrations below 420 ppm. The least stringent is category E. It consists of mitigation scenarios have a radiative forcing in 2100 above 6 W/m^2 CO_2-only concentrations of above 660 ppm. Other three categories, B, C and D are intermediate. By far the most studied group of scenarios are those that aim to stabilize radiative forcing at 4 to 5 W/m^2 or 490 to 570 ppm CO_2 (Table TS.4).

Table TS.4: *Groups of mitigation scenarios for ranges of stabilization targets and alternative stabilization metrics*

Category	Additional radiative forcing	CO_2 concentration	CO_2 - eq. concentration	Global mean temperature increase above pre-industrial, at equilibrium, using best guess clim. sensitivity[2] [3]	No. of scenarios
	W/m^2	ppmv	ppmv	^{0}C	
A	< 3.25	< 420	<510	1.3-2.6	16
B	3.25 - 4	420 - 490	510-590	2.6-3.3	9
C	4 - 5	490 - 570	590-710	3.3-4.1	83
D	5 - 6	570 - 660	710-860	4.1-4.9	6
E	> 6	> 660	<860	4.9-5.5	3
Total					117

Figure TS.14 shows the projected CO_2 emissions associated with the new mitigation scenarios. In addition, the figure depicts the range of the TAR stabilization scenarios, comprised of more than 80 scenarios that are stabilizing atmospheric CO_2 between 450 and 750 ppmv.

Independent of the stabilization level, scenarios show that the scale of the emissions reductions required relative to the reference scenario increases over time. Essentially, any specific concentration or radiative forcing target requires emissions to fall very low 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 given stabilization ultimately the emissions must be reduced well below current levels, to almost zero.

An increasing body of literature is assessing the attainability of very low targets of 350 ppmv CO_2 and below (category A). An important characteristic of the new stabilization scenarios (black lines in Figure TS.14) is thus that they extend beyond the lower boundary of the range of TAR stabilization scenarios of 450 ppmv CO2 (see upper left panel of Figure TS.14).

[2] Note that global mean temperature at equilibrium is different from expected global mean temperatures in 2100 due to the inertia of the climate system
[3] These equilibrium temperatures follow from the equivalent CO2 concentration value and the simplified expression for equilibrium temperatures as used in WG I, Chapter 10, section 10.7.2

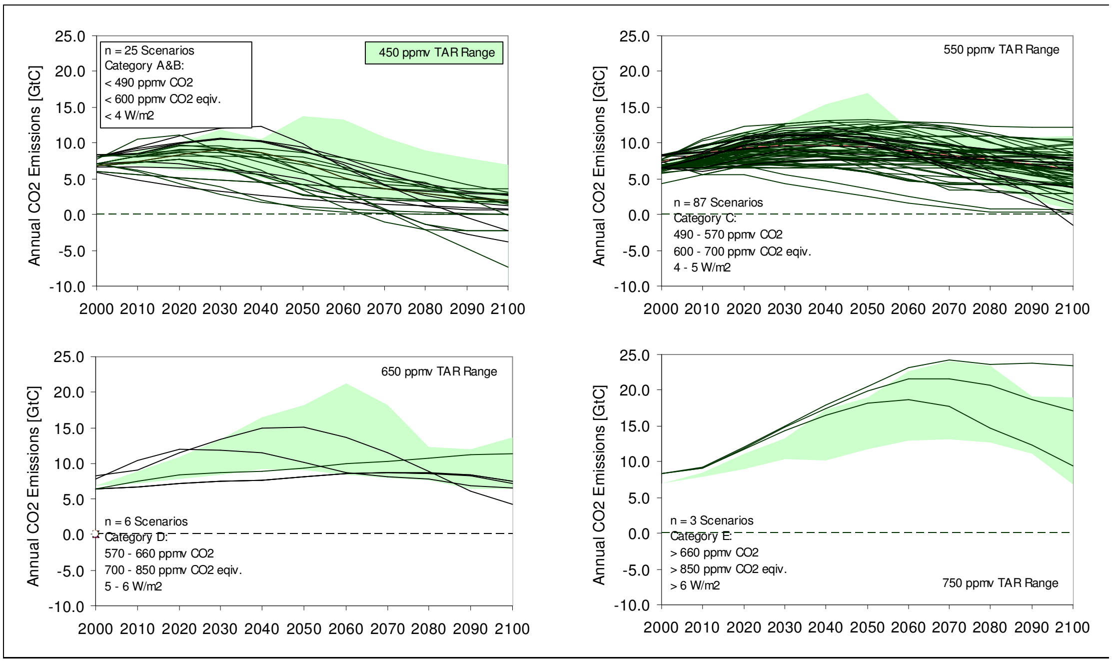


Figure TS.14: Emissions pathways of mitigation scenarios for alternative groups of stabilization targets (Category ! to E, see Table TS.4. Black lines give the projected CO_2 emissions for hte recent mitigation scenarios developed post TAR (Source: Nakicenovic et al., 2006, and Kainuma et al., 2006). Green shaded areas depict the range of more than 80 TAR stabilization scenarios.

[1] Note that global mean temperature at equilibrium is different from expected global mean temperatures in 2100 due to the inertia of the climate system.

[2] These equilibrium temperatures follow from the equivalent CO_2 concentration value and the simplified expression for equilibrium temperatures as used in WG I, Chapter 10, section 10.7.2).

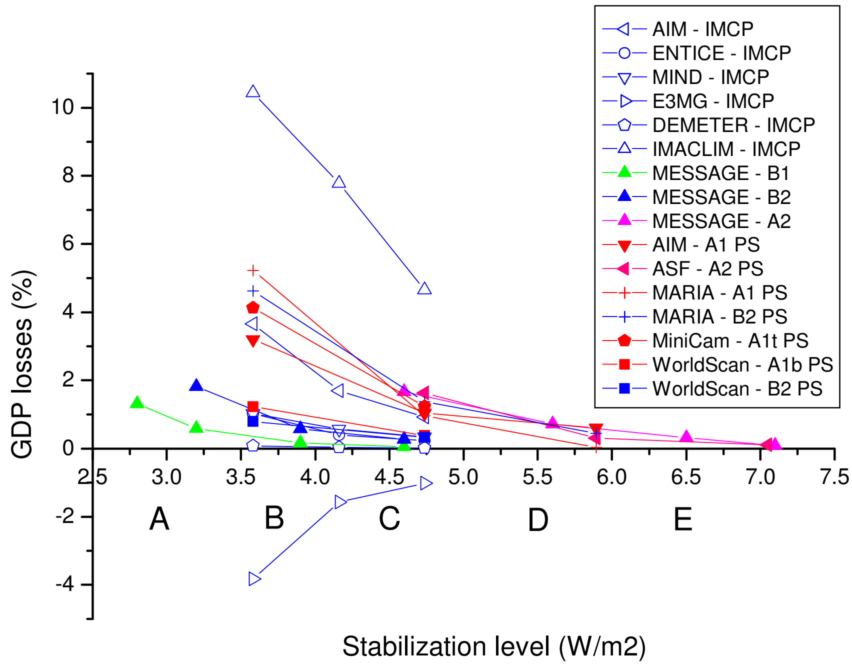
The different scenario categories also reflect different contribution of mitigation measures. However, all stabilization scenarios concur that 60 to 80 percent of all reductions would come from the energy and industry sectors. Non-CO_2 gases and land-use would contribute the remaining 30 to 40 percent. Models suggest significant land use related mitigation in stabilisation, but diverge on land mitigation's share and timing, in part due to differences in the modelling of competition for land. In general, recent stabilization studies have found that including land-use mitigation options (both non-CO_2 and CO_2) provided greater flexibility and cost-effectiveness, with absolute land based emissions reductions projected to increase over time with biomass providing most of the cumulative land based mitigation, and possibly a quarter of total mitigation over the century when combined with CO_2 capture and storage.

The baseline choice is crucial in determining the nature and cost of stabilization. This influence is largely due to different assumptions made about technological change in the baseline scenarios. Literature identifies low-cost technology clusters allowing for endogenous technological learning with uncertainty. This suggests that a decarbonised economy may not cost any more than a carbon-intensive one, if technological learning curves are taken into account.

The costs of stabilization depends on the stabilization target and level, the baseline and the portfolio of technology considered and the rate of technology change.

Global mitigation costs4 rise with lower stabilisation levels and with higher baseline emissions. Costs for multigas stabilisation at 650 ppmv CO_2 eq are generally below 2% loss of GDP in 2050, but a few studies give higher or negative numbers. For 550ppmv CO_2 eq these costs are 1 to 5% loss of GDP[5] ,again with a few studies giving higher or negative numbers; for 450 ppm CO_2 eq there are too few studies to give reliable estimates. (see Fig TS.15). A multi-gas approach and inclusion of carbon sinks generally reduces costs substantially compared to CO_2 emission abatement only. Global average costs of stabilisation are uncertain, because assumptions on baselines and mitigation options in models vary a lot and have a major impact. Costs could vary considerably from the global and long-term average for some countries, sectors, or shorter time periods.

a) Selected studies reporting GDP losses



[4] These results are from top-down models that assume least cost application of mitigation in all regions, but do not make assumptions on who should pay for this mitigation

[5] Loss of GDP with 1-5% in 2050 is equivalent to a reduction of the annual GDP growth rate of 0.03 - 0.1 percentage points.

b) Selected studies reporting abatement costs

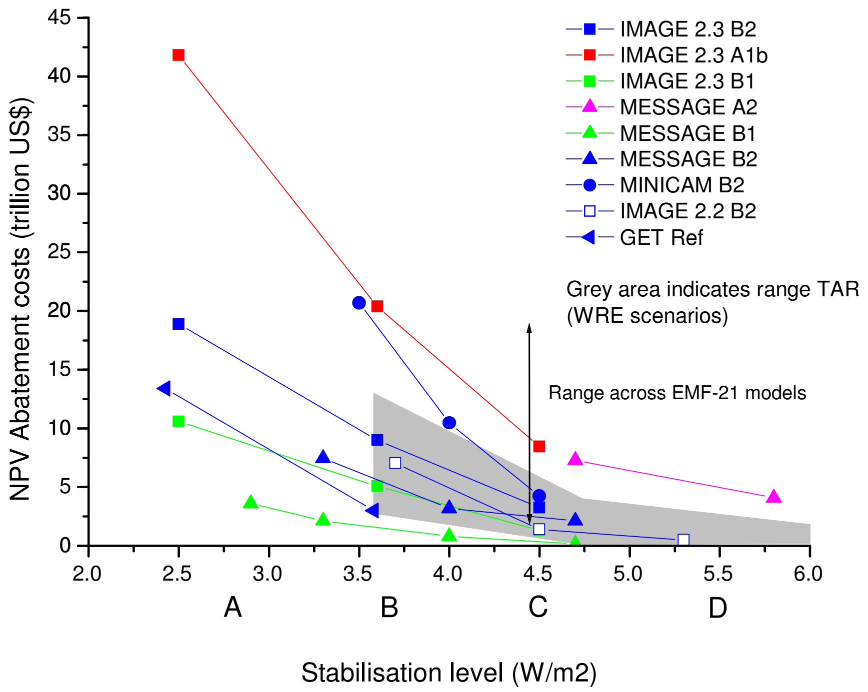


Figure TS.15: Selected of studies that report GDP losses (a) or abatement costs (b) as a function of the stabilization level. For GDP, reduction in 2050 is reported. For abatement costs, the Net Present Value of abatement costs in the 2000-2100 period are reported using a 5% discount rate. The range of EMF-21 models instead is indicated based on a proxy of abatement costs by multiplying the marginal price and reduction rates

Different stabilization targets can lead to somewhat different strategies in emission reduction.

- New studies exploring more stringent stabilization levels indicate that a wider portfolio of technologies are needed. Those could include nuclear, CCS and BECCS.

The scenarios show that a multigas approach and inclusion of carbon sinks will be less costly than policies depending upon CO2 abatement only. This is especially true with reduction goals based on the possibility of abrupt climate change. That is, when a policy concern is the avoidance of a near-term climate threshold, increased focus needs to be on the shorter lived gases, eg, CH_4. This more diversified approach provides greater flexibility in the timing of the reduction program.

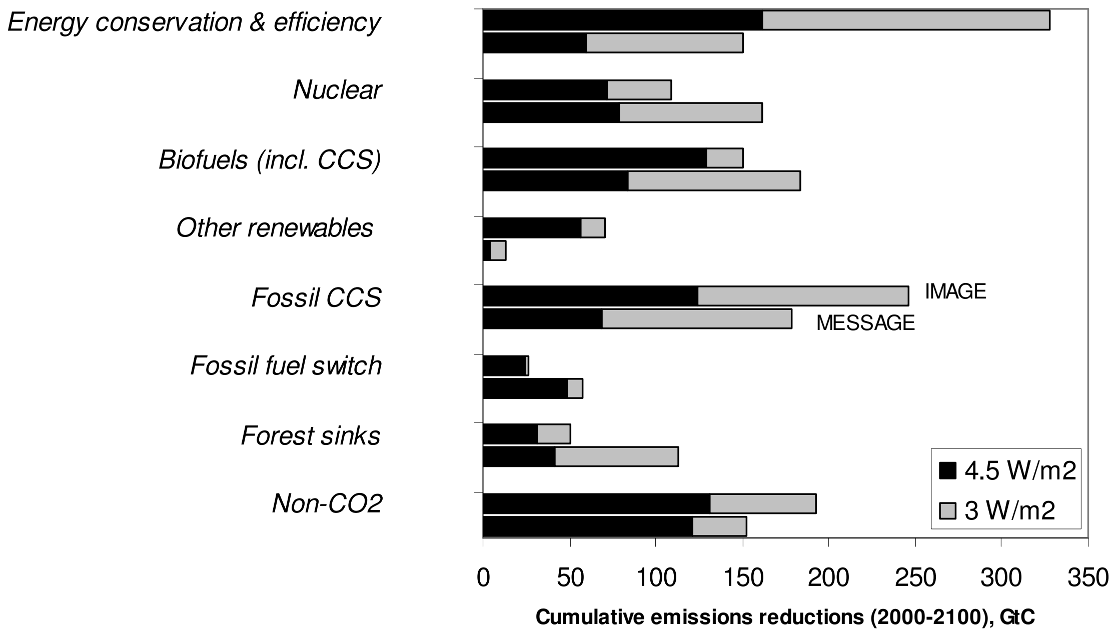


Figure TS.16: *Cumulative emissions reductions for alternative mitigation measures (2000-2100). The figure shows scenarios from two illustrative models (IMAGE and (MESSAGE) aiming at the stabilization of radiative forcing for 3 and 4.5 W/m^2 repectively. Black bars denote reductions for a target of 4.5 W/m^2 and grey bars the additional reductions to achieve 3 W/m^2. Data source: Van Vuuren et al., 2006, and Riahi et al., 2006.*

Figure TS.16 illustrates the importance of a wide portfolio of reduction measures, with most of the measures showing contributions of more than 50 GtC over the course of the century (in at least one of the two modeling frameworks). The numbers should be seen as indicative because they are from just two models. The strong agreement between the two models with respect to the large potential of energy conservation, biomass, carbon capture and storage, nuclear and non-CO_2 gases nevertheless indicates the possible potential of these measures as part of the mitigation portfolio. Also illustrated in Figure TS.16 is the increase of emissions reductions that become necessary when the target moves from 4.5 to about 3 W/m^2. Most of the mitigation options increase their contribution significantly by up to a factor of more than two.

3.4 The role of technologies

Technology is among the central driving forces of GHG emissions. It is one of the main determinants of economic development, consumption patterns and thus human well being. At the same time, technology and technological change offer the main possibilities for reducing future emissions and achieving the eventual stabilization of atmospheric concentrations.

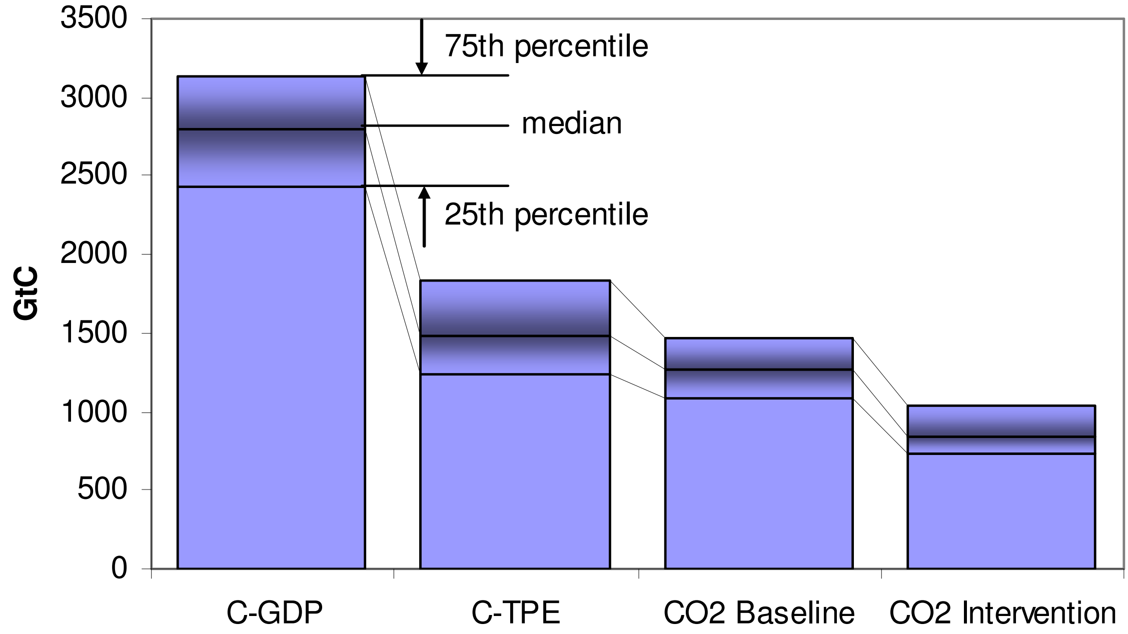


Figure TS.17: *Median, 25th and 75th percentile of global cumulative carbon emissions by 2100 in the scenarios developed since 2001: The range labeled C-GDP refers to hypothetical futures without improvement in energy and carbon intensities in the scenarios, the range labeled C_TPE keeps only carbon intensity of energy constant while energy intensity of GDP is the same as originally assumed in scenarios, the range labeled CO_2 baseline are the 39 baseline scenarios in the database, while the region labeled CO_2 intervention includes 140 mitigation and/or stabilization scenarios. Source: After Nakicenovic et al. (2005).*

Virtually all scenarios assume that technological and structural changes occur during this century leading to relative reduction of emissions compared to the hypothetical case of attempting to 'keep' emissions intensities of GDP and structure the same as today (see Ch. 2, Section 2.9.1.3). Figure TS.17 shows a hypothetical range of cumulative emissions under the assumption of 'freezing' technology and structural change in all scenarios at current levels, but letting populations change and economies develop as assumed in the original scenarios. The bars in the figure give the cumulative emissions ranges between the 25th and the 75th percentile of the scenarios in the scenario database.[6] The hypothetical cumulative emissions (without technology and structural change) range from 2427 (25th percentile) to 3133 (75th percentile) with a median of 2804 GtC by 2100.

The next bar in Figure TS.17 shows cumulative emissions by keeping carbon intensity of energy constant while allowing energy intensity of GDP to evolve as originally specified in the underlying scenarios. The third bar in Figure TS.17 also allows carbon intensities of energy to change as originally assumed in the underlying scenarios. Together the baseline assumptions lead to substantial reductions of cumulative emissions, by some 13 to more than 20 per cent (25th and 75th percentile, respectively), or less than half of emissions, as compared to the case of no improvement of energy or carbon intensities.

The next and final step is to compare the cumulative emissions across baseline scenarios with those in the mitigation and stabilization variants of the same scenarios. Figure TS.17 shows in the last bar yet another

[6] The outliers, above the 75th and below the 25th percentile are discussed in more detail in the subsequent sections.

significant reduction of future cumulative emissions from 728 to 1032 (corresponding to the 25th to the 75th percentile of the full scenario range) with a median of 847 GtC by 2100. This corresponds to about 70 per cent emissions reduction across mitigation scenarios compared to the hypothetical case of no changes in energy and carbon intensities and still a large, or about a 30 per cent reduction compared to the respective baseline scenarios.[7]

Baseline scenarios usually assume significant technological change and diffusion of new and advanced technologies. In mitigation scenario's 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 for both achieving the stabilization targets as well as 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 employment of technologies leads to benefits of learning and cost reductions in the end.

In mitigation scenarios, diffusion of carbon-saving technologies takes many decades due to long lifetimes of energy and infrastructure capital stock. This is the reason why in the short-term, emissions either continue to increase or reach a maximum in most of the stabilization scenarios. Deeper reductions occur in latter decades as carbon-saving technologies acquire larger market shares due to mitigation measures and policies introduced in stabilization scenarios.

3.5 Interaction between mitigation and adaptation

Possible responses to climate change include a portfolio of measures. In the search for an appropriate mix of near term actions, there are implicit tradeoffs between the investment in mitigation and in adaptation and the amount of residual climate impacts that society is either prepared to or forced to tolerate.

Recent assessments of the interactions between these alternative response policies indicate that they are complementary rather than alternatives. Climate change is partly inevitable in the coming decades, owing to the inertia of the climate system, and most of the direct climate benefits of mitigation measures will not be felt until later this century (important near-term co-benefits are possible, e.g., air quality improvements). Adaptation will be necessary even if drastic mitigation is implemented, however, there are limits to adaptation. Thus if climate impacts are to be avoided, mitigation will also be necessary. A combined consideration of the costs and benefits of mitigation vis-à-vis those of adaptation and impacts can provide insights for long term mitigation strategies, including consideration of the distribution of costs and benefits of each across sectors and regions of the world.

One of the methodological challenges in assessing any economic trade-off among the levels of mitigation, adaptation and residual impacts is valuing and aggregating the damages (impacts) of climate change across differing locations. Many authors point to the need for monetized metrics of climate change impacts and their economic consequences in formal policy analysis. However increasingly there is recognition that a range of different monetary and physical impact metrics can be used to inform policy decisions.

[7] In comparison, the full range of cumulative emissions from mitigation and stabilization scenarios in the database is from 214 to 1853 GtC.

These trade-offs between adaptation, mitigation and residual impacts are intertwined with development pathways. Development pathways determine adaptive and mitigative capacity, as well as sensitivity and vulnerability to climate change. Another important question is how different emission pathways leading to stabilization of concentrations relate to possible policy targets, such as a possible threshold or upper bound for GMT increase.[8] In general, for a given target both early action and delayed response emissions profiles can be developed. Table TS.5 provides an overview of the implications of different stabilization targets for the timing of global emission reductions.

Table TS.5: *Properties of emissions pathways for alternative ranges of CO_2 and CO_2 eq. stabilization targets. All stabilization scenarios in the scenario database (see also sections 3.2 and 3.3; data source Nakicenovic et al., 2006 and Hanaoka et al., 2006)*

Scenario Category	CO2-only concentrations by 2100	CO2-equivalent concentrations by 2100	Year when global emissions peak	Year when global emissions fall below 2000 levels	Change in global emissions in 2050 relative to 2000 levels	Change in global emissions in 2100 relative to 2000 levels
	ppmv	ppmv	year	year	%	%
The 90th precentile range of the stabilisation scenarios in the literature						
A	< 420	<510	2000 - 2040	2000 - 2060	-86 to +18	-161 to -67
B	420 - 490	510-590	2000 - 2050	2000 - 2060	-41 to +33	-91 to -38
C	490 - 570	590-710	2010 - 2080	2010 - dnr	-3 to +73	-85 to +47
D	570 - 660	710-860	2030 - 2100	2060 - dnr	+27 to +116	-24 to +81
E	> 660	>860	2040 - 2090	2100 - dnr	+67 to + 143	-5 to +186

Long term mitigation policy in a risk management framework is informed not only by concern about costs and mitigation options (see 3.3 and 3.4) but also by concern about climate change impacts. Global mean temperature can be used as a key indicator of change that links future emission pathways and mitigation scenarios to climate impacts (see TableTS.6).

[8] Meinshausen (2006) also carried out a probabilistic analysis of transient exceedance of temperature thresholds (note that Table TS3.1) refers to equilibrium temperature rises), for which the probabilities would differ from Table TS3.2 and would be emission-pathway dependent as well as stabilization-level dependent.

Table TS.6 Ranges of radiative forcing, CO_2 eq. concentrations and temperatures (table 3.5-2)

Stabilization concentration (CO_2 equivalence)	Equilibrium Warming with best-guess climate sensitivity[9]		Probability to stay below equilibrium warming level[10]						
			above pre-industrial	1.5°C	2°C	2.5°C	3°C	3.5°C	4°C
	above pre-industrial	above 1980-2000 average	above 1980-2000 average	1.0°C	1.5°C	2.0°C	2.5°C	3.0°C	3.5°C
350 ppm	1.0°C	0.5°C		very likely	very likely	Very likely	Very likely	very likely	Very likely
400 ppm	1.6°C	1.1°C		medium	likely	Very likely	Very likely	very likely	Very likely
450 ppm	2.1°C	1.6°C		unlikely	medium	likely	likely	very likely	Very likely
500 ppm	2.5°C	2.0°C		very unlikely	unlikely	medium	likely	likely	Very likely
550 ppm	3.0°C	2.4°C		very unlikely	unlikely	unlikely	Medium likelihood	likely	Very likely
600 ppm	3.3°C	2.8°C		very unlikely	very unlikely	unlikely	Medium likelihood	medium likelihood	likely
650 ppm	3.7°C	3.2°C		very unlikely	very unlikely	unlikely	unlikely	medium likelihood	likely
700 ppm	4.0°C	3.5°C		very unlikely	very unlikely	very unlikely	unlikely	medium likelihood	Medium likelihood
750 ppm	4.3°C	3.8°C		very unlikely	very unlikely	very unlikely	unlikely	unlikely	Medium likelihood
800 ppm	4.6°C	4.1°C		very unlikely	very unlikely	very unlikely	unlikely	unlikely	Medium likelihood
850 ppm	4.8°C	4.3°C		very unlikely	very unlikely	very unlikely	Very unlikely	unlikely	unlikely
900 ppm	5.1°C	4.6°C		very unlikely	very unlikely	very unlikely	Very unlikely	unlikely	unlikely
950 ppm	5.3°C	4.8°C		very unlikely	very unlikely	very unlikely	Very unlikely	unlikely	unlikely
1000 ppm	5.5°C	5.0°C		very unlikely	very unlikely	very unlikely	Very unlikely	very unlikely	unlikely

Legend:

very likely	likely	medium likelihood	unlikely	very unlikely
>90%	66%-90%	33%-66%	10%-33%	<10%

In summary, integrated assessment tools facilitate integration of knowledge about climate change risk, mitigation strategies and economic development to explore the trade-offs and interactions between mitigation, adaptation and avoided impact damages. Compared to the TAR, several new issues emerge in this literature with implications for long-term mitigation strategies: more sophisticated, probabilistic representation and a shift in the range of climate sensitivity; a growing understanding of key vulnerabilities, including from abrupt change in geophysical systems, at relatively low levels of climate change (e.g. in the 2-4 C range and possibly in the 0-2 C range); recognition of the broad inter-linkages between climate change and economic development, potentially raising the stakes for "good" decision-making to address the risks of climate change.

3.6 Linkages between short term and long term

For a given vision of the adaptation potential to adverse impacts of climate change, policymakers must determine whether the present emissions trajectory is consistent with the possible range of

[9] Note that global mean temperature at equilibrium is different from expected global mean temperatures in 2100 due to the inertia of the climate system. These equilibrium temperatures follow from the equivalent CO2 concentration value and the simplified expression for equilibrium temperatures (namely dT = (ln(CO2 eq/278ppm))/ln(2))*S, where CO2 eq is the equivalent concentration level, and S the climate sensitivity - see AR-4 WG1, Chapter 10, section 10.7.2).

[10] These probability estimates are derived for illustrative purposes by assuming WG1's estimate of the likely range of climate sensitivity, 2.0°C to 4.5 °C, as being a 80% confidence interval of a lognormal distribution. This translation of a confidence range into a lognormal probability density function (pdf) is equivalent to the applied procedure in e.g. Wigley & Raper (2001), who assumed the IPCC TAR's climate sensitivity estimate of 1.5°C to 4.5°C as being a 90% confidence interval of a lognormal pdf.

long term GHGs stabilization objectives and the sensitivity of various end points to near term decisions.

For a given discount rate and risk premiums, factors affecting the timing of policy action include the level of concentration or temperature targets, the effect of technical and socio-economic system dynamics on short term mitigation efforts; and the influence of non-CO_2 gases and sequestration options on the time profile of decarbonisation efforts.

With damage functions exhibiting smooth but incremental increases followed by steeper increases later on, GHG abatement is postponed because, for several decades, the temporal rate of increase in marginal climate change damage remains far lower than the discount rate (which lowers the marginal damages over time). Recent modelling has shown that including even small probabilities of catastrophic events may substantially alter near term optimal emissions targets and raise the optimal carbon tax. It has been concluded that cost benefit analysis can justify any emission reduction targets if 'nasty surprises' in the climate system are considered.

For any chosen greenhouse gas 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.

Table TS.7 illustrates the global mitigation potential estimates by sector in the year 2030 across a range of scenarios with stabilization targets in the 4 to 5 W/m^2 range. The marginal cost of meeting the potential emission reduction estimates of up to approximately 16,000 $MtCO_2eq$ across all greenhouse gases in the top down model scenarios ranges from less than \$10/tCO_2eq to approximately \$60/tCO_2eq. Three important considerations need to be remembered with regard to the reported marginal costs. First, these mitigation scenarios assume complete "what" and "where" flexibility, i.e., 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 greenhouse gases varies significantly across the different model scenarios.

Table TS.7: *Global Emission Reductions in 2030 by Sector for Stabilization Targets of 4-5 W/m²*

	Model	IPAC	GRAPE	AIM	MiniCAM	MERGE	IMAGE	MESSAGE	WIAGEM	POLES	SGM
	Model Time Horizon	Long term	Long term	Long term	Long term	Long term	Long term	Long term	Long term	Short term	Short term
	Stabilization Target	550 ppmv	4.5 W/m² from pre-Industrial	4.5 W/m² from pre-Industrial	4.5 W/m² from pre-Industrial	4.7 W/m² from pre-Industrial	4.5 W/m² from pre-Industrial	B2 Scenario, 4.5 W/m² from pre-Industrial	2°C from pre-Industrial	550 ppmv	from Mini-CAM trajectory
	Marginal Cost (2000 U.S. $/tCO2eq)	$14	$2	$29	$12	$15	$18	$9	$9	$57	$21
	Reference Emissions 2030 Total All Gases ($MtCO_2eq$)	55,311	57,030	49,365	54,217	47,243	65,465	57,801	43,100	53,031	53,452
Sector Mitigation Potential in 2030 (Total All Gases $MtCO_2eq$)	Energy Supply: Electric	6,413	529	5,190	7,346	653	2,400	1,109	6,952	9,459	3,012
	Energy Supply: Non- Electric	579	37	1,083	1,486	412	2,204	517	1,741	2,964	1,660
	Transportation Demand	806	56	487	206	Included in another sector	1,318	276	Included in another sector	467	462[b]
	Buildings Demand	625	389	478	287	Included in another sector	754	531	Included in another sector	983	Included in another sector
	Industry Demand	1,231	Included in another sector	469	1,726	Included in another sector	846	136	Included in another sector	1,879	Included in another sector
	Industry Production	10	276	837	228		1,133	339	3,593	807	1,631[b]
	Agriculture	-1,012	583	2,000	267		690	584	1,128	-175	4,210
	Forestry	Included in another sector	0	13	0	1,462[a]	1,444	40	16	Incl. in another sector	Incl. in another sector
	Waste Management	0	4	Included in another sector	340		677	896	Incl. in another sector	Incl. in another sector	837
	Global Total	**8,652**	**1,875**	**10,556**	**11,885**	**2,527**	**11,465**	**4,428**	**15,531[d]**	**16,384**	**14,026[c]**
Mitigation as % Reference Emissions		**16%**	**3%**	**21%**	**22%**	**5%**	**18%**	**8%**	**36%**	**31%**	**26%**

[a] MERGE sector mitigation potentials for Industry Production, Agriculture, Forestry and Waste Management are aggregated.
[b] SGM sector mitigation potentials for Transportation Demand and Industry Production are not complete global representation due to varying levels of regional aggregation.
[c] SGM sector mitigation potentials do not sum to global total due to varying levels of regional aggregation.
[d] WIAGEM sector mitigation potentials do not sum to global total due to the breakout of the household and chemical sectors.

Table TS.8: *Global Emission Reductions in 2030 by Sector for Lower Stabilization Targets*

	Model	MiniCAM	MERGE	IMAGE[b]	IMAGE[b]	MESSAGE
	Model Time Horizon	Long-term	Long-term	Long-term	Long-term	Long-term
	Stabilization Target	3.5 W/m^2 from pre-Industrial	3.4 W/m^2 from pre-Industrial	3.7 W/m^2 from pre-Industrial	3.0 W/m^2 from pre-Industrial	B2 Scenario, 3.2 W/m^2 from pre-Industrial
	Marginal Cost (2000 U.S. $/tCO2eq)	$53	$192	$48	$112	$115
	Reference Case Emissions in 2030 Global Total All Gases ($MtCO_2eq$)	54,217	47,243	59,735	59,735	57,801
Sector Mitigation Potential in 2030 (Total All Gases $MtCO_2eq$)	Energy Supply: Electric	11,945	9,533	3,853	8,736	4,296
	Energy Supply: Non-Electric	3,308	3,188	2,252	3,669	2,242
	Transportation Demand	627	Included in another sector	1,491	2,840	2,238
	Buildings Demand	1,372	Included in another sector	522	1,000	1,420
	Industry Demand	5,222	Included in another sector	1,612	3,188	795
	Industry Production	270		1,126	2,024	811
	Agriculture	604	3,580[a]	980	1,208	1,656
	Forestry	0		173	247	604
	Waste Management	768		1,041	1,105	896
	Global Total	**23,848**	**16,302**	**13,039**	**24,018**	**14,959**
	Mitigation as % of Reference Emissions	**44%**	**35%**	**28%**	**40%**	**26%**

[a] MERGE sector mitigation potentials for Industry Production, Agriculture, Forestry and Waste Management are aggregated.
b IMAGE scenarios with lower stabilization targets were developed using IMAGE 2.3. IMAGE scenarios shown in Table 3.6-2 were developed using IMAGE 2.2.

In scenarios with lower stabilization targets, higher levels of near term mitigation are required to achieve the target in the long run. Table TS.8 shows mitigation potential and costs for selected model scenarios with lower stabilization targets in the 3-4 W/m^2 range. For these lower target scenarios, the marginal costs range from approximately $50/$tCO_2eq$ to $190/$tCO_2eq$. The mitigation required to meet the targets ranges from approximately 15,000 -24,000 $MtCO_2eq$.

These potential mitigation ranges highlight sectors on which to focus near term mitigation strategies, consistent with an emission projection path that will meet the stabilization targets. Across all of the models assessed in the 4-5 W/m^2 stabilization target range, the electricity supply sector has the largest potential for near term greenhouse gas mitigation, ranging up to over 9,000 $MtCO_2eq$ of potential mitigation. Other sectors with relatively high CO_2 mitigation potential include energy demand in the transportation and industry sectors. Mitigation of non-CO_2 greenhouse gases also contributes to the stabilization goals. For methane emission reduction, the largest near term potential mitigation across the model scenarios is in the non-electric energy supply sector (over 2,000 $MtCO_2eq$), the agriculture sector (over 2,500 $MtCO_2eq$), and the waste management sector (nearly 1,000 $MtCO_2eq$). The agriculture sector also has the largest potential for N_2O emission reduction, up to over 1,400 $MtCO_2eq$ across the model scenarios. For F Gas emission reduction, mitigation potential in the industry production sector range up to over 800 $MtCO_2eq$.

Mitigation policies are developed in response to concerns about climate change impacts. However, deciding on a proper reaction to these concerns means dealing with uncertainties. Integrated assessments can inform decision makers of the relationship between geophysical climate change, climate impact predictions, adaptation potentials and costs of emissions reductions and the benefits of avoided climate change damages. In each of these relationships there is considerable uncertainty, as demonstrated below.

Large uncertainties persist related to the cost of mitigation, the efficacy of adaptation and the extent to which the negative impacts of climate change, including those related to rate of change, can be avoided. Yet, when viewed from a risk management perspective, action can be justified. 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 geo-physical 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.

Near-term mitigation and adaptation decisions are related to long-term climate goals. The issue for today's policy makers is not what the best climate policy is for the next century. It is what the best climate policy is for today given the uncertainty about the long-term goals. There will be ample opportunity for learning and mid-course corrections as new information becomes available. Hence, analysis of near-term decisions should not be decoupled from analysis which considers the long-term as well.

Analyses which use monetization suggest social costs of carbon are positive but the range of values is wide and is strongly dependent on modelling methodology, value judgements and assumptions (see also Ch. 20) . Adaptation is scale-dependent and hence more difficult to characterise in global modelling and is thus largely under - studied in long-term emission scenario literature. Yet, overall, the small but growing literature to consider both adaptation and mitigation suggests that adaptation and mitigation are complementary.

4. Energy Supply

4.1 Status of the sector, development trends until 2030 including production and consumption, and implications.

The overall aim of energy supply systems is to provide reliable and affordable energy services for everyone but this can conflict with environmental and other societal goals. The conundrum for 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 associated greenhouse gas (GHG) emissions and other pollutants. Selection of future energy supply systems for each region of the world will depend on its developmental status, existing infrastructure and the energy resources available.

Global energy consumption continues to grow but with regional differences. The annual average growth of global primary energy consumption was 1.4 % in the 1990-2002 period, being lower than in the previous two decades due to the economic transition in the former Soviet Union countries, but that is now trending upwards again (Fig. TS.18). Increased uptake of energy conservation and energy efficiency improvements has resulted in a consequent slowing in energy demand growth in many OECD countries.

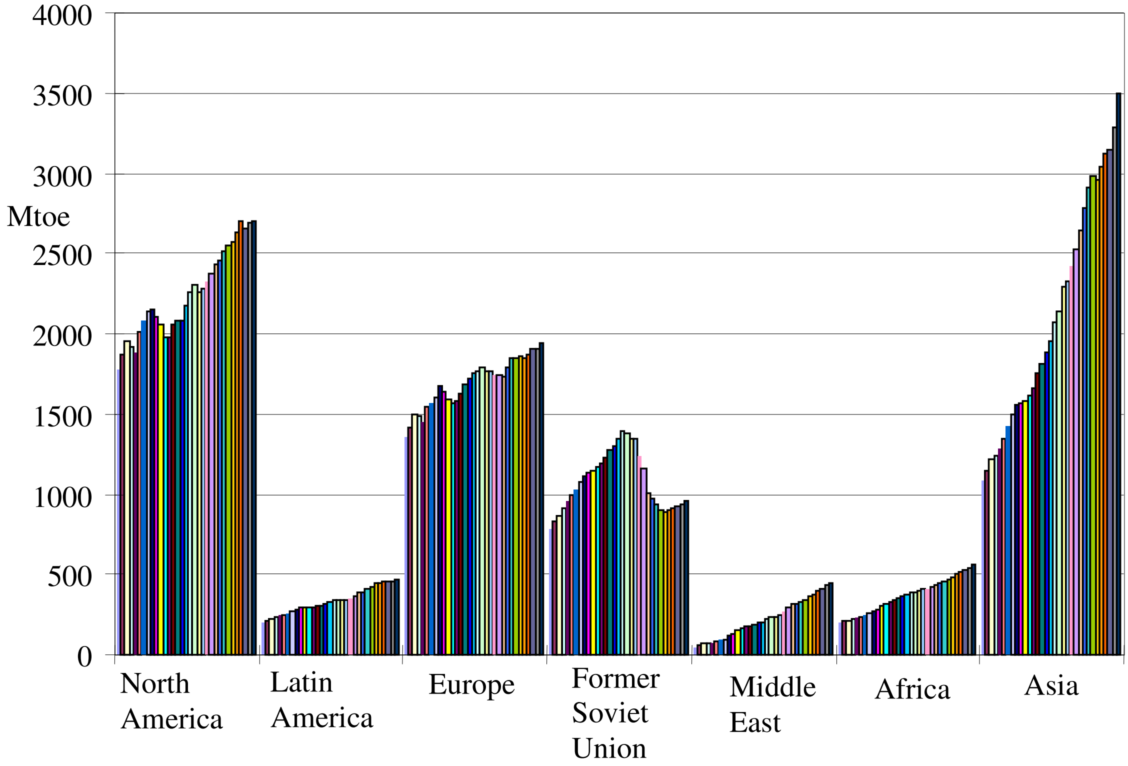


Figure TS.18 Global annual primary energy demand (Mtoe including biomass), from 1971 to 2003 by region (IEA, 2004a).

Rapid growth in energy demand per capita is occurring in many developing countries particularly China, Brazil, India, South Africa, Mexico and Korea. Africa has become the region with the lowest per capita consumption. Energy access, equity, and sustainable development of the poorest countries are compromised by increasing prices of oil and gas. Poverty reduction targets imply improved access to electricity, modern cooking and heating fuels and transportation.

Fossil fuel consumption has increased steadily during the past three decades (Fig TS .19). Nuclear has slowed since the 1980s and large hydro and geothermal are relatively static. The share of fossil fuels dropped from 86% in 1972 to 80% in 2003. Wind and solar are growing most rapidly but from a very low base (TS.19). Fossil fuels concentrated in individual locations at many MW/m^2 of land area have been discovered, extracted and distributed whereas renewable energy is usually widely disbursed at only 1-5 W/m^2 and hence must either be used in a distributed manner or will need concentrating to meet the intensive energy demands of cities and industries.

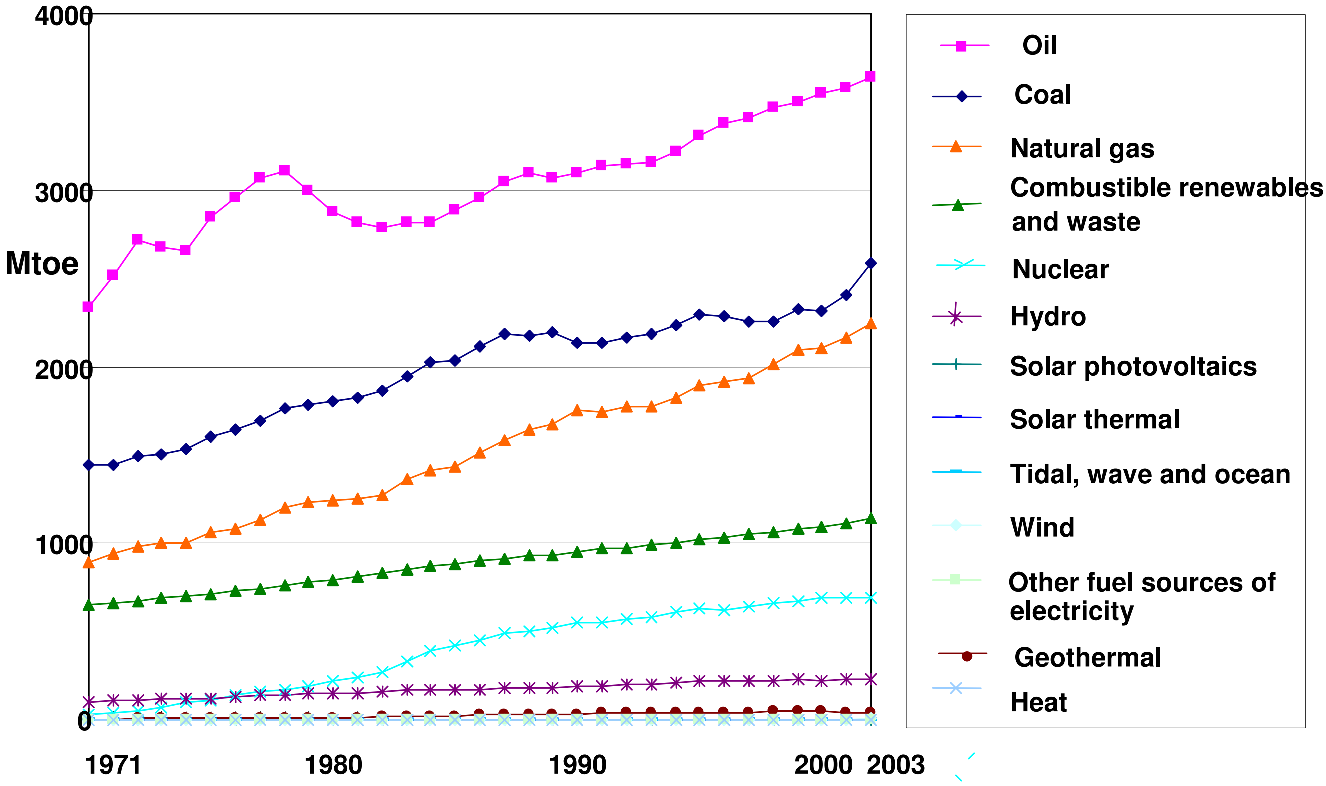


Figure TS .19. World primary energy consumption by fuel type (IEA, 2005d) (23.9 Mtoe = 1EJ)

Future energy demand will increase until at least 2030. Most business as usual (BAU) scenarios point to continued growth of world population and GDP leading to a significant growth in energy demand. High growth rates in Asia (3.2% per year between 1990 and 2002) are predicted to continue and to be met mainly from fossil fuels. The IEA World Energy Outlook 2004 predicted that the fossil fuel share will rise again to 82% by 2030 (though based on an assumed low oil price).
If the oil price remains high, demand may decrease temporarily until other hydrocarbon reserves in the form of tar sands, oil shales, coal-to-liquids, gas-to-liquids etc become commercially viable. When this happens, emissions will increase further as the carbon intensity increases, unless carbon capture and storage (CCS) is applied. Hydrogen may also eventually contribute as an energy carrier with carbon emissions dependent on the source of the hydrogen and the successful uptake of CCS. If energy demand continues to grow along the current trajectory and rate, by 2030 an improved infrastructure and conversion systems will require a total cumulative investment of around $US16 trillion (16 x 10^{12}) or 1% of global GDP per year). Total annual capital investment by the global energy industry is currently around US$280 billion (280 x 10^{9}).

In the TAR, known oil, gas and coal reserves were reported to contain 1549 GtC, with the non-conventional resource base estimated at 4,959 GtC. Hence there is at least 5 times as much carbon in the proven and probable conventional reserves as has been burned since the industrial revolution. Fossil-fuel scarcity, at least at the global level, is therefore not a significant factor in considering climate change mitigation, though debate continues over when conventional oil and gas are likely to peak.

Energy security considerations will drive changes infuture energy supply. In all regions of the world the policy aim towards security of supply has grown in importance since the TAR due to reduced investments in infrastructure, increased global demand for constrained oil and gas supplies, political instability in key areas and the threats of conflict, terrorism and extreme weather events. The choice of appropriate energy technologies based upon the need for structural investments in developing countries, upgrades of capacity constrained infrastructure in developed countries and security of supply policies opens a window of opportunity for the co-benefits of choices in the energy mix to lower GHG emissions.

4.2 Global and regional emission trends, potential reductions and costs

Dependence on fossil fuels leads to increasing GHG emissions from the energy supply sector. With the exception of the former Soviet Union (FSU) (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 GHG emissions from the energy supply sector are predicted to rise over 50% from around 24.6 $GtCO_{2eq}$ (6.6 GtC_{eq}) in 2003 to between 37 - 39 $GtCO_{2eq}$ (10-10.5 GtC_{eq}) by 2030. Emissions resulting from energy demand relate directly to economic activity (GDP /yr), energy intensity per unit of GDP (GJ/USD), population (GJ/capita) and the carbon intensity of the fuel mix (CO_{2eq} emissions/GJ). Energy intensity relates to energy efficiency and energy management measures for the energy conversion processes and for specific end-use technologies used by each of the major sectors (Chapters 5-10). Carbon intensity and related emissions from the energy supply sector are considered below.

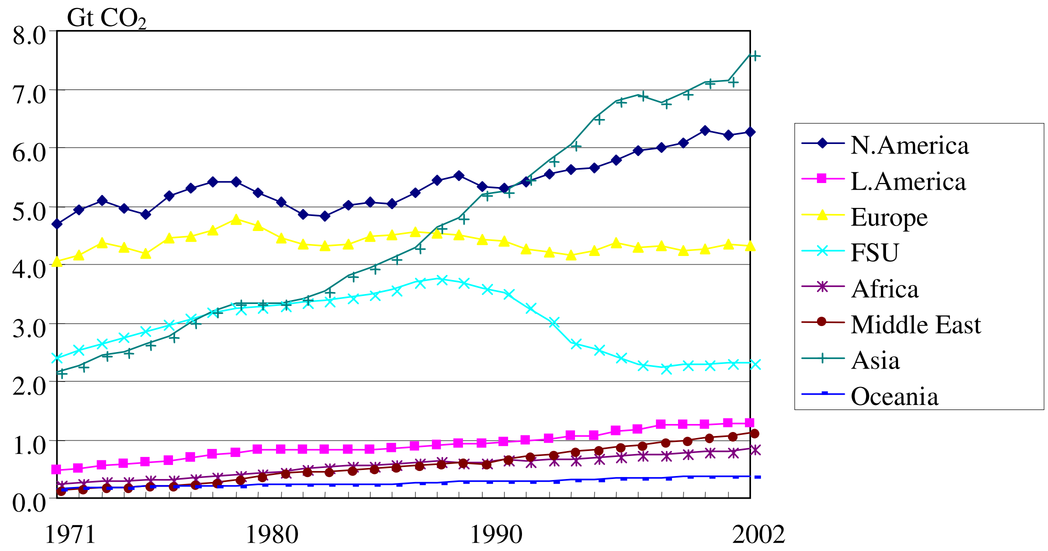


Figure TS.20. Global CO_2 emission trends by region from 1972 to 2002 (IEEJ, 2005)

4.3Description and assessment of mitigation technologies and practices, options, potentials, costs and sustainability

The electricity sector has a good mitigation potential using a range of technologies. An indication of maximum mitigation potentials by 2030 in excess of the IEA World Energy Outlook 2004 Reference case, has been produced for selected technologies at various cost class ranges (Table TS.9). The 2030 baseline gave fossil fuels an 82.2% share of total primary energy and 72.0% of electricity;

nuclear 4.1% and 7.3%; and renewables (including bioenergy) 13.7% and 20.7%. The upper estimate for the economic potential of each individual technology is based on what might be a realistic deployment expectation of the various technologies using all efforts but given the qualitatively expected practical constraints of rate of manufacturing uptake, public acceptance, capacity building and commercialization.

Table TS.9. Potential maximum total greenhouse gas emissions avoided, in excess of the IEA World Energy Outlook (2004) Reference case baseline for selected mitigation technologies for heat and power generation, and estimated cost class ranges (USD2006) compared with conventional fossil fuel plants.

[Baseline: WEO Reference scenario]	**Region**	**Potential total CO_2 emissions saved in 2030 (Gt CO_2)**	**Cost class ranges USD / t CO_2 avoided**				
			<0	**1-20**	**20-50**	**50-100**	**>100**
			%	%	%	%	%
Option 1	OECD	0.48		100			
Fuelswitch	EIT	0.21		100			
	Non-OECD	0.84		100			
	GLOBAL	**1.53**		**100**			
Option 2	OECD	1.88	65	35			
Nuclear	EIT	0.08	90	10			
	Non-OECD	0.89	80	20			
	GLOBAL	**2.85**	**70**	**30**			
Option 3	OECD	0.09	20	35	45		
Hydro	EIT	0.03	25	35	40		
	Non-OECD	0.97	25	35	40		
	GLOBAL	**1.10**	**25**	**40**	**35**		
Option 4	OECD	0.07	15	30	40	15	
Wind	EIT	0.09	20	25	35	20	
	Non-OECD	0.91	15	25	40	20	
	GLOBAL	**1.07**	**15**	**25**	**40**	**20**	
Option 5	OECD	0.02		5	15	25	55
Solar	EIT	0.02		5	10	20	65
	Non-OECD	0.19		5	10	15	70
	GLOBAL	**0.24**		**5**	**10**	**20**	**65**
Option 6	OECD	0.45	15	25	35	25	
Bioenergy	EIT	0.08	20	25	35	20	
	Non-OECD	2.56	15	25	40	20	
	GLOBAL	**3.09**	**15**	**25**	**40**	**20**	
Option 7	OECD	0.06	25	50	25		
Geothermal	EIT	0.07	35	40	25		
	Non-OECD	0.37	30	45	25		
	GLOBAL	**0.50**	**30**	**45**	**25**		
Option 8	OECD	0.31			10	35	55
CCS + coal	EIT	0.04			10	35	55
	Non-OECD	0.51			10	35	55
	GLOBAL	**0.86**			**10**	**35**	**55**
Option 9	OECD	0.13			0	55	45
CCS + gas	EIT	0.07			0	55	45
	Non-OECD	0.14			0	55	45

GLOBAL	**0.34**	0	**55**	**45**

Since these are estimates of maximum individual potentials without considering the actual supply mix, they cannot be added. Therefore an additional analysis of the supply mix to avoid double counting was done.

A wide range of energy supply mitigation options is available, and cost effective now at <USD 20/tCO_2 avoided include fuel switching and power plant efficiency improvements, nuclear power, renewable energy systems other than solar, and some biofuels. Others still under development include advanced nuclear power, improved renewables, second generation biofuels, CO_2 capture and storage (CCS), and possibly hydrogen in the longer term. 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 5 GtCO_{2eq} / yr at costs up to 50 USD/tCO_{2eq} but uncertain (Table TS.9).This potential by 2030 is based mainly on the increased uptake of nuclear power (1.0Gt), renewable energy (1.0Gt), bioenergy and biofuels (2.1 t), CCS with coal and also gas plants (0. 06 Gt with potential for rapid growth after 2030) and fuel switching (0.7 GtCO_2). This analysis does not take into account potential savings in electricity demand in the building and industry sector (see chapter 11 for a complete overview).

The TAR analysis of 1.3 -2.6 GtCO_{2eq} mitigation potential being feasible by 2020 fits this current analysis. Actual mitigation levels achieved will depend on the energy demand reduction from efficiency measures in the end use sectors and the rate of replacement of existing stock.

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 thermal power plants may become problematic when river waters are warmer. Renewable energy resources can also be affected 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; wind power influenced by changing wind velocity; and energy crop yields reduced by drought and higher temperatures). Mitigation in the local energy supply sector can be adversely affected by adaptation to climate change in the form of more air-conditioning or higher electricity use for irrigation and water pumping.

4.5 Effectiveness of and experience with climate policies, potentials, barrier, opportunities and implementation issues

Policies in the short term affect emissions in the longer term. The whole spectrum of policy instruments is being applied to the energy sector for climate change policies because no single instrument will enable the desired transition to occur. The need for short term action in order to make any significant impact in the longer term has become apparent. Large scale energy conversion technology power or heat plants have a life of 30 - 100 years, and hence a rate of turnover around 1-3% per year. Policy decisions taken today will affect the rate of deployment of carbon emitting technologies, especially in the rapidly developing world, and have profound consequences on development paths for the several decades.

Economic and regulatory instruments have been employed but with limited success. 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 Denmark for wind energy and Japan with solar PV). In the support for renewable electricity projects, feed-in-tariffs appear to be superior to 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.

4.6 Integrated and non-climate policies can affect emissions of greenhouse gases and the co-benefits of mitigation policies

Investments in developing countries provide opportunities for sustainable energy. Developing countries that continue to experience particularly high economic growth will require significant increases in energy services at present being met mainly by fossil fuels. An estimated 2400 GW of power plants plus related infrastructure will need to be built by 2030 to meet increased consumer demand, requiring an investment of around USD 5 trillion ($5*10^{12}$). Sustainable development policies that match mitigation objectives can generate local employment, provide greater access to energy, reduce poverty and promote equity. Analysis of policies should include co-benefits of improved health, security, reduced import dependency, price fluctuations, employment, minimized transmission losses, water quality and air quality often neglected in many basic economic analyses.

Liberalisation and privatisation 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 with scant regard for environmental impacts.

There are substantial co-benefits of GHG mitigation in the energy supply sector**.** When applying cost-effective energy efficiency measures there is an immediate economic benefit for consumers from lower energy costs. Co-benefits from energy supply security, technological innovation, air pollution abatement and employment also result typically 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 or 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, creation of additional jobs may result.

4.7 Technology research, development, diffusion and transfer

Energy technology research, development, diffusion and transfer is a good investment.
Investment in energy technology R, D & D has declined overall since the levels achieved in the 1970s as a result of the oil shocks. Current levels may be inadequate to reduce GHG emissions and meet growing energy demand. Greater public and private investment will be required if more rapid deployment of low carbon energy technologies is to result. An investment of about USD8 billion today could produce a USD200 trillion return on investment by 2050 in terms of projected GHG emission savings due to the increased rate of implementation. This expenditure is far less than that which must be made if the Millenium Development Goals are to be met.

4.8 Long term outlook/systems transitions, decision making

The energy systems transition required can be successfully achieved. Outlooks from both the IEA and World Energy Council project increases in primary energy demand between 40 to 150 % by 2050, depending on the various scenarios for population growth and rate of technology development. Electricity use is expected to grow by between 110 and 260%. Both organizations realize that these 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 that the sooner it begins the lower the overall cost on total GDP will be.

5. Transportation and its infrastructure

5.1 Status of the sector, development trends and implications

Transport energy use currently amounts 28% of total world energy use; it follows closely the growth of transportation activity and is rising steadily everywhere. Current transportation activity is driven by internal combustion engines powered by petroleum fuels (96% of total transport energy use). As a consequence, petroleum use closely follows the growth of transportation activity. In the developed world, transport energy use continues to increase at 2.1 % per year; passenger transport currently consumes 60-75 % of total transport energy. In developing countries transport energy use rise at a much faster rate (2.6 %) and is projected to grow from 32% now to 46% of world transport energy use by 2030. Currently, energy use of passenger and freight transport in developing countries is almost equal, on average.

In contrast with passenger transport, where passenger cars dominate, the modal split of freight varies from country to country; in Europe and Japan, road transport dominates, but in US rail transport has a major share (see Figure TS.21). In the future, the share of passenger transport will decrease slightly in developed countries, but will increase in developing countries due to the rapid increase in the number of private cars, associated with growing incomes**.** As incomes grow and the value of travelers' time increases, travelers 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.

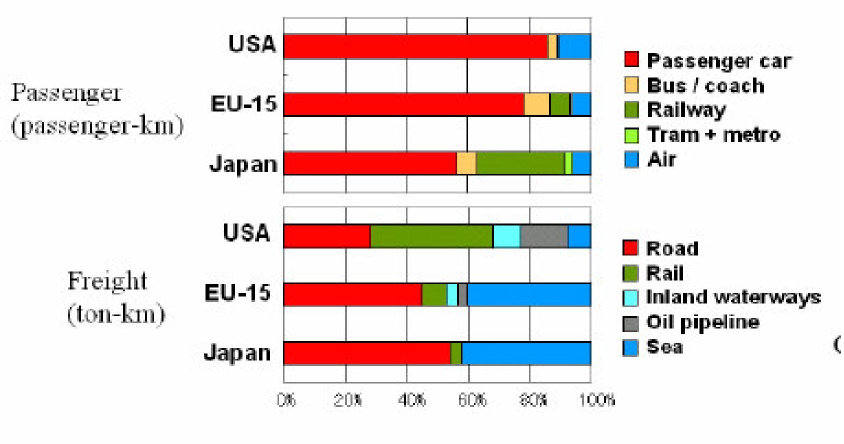


Figure TS.21 Modal split in passenger and freight transport for the year. Source: EC(2004)

In developed economies, motor vehicle ownership approaches one per adult (see Figure TS.22). In the developing world, levels of vehicle ownership are an order of magnitude lower, non-motorized transport plays a significant role, and there is much 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**.**

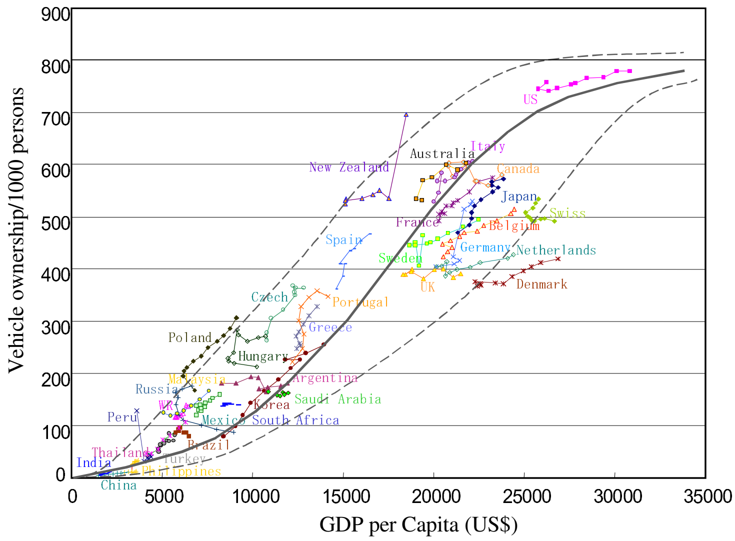


Fig TS.22 Vehicle ownership and GDP per capita as a time line per country.
Note: plotted years vary per country, depending on data availability. Source: Worldbank

Rapid motorization has created severe congestion and air quality problems in the large cities of the developing world, leading to policy attention for expanding infrastructure but also for emissions standards and, in some cases, for fuel economy standards to control the increased dependence on imported oil. Urbanization has been extremely rapid in the past century, and fully 75% of people living in the industrialized world and 40% in the developing world now live in urban areas. Also, cities have gotten larger, with 19 cities now having a population over 10 million. A parallel trend has been the decentralization of cities - they have spread out faster than they have grown in population, with rapid growth in suburban areas and the rise of “edge cities” in the outer suburbs. This decentralization has created both a growing demand for travel and an urban pattern that is not easily served by public transit.

5.2 Emission trends (global and regional)

The transport sector represents the fastest growing source of greenhouse gas emissions among all the end-use sectors. There is little prospect that this situation will be resolved with a single technological measure. It is also important to note that GHG emissions reductions will not be viewed as the critical issue in transportation during the coming decades since in most countries, concerns will focus on the local scale problems like congestion and air pollution.

In the year 2000, the transport sector produced 24% of world energy-related CO_2 emissions (5.6 gigatonnes of CO_2) and its growth rate is highest among the end-user sectors. Road transport currently accounts for 75% of total transport CO_2 emissions, while aviation now accounts for 12% and it is projected to increase to 16% by 2030.
The share of Non-OECD countries is 32% now and will increase rapidly to 46 % by 2030.

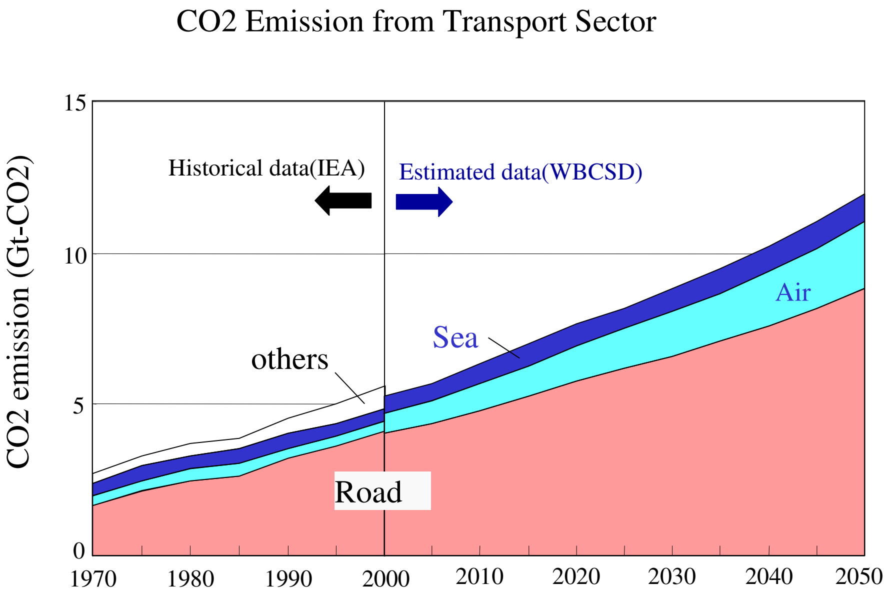


Figure TS.23 Historical and Projected CO_2 emission from transport

The transport sector also contributes small amounts of CH_4 and N_2O emissions from fuel combustion and F-gases from air conditioning. CH_4 emissions are between 0.1-0.3% of total transport GHG emissions, N_2O between 2.5 and 2.8% and F-gases between 1.4 and 8.9% (based on US, Japan and the EU data only)

The electricity used in the transport sector is 1% of total transport energy consumption and 1.8% of total electricity consumption in 2003. Emission related with power generation is covered in Chapter 4, but in terms of CO_2 emissions this is only 2.7% of transport CO_2 emissions.

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

Significant developments in mitigation technologies since the TAR include the initial market success of hybrid vehicle technology, the development of clean diesel technology, and the institution of significant research, development and demonstration programs around the globe for hydrogen-powered fuel cell vehicles . In addition, numerous opportunities for improvement of conventional technologies still exist. Biofuels continue to be important in certain markets and hold much greater potential for the future.

Road traffic: Efficient Technologies and Alternative Fuels

Advanced conversion techniques are necessary for a greater share of biofuels. At present ethanol is the most widely used biofuel. It is now produced by fermentation and distillation from sugar cane (Brazil) or corn (North America). As the production process itself uses a lot of energy and only utilises a small fraction of the total chemical energy in the biomass, costs per tonne of CO_2 avoided are high and CO_2 reduction is limited compared to gasoline. It appears unlikely that biofuels produced by fermentation and distillation could reach more than 10% of road transport energy use. Achieving this level could reduce road transport carbon emissions by 2-5% on a well-to-wheel basis.

However, using advanced production methods, such as conversion by enzymatic processes or by gasification and synthesis from cellulose, the potential for biomass fuels could increase up to 20% of road transport energy use by 2030 and 50% by 2050. This would reduce transport carbon emissions by 35% on well-to-wheel basis. At these levels no limitations due to land needed for food production or protection of biodiversity are expected. (see Figure TS.24)

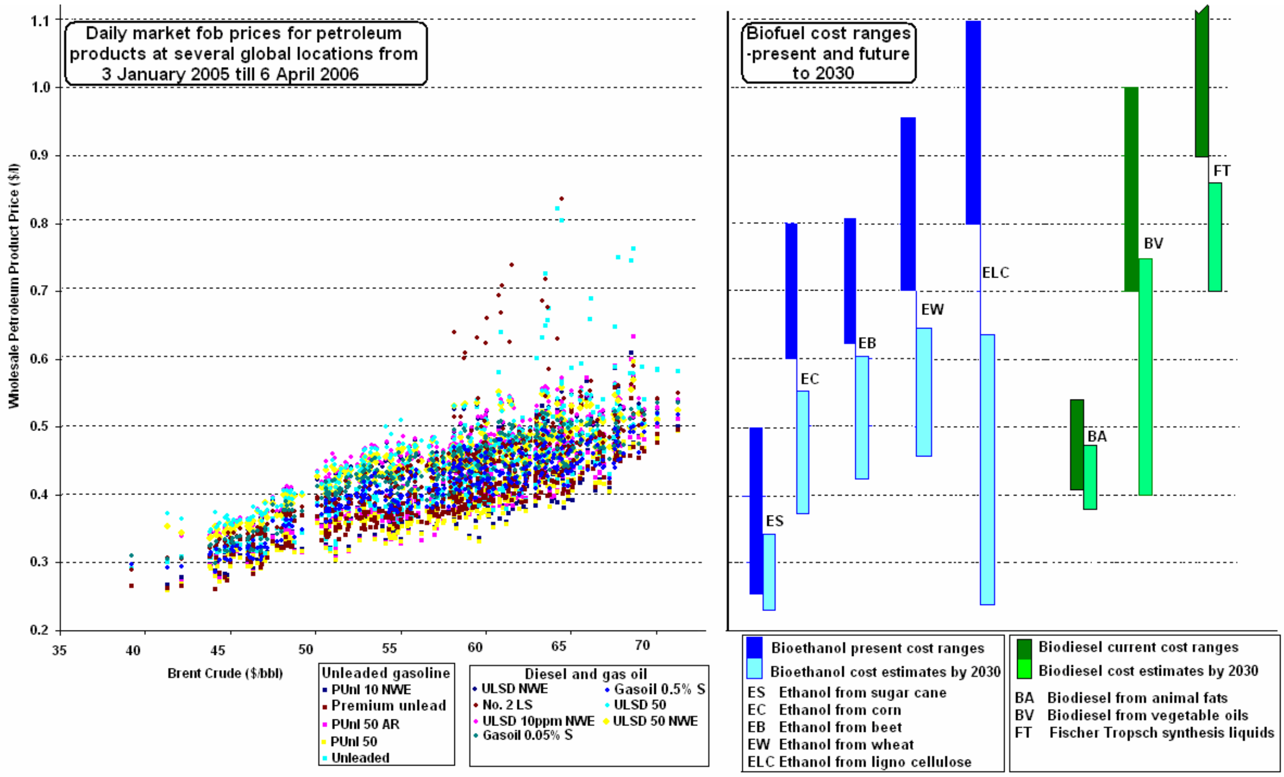


Figure TS.24 Comparison between current and future biofuels prices versus gasoline and diesel ex-refinery (fob) prices for a range of crude oil prices.
Source: IEA.

Since the TAR, energy efficiency of road vehicles has improved by the market success of hybrids and "clean diesels". Further technological advances are expected for hybrid system vehicles, leading to an improvement in the fuel economy by 40% in a light duty vehicle compared to a conventional gasoline engine by 2030.
Direct injection, turbo-charged diesel engines capable of meeting Euro4 tier 2 emissions standards can deliver about 30% greater fuel economy (on a volumetric basis) than conventional drivetrains. Given the higher carbon content of diesel fuel, however, the reduction in carbon emissions is only about 20%. A combination of other technologies, including materials substitution, reduced aerodynamic drag, reduced rolling resistance, reduced engine friction and pumping losses, etc., when combined with hybrid or diesel technologies would approximately double the fuel economy of new light-duty vehicles by 2030, thereby roughly halving carbon emissions per vehicle mile travelled.

The total mitigation potential in 2030 of these options applied to Light Duty Vehicles would be around 1 $GtCO_2eq$ in 2030. The use of advanced biofuels, as mentioned above, would give a additional reduction potential of another 1 $GtCO_2eq$ based on the WEO baseline scenario in 2030.

Economic and market potentials of hydrogen vehicles remain uncertain. Despite very substantial investments in research and development of hydrogen-powered fuel cell vehicles, further technological advances and/or cost reductions are needed in fuel cell stack cost, hydrogen storage, and hydrogen production with low- or zero-carbon emissions. The public funds spent yearly in US, EU, and Japan totals up to more than US$1 billion. The GHG mitigation potential of hydrogen fuel cell vehicles depends strongly on the energy efficiency of the vehicle system and the fuel-cycle pathway by which the hydrogen is produced. With a 50% vehicle efficiency and hydrogen produced from natural gas with a conversion efficiency of 60%, well-to-wheel carbon emissions could be reduced by 50-60% versus a conventional gasoline powered vehicle. If the hydrogen were produced by electrolysis in the US, where coal currently accounts for more than half of primary energy used in electricity generation, carbon emissions would actually increase by 25%. Well-to-wheel CO_2 emission for fuel cell vehicles with hydrogen from natural gas or coal, with CCS, can be below 20 % of that for conventional gasoline powered vehicle and the hydrogen costs in this are not much higher than from coal without CCS. In the long-run, if hydrogen could be produced economically from biomass, solar, or wind power, , well-to-wheel carbon emissions could be nearly eliminated. Hydrogen costs are currently estimated to be 2 to 7 times the cost of gasoline (without taxes). There are other obstacles however to the marketing of hydrogen fuel cell vehicles, such as the costs of the fuel cell and the infrastructure needed for fuel distribution.

<u>Well-to-Wheel CO2 emission for Various Hydrogen FCVs</u>

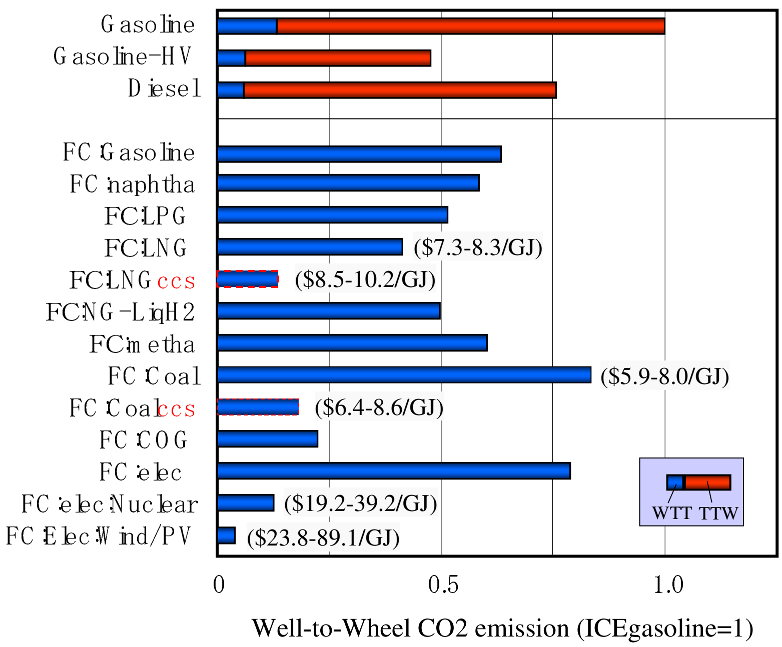


Figure TS.25 Well-to-Wheel CO_2 emission for major pathways of hydrogen with some estimates of hydrogen production cost (numbers in parentheses) . Source:Toyota/Mizuho(2004), IEA(2005)

A critical threat to fuel economy technologies is that they can be used either to increase fuel economy and reduce carbon emissions or to increase vehicle power and size. 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.

The question of how much transport can be shifted to less energy intensive modes is highly dependent on local conditions.

Existing studies indicate that increasing the price of carbon fuels by 10% could increase use of public transport by 1-3%. The potential for telecommuting to reduce overall automotive CO_2 emissions has been estimated at approximately 1% under real-world conditions.

The energy requirements for urban transport are strongly influenced by the density and spatial structure of the built environment, as well as by location, extent and nature of transport infrastructure. Existing studies indicate that increasing population density by 10% could reduce car use by 0.5-9%. Expansion of public transport in form of large capacity buses, light rail transit and metro or suburban rail are in demand. Urban rail systems do however have high capital and operational costs. The literature indicates that reduction in auto use becomes significant only at densities of 10,000 people or more per square mile - densities unlikely observed in American suburbs but often reached in other cities around the world. The few success stories of Bus Rapid Transit systems (e.g. of Bogotá, Curitiba, Quito and Lima) have not been replicated in other countries This is partly due to the technical difficulties to find a suitable system for each cities/regions with quite different conditions, and also partly due to the political challenge to overcome strong resistance from special interest groups. Estimated CO_2 reduction from case studies for the increased share of bus systems of 5-10% is estimated to be 4-9% at costs of the order of US$ 60 -70/tCO2 avoided..

Air traffic

The only mitigation option in the short to medium term in terms of fuel change for aviation is the introduction of biofuels or synthetic kerosene based on biomass gasification or on coal or gas with CCS. Apart from the very strict specifications that jet fuel has to meet, there will be (currently unavailable) additional costs for such alternative aviation fuel.

Energy efficiency gains from continuous improvements in aerodynamics, weight reduction and fuel efficient aircraft engines is estimated to be able to achieve significant emission reductions at low cost.
Considering all sources, a 20% improvement in fleet aircraft efficiency over 1997 levels is expected by 2015 with a cumulative 40-50% improvement likely by 2050. Such improvements will not be sufficient to keep carbon emissions from global air travel from increasing significantly.

Aviation system operations can be optimized for energy use and CO_2 emissions by minimizing taxi 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 to minimize the total climate impact of aircraft operations, including ozone impacts, contrails, and nitrogen oxides emissions.
The blended wing body, a concept that promises up to a 50% fuel consumption reduction, and therefore aircraft carbon emission reduction, still faces challenges of costs of design, development and production, as well as market acceptance.

Fuel efficiency improvement, the flying wing concept and using biofuels with a blend of 10-50%, could in total contribute to 800 $MtCO_2eq$ in the WEO scenario for 2030. As no cost information is available, an unknown share of the mitigation potential of aviation may fall in the category of >100 US$/$tCO_2eq$ avoided.

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 just applying state-of-the-art knowledge**.** **T**he short-term potential for operational measures ranged from 1-40%, depending on a variety of factors related to the current operation of the vessels. The study estimated a total reduction potential for the world fleet of about 18% by 2010 and 28% by 2020 This is not expected to be sufficient to offset the growth in shipping activity over the same period.

Rail transport
The main opportunities for mitigating GHG emissions associated with high-speed passenger rail travel are improving aerodynamics, introducing regenerative braking and on-board energy storage and, of course, mitigating the GHG emissions from electricity generation. There are no reliable estimates of the total mitigation potential and the costs.

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

Policies and measures for Surface Transport
Land use and transportation planning policies have important roles.
Given the positive effects of higher population densities on public transport use and CO_2 emissions, better coordination of land use and transportation planning are a key policy element in the transportation sector. There are some good examples for large cities in several countries. Involvement of national governments can support municipal and regional government agencies in implementing such policies.

Fuel economy standards or CO_2 standards have been effective to reduce GHG emissions, but so far not good enough to compensate its growth. Most industrialized nations have set fuel economy standards for new light-duty vehicles. In addition to the EU, Japan, United States, Canada, and Australia, China has now established a system of weight-based fuel economy regulations. The forms of standards vary widely, from uniform, mandatory corporate average standards (US), to graduated standards by vehicle weight class (Japan and China), to voluntary industry-wide standards (EU and Canada). The universality of the use of regulatory policy to address light-duty fuel economy appears to acknowledge a nearly universal failure of the market to achieve acceptable fuel economy levels regardless of the widely varying cost of fuel among these countries. Fuel economy standards have been universally effective in raising 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. A key feature of fuel economy standards is that they direct the trade-off of potential fuel economy gains for vehicle performance and increased weight in favour of fuel economy.

Well designed and capably implemented Transportation Demand Management (TDM) plans have been demonstrated to achieve vehicle travel reductions exceeding 10% in some cities.
TDM consists of more than three dozen different strategies whose goal is to improve the performance of road systems by reducing traffic volumes. TDM strategies range from the provision of information to travelers, traffic restrictions (e.g. freeway ramp metering or high-occupancy vehicle lanes), to employer incentives to ride sharing.

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. A review of studies show that fuel consumption and associated CO_2 emissions would be reduced by 6% as a result of a permanent fuel price increase of 10%. Rebates on vehicle purchase and registration taxes for fuel efficient vehicles have shown to be effective. Road and parking pricing policies are applied in several cities, with marked effects on public transport use. The overall effect of taxing and pricing policies is estimated to be in the order of 15-20% reduced private car use, compared with business as usual.

Policies and measures for Aviation

Several studies have estimated the potential impacts of emissions charges or trading systems. An EU study found that charges of € 30 per tonne of CO_2 and € 3.6 per tonne of NO_x would reduce CO_2 emissions in EU airspace by 9%; about half of the reduction would be due to technical and operational changes, the other half to reduced air travel. An ICAO study concluded that a charge of \$0.50/kg of jet fuel (= € 123 per tonne of CO_2) would reduce CO_2 emissions by 18%, three quarters of which would be due to reduced air travel. An additional analysis by ICAO indicated that if aviation were to participate in an open emissions trading system with a carbon price of US\$ 20/tCO2 (meaning emissions from international aviation would be covered by the Kyoto protocol), total air transport activity would be reduced by only 1%, because aviation would purchase the vast majority of the credits it would need. Discussions on bringing aviation under the EU emissions trading system are ongoing.

A major difficulty in developing a mitigation policy for the climate impacts of aviation is how to cover non-CO_2 climate impacts. The IPCC Special report on Aviation estimated these effects to be about 2 to 4 times greater than those of CO_2 alone, even without considering the potential impact of cirrus cloud enhancement.

Emission charges or trading would lead to an increase in fuel costs that will have a positive impact on engine efficiency and air traffic management.

Policies and measures for Marine transport

Current policy initiatives in the shipping sector are mostly based on voluntary schemes, using indexes for fuel efficiency of ships. Environmentally differentiated port dues are being used in a few places. The most promising policy to affect shipping emissions would be the inclusion of international shipping in international emissions trading schemes, but implications of such an approach has not been analysed so far.

5.5 Integrated and non-climate policies affecting emissions of greenhouse gases and co-benefits of greenhouse gas mitigation policies

Many policies not aimed at transport's GHG emissions nevertheless have a significant impact on them.

Transport planning and policy have recently placed more weight on sustainable development. This includes air quality, noise pollution, safety, congestion and access to transport facilities. Policies to improve these can have important synergies with reducing GHG emissions. In several cases monetised public health benefits from sustainable transportation programmes were shown to be larger than the costs of such measures.

Globally, transport subsidies of various kinds have been estimated at almost 1% of global GDP. Some subsidies, such as of public transport systems, may reduce GHG emissions while others, such as fuel price subsidies in certain countries, undoubtedly increase them. Unfortunately, little is known about the quantitative impacts of transport subsidies on GHG emissions.

5.6 Technology R&D, deployment, diffusion and transfer

Further R&D efforts are key to the development and deployment of mitigation options that could lead to deep reductions in GHG emissions. This holds, amongst others, for hydrogen fuel cell vehicles, advanced biofuel conversion, improved batteries for electric vehicles, synthetic kerosene for aviation, advanced rail systems, and fuel cell propulsion in ships.

5.7 Long-term outlook/systems transitions, decision making

What replaces oil as the predominant source of energy for transport will have enormous implications for the sector's future GHG emissions. Given high oil prices and the prospect that this may get worse, and considerations about import dependency of oil has lead to a considerable interest in the usage of liquid fuels from so-called unconventional oil (heavy oil, oil sands), biofuels and synthetic fuels manufactured from natural gas or coal or biomass gasification.. A transition to alternative fossil energy resources (tar sands and coal- to-liquid) would significantly increase transportation's GHG emission, unless the addition carbon emissions were captured and stored or biomass based fuels are used. Alternatively, greatly increased energy efficiency of vehicles could postpone the transition and increased use of biofuels and energy carriers such as electricity or hydrogen -if obtained from fossil fuels with carbon capture and storage, could direct the transport sector towards a low-carbon future (see figure TS.26). For aviation the development of biomass based synthetic kerosene and advanced airplane design would be key to a significant reduction of aviation emissions.

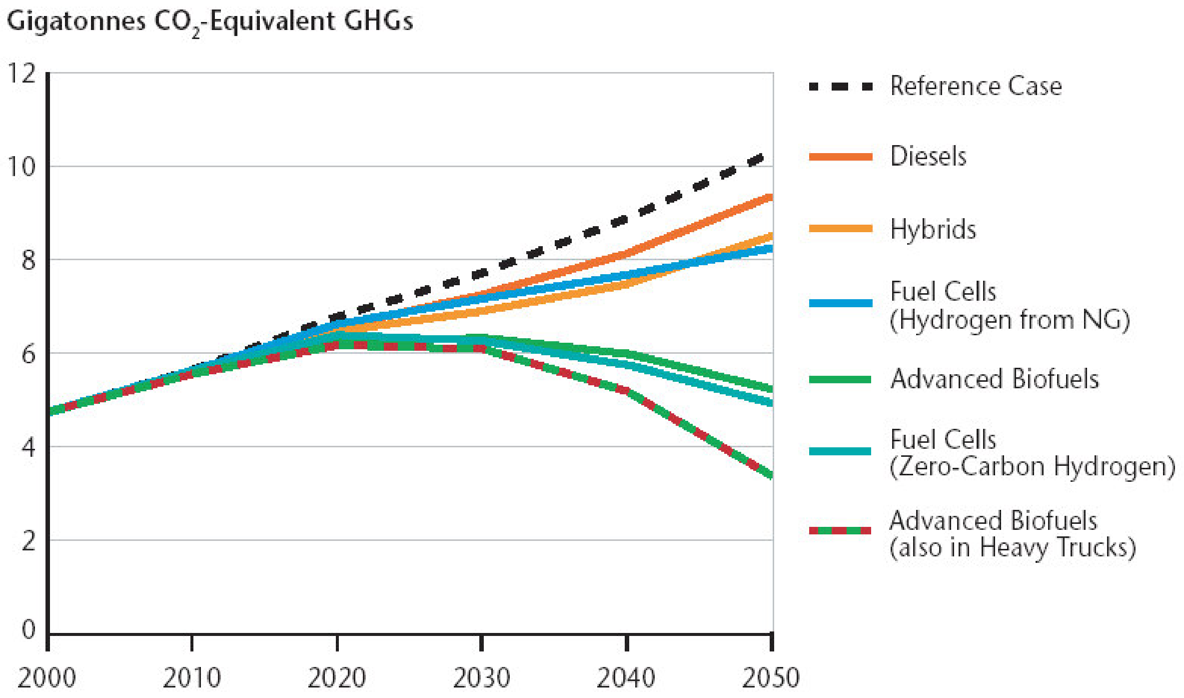


Figure TS.26 Single technology scenario for GHG emissions.

6. Mitigation options for residential/commercial building

6.1 Status of the sector: emission trends

The buildings sector was responsible for 7.85 Gt carbon dioxide (CO_2) emissions in 2002, 33% of the global total. Carbon dioxide emissions from energy use in buildings grew from 1971 to 2002 at an annual rate of 1.8%, about equal to overall growth rate of CO_2 emissions from all uses of energy. CO_2 emissions for commercial buildings grew 0.8% per year more rapidly than those for residential buildings during the 1971 - 2002 period. During the past five years (since the previous IPCC report), CO_2 emissions from energy use in residential buildings have increased much slower than the 30-year trend (annual rate of 0.1% versus trend of 1.4%) and emissions associated with commercial buildings have grown faster (3.0% per year in last five years) than the 30-year trend (2.2%).

The largest regional increases since 1971 in CO_2 emissions for commercial buildings were from North America (30%), Centrally Planned and Other Asia (27%) and OECD Pacific (20%). The largest regional increase in CO_2 emissions for residential buildings were from Asia (Centrally Planned and Other) accounting for 40% and Middle East/North Africa with 20%.

The IPCC estimates that about 1.5 Gt CO_{2eq} of halocarbon emissions, or 60% of total, were due to refrigerants and blowing agents for use in buildings (refrigerators, air conditioners, and insulation) in 2020. Projections show the emissions due to these uses remaining about constant in 2015. We devote little attention to halocarbons in this chapter, even though they are of considerable significance, because they are treated comprehensively elsewhere.

6.2 Future carbon emissions resulting from energy use in buildings

Buildings related CO_2 emissions in 2030 range from 11.4 to 15.6 Gt CO_2 (SRES B2 and A1b respectively), representing an app. 34% share of total CO_2 emissions in both scenarios**.** In the SRES B2 scenario (fig TS.27), which is based on relatively lower economic growth, especially in the developing world (except China), North America and Centrally Planned Asia account for the largest portion of the increase in emissions. In the SRES A1b scenario (fig TS.28),, which shows rapid economic growth, especially in developing nations, all of the increase in CO_2 emissions occurs in the developing world: Centrally Planned Asia, Other Asia, Middle East/North Africa, Latin America, and Sub-Saharan Africa, in that order. Overall, average annual CO_2 emissions growth is 1.3% in Scenario B2 and 2.5% in Scenario A1b over the 28-year period.

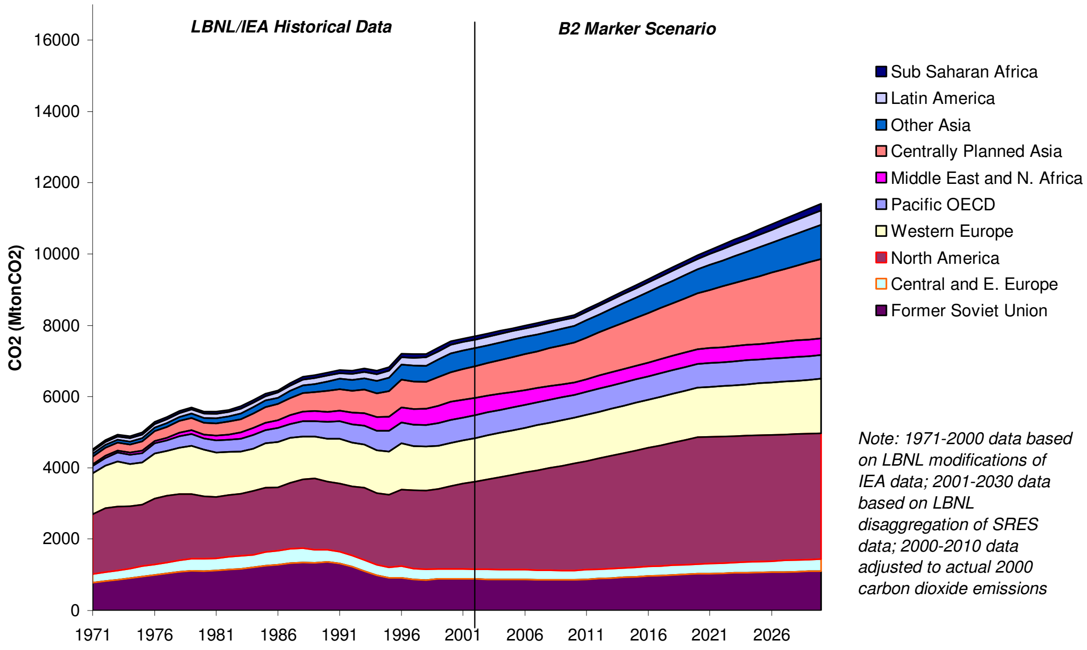


Figure TS.27 CO_2 emissions from buildings energy use: B2 marker scenario

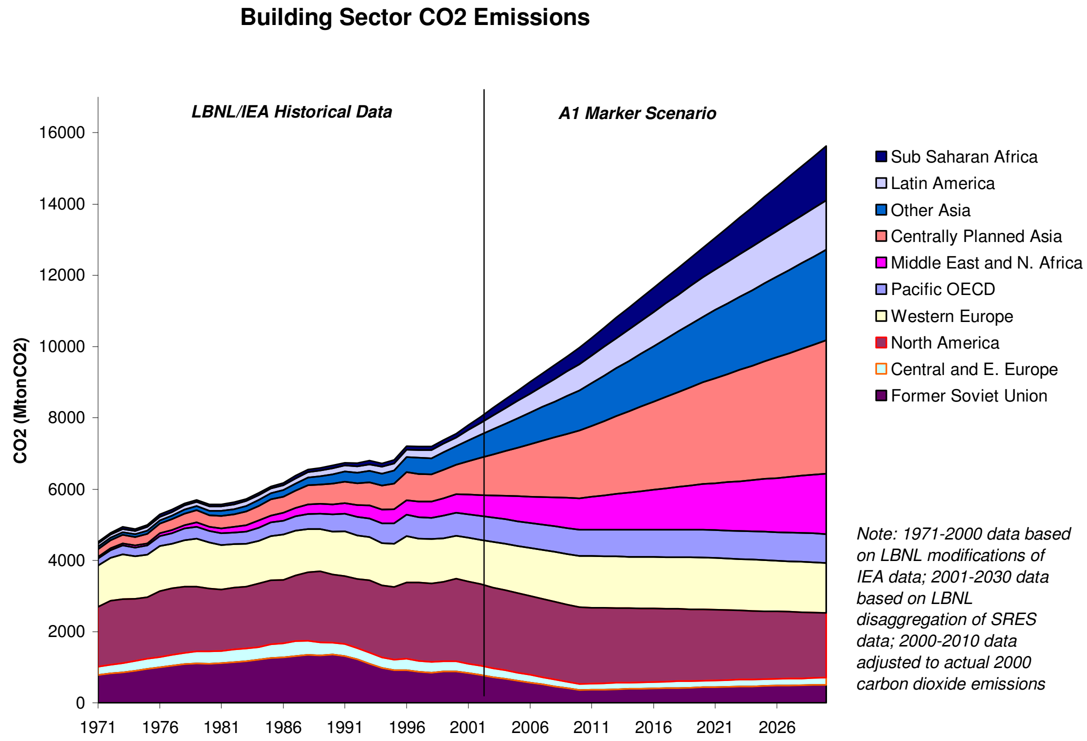


Figure TS.28 CO_2 emissions from buildings energy use: A1 marker scenario

6.3 Description and assessment of mitigation technologies and practices, potentials, and costs

Greenhouse Gas (GHG) emissions from buildings can be cut in three major ways: by reducing energy consumption in buildings , switching to low-carbon fuels including a higher share of renewable energy, and controlling the emissions of non-CO_2 GHGs. Energy consumption can be reduced through more effective building envelopes, passive solar design methods for heating, cooling, and ventilation; as well as changes in the demand for energy services provided by these equipment and for heating and cooling. 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.

Substantial CO_2 emission reduction from energy use in buildings can be achieved over the coming years. The considerable experience in a wide variety of technologies, practices, and systems for energy efficiency and an equally rich experience with policies and programs 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_2 emissions that have a net negative cost (generally higher first cost but lower operating cost).

While there are methodological challenges in aggregating potential GHG reductions to a global level due to differing assumptions used in different studies, the current report provides an estimate for the global economic potential. Globally, by 2020, approximately 1.6 and 1.4 Gt CO_2eq. can be avoided annually through mitigation measures in the residential and commercial sectors respectively. Using the A1 and B1 SRES Scenarios as the baseline, this estimate represents a reduction of 21% and 27%, respectively, for all buildings in 2020. Due to the limited number of demand-side end-use efficiency options considered by the studies and the exclusion of the positive integration effects, the real potential is likely to be higher. Realizing such emissions reductions up to 2020 require 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.

Table TS.10. Greenhouse gas emissions reduction potential for the buildings stock in 2020[11]

Economic region	**Countries/ country groups reviewed for region**	**Potential as % of national baseline for buildings**[12]	**Measures covering the largest potential**	**Measures providing the cheapest mitigation options**
Developed countries	USA, EU, Canada, Greece, New Zealand, Australia, Republic of Korea, UK	Technical: up to 54% Economic: 16%-21% Market: 14%-37%	1. Shell retrofit, inc. insulation, esp. windows and walls; 2. Space heating systems and standards for them; 3. Efficient lights, esp. shift to CFLs and efficient ballasts.	1. Appliances such as efficient TVs and VCRs (both on-mode and standby), refrigerators and freezers, followed by ventilators and air-conditioners; 2. Water heating equipment;

[11] Except for EU-15, Greece, Canada, and India, for which the target year was 2010, and Hungary and South Africa, for which the target was 2030.

[12] 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.

Economic region	Countries/ country groups reviewed for region	Potential as % of national baseline for buildings[12]	Measures covering the largest potential	Measures providing the cheapest mitigation options
				3. Lighting best practices.
Economies in Transition	Hungary, Russia	Economic: 18%-45%	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. Water and space heating control systems; 2. Retrofit and replacement of building components, esp. windows; 3. Efficient lighting and its controls.
Developing countries	Myanmar, India, Indonesia, Argentine, Brazil, China, Ecuador, Thailand, Pakistan, South Africa	Technical: up to 79% Economic: 18%-71% Market: up to 23%	1. Efficient lights, esp. shift to CFLs, light retrofit, and kerosene lamps; 2. Various types of improved cook 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 cook stoves, esp. biomass based, followed by kerosene stoves; 3. Efficient electric appliances such as refrigerators and air-conditioners.

A review of 11 studies representing 17 countries or groups of countries worldwide assessing the costs of GHG mitigation in buildings attests that there is considerable potential for low-cost energy-efficiency improvements in the buildings sector. Up to 62% of the GHG emissions in the buildings of developing countries and economies in transition studied, and up to 25% of those in developed countries, can be captured at negative cost.[13] If measures with costs up to US$20/tCO2eq. are considered, some developing countries and economies in transition may eliminate between 17% and 66% of their emissions in this sector; the range of potential that can be tapped at this cost in developed countries is 21-28%. Due to the abundant opportunities for negative- or low-cost GHG mitigation in buildings, most studies do not assess options with high costs

Table TS.10 attests 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 size of potential savings. By 2020, app. 760Mt of CO_2 emissions can be abated by the adoption of least life-cycle cost lighting systems globally, at an average cost of US$ -161/tCO_2. 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 cook stoves in developing countries. Other measures that rank high in terms of savings potential are solar water heating and efficient appliances, as well as building energy management systems.

[13] For a GHG mitigation measure, the net cost of avoided carbon emissions is the sum of benefits and costs. In the case of energy efficiency measures that result in GHG reductions, the benefit component will include energy cost savings which-in the case of cost-effective energy-saving measures-will be greater than the cost of implementing the action, thus resulting in negative cost of conserved carbon. This means that private individuals benefit from introducing this mitigation action-instead of paying for it, as with other carbon mitigation actions.

As far as costs are concerned, efficient cook stoves rank second after lighting in developing countries, while the second-place measures differ in the industrialized countries by climatic and geographic region. Almost all studies examining economies in transition (typically in cooler climates) have found heating-related measures to be most cost-effective, including insulation of walls, roofs, windows, and floors, as well as improved heating controls for district heat. In developed countries, appliance-related measures are typically identified as the most cost-effective, with cooling-related equipment upgrades ranking high in the 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 50 - 75% energy savings compared to recent current practice. Realizing these savings requires an integrated design process involving architects, engineers, contractors and clients, with full consideration of opportunities for passively reducing building energy demands. 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; 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.

6.4 Interactions of mitigation options with vulnerability and adaptation

If the world experiences warming in areas with the largest fraction of population, as expected, then energy use will decline for heating in temperate climates (e.g., Europe, parts of Asia, and North America), and increase for cooling in most world regions. Depending on the relative magnitude of the impacts on heating and cooling, this could lead to a positive or negative feedback effect. Recent results suggest that for the US and the UK, likely climate change scenarios would cause an increase in CO_2 emissions because cooling changes (increases) exceed heating changes (decreases).

There are many potential synergies where investments in the buildings sector may reduce the overall cost of climate change-in terms of both mitigation and adaptation. These include appropriate application of the tools of integrated building design, heat pumps with high efficiency on both heating and cooling sides, adaptive window glazings, and retrofits including both increased insulation that it optimized for specific climates and storm-proofing. Policies that actively promote integrated building solutions for both mitigating and adapting to climate change are especially important for the buildings sector, including well-designed policies supporting less energy-intensive cooling alternatives. Good urban planning, including increasing green areas as well as cool roofs in cities, has proven to be an efficient way to limit the heat island effect, which also aggravates the increased cooling needs and reduces 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.

6.5 Effectiveness of and experience with policies for reducing CO_2 emissions from energy use in buildings

A wide range of policies has been demonstrated in many countries to be successful in cutting GHG emissions in buildings. Due to the especially numerous, diverse and strong barriers in the buildings sector, no single instrument alone can capture the above described large low-cost GHG abatement potentials. For effective and far-reaching GHG abatement in buildings, and for taking advantage of synergistic effects, a diverse portfolio of policy instruments is necessary. As a result, different packages of various policy instruments have been recently employed in different countries, as well as several new, innovative instruments have been introduced and planned in the buildings sector. Table TS.11 summarises the key policy tools applied for GHG mitigation in buildings, and compares them according to three indicators, based on selected best practices. All of the instruments reviewed can achieve significant energy and CO_2 savings; however, the costs per ton of CO_2 saved diverge greatly. Building code, appliance standards and tax exemption policies achieved the highest CO_2 emission reductions in the sample. Appliance standards, energy efficiency obligations and quotas as well as public benefit charges (invested in carbon abatement mechanisms such as demand-side management), and mandatory labelling were found to be among the most cost-effective policy tools, all achieving significant reductions in CO_2 emissions at net negative costs. Subsidies were revealed as the least cost-effective instrument. Labelling and voluntary programs can lead to large savings at low costs in buildings. Finally, information programs can also achieve significant savings and effectively accompany most other policy measures.

Table TS.11 The impact and effectiveness of various policy instruments aimed to mitigate GHG emissions in the buildings sector

Policy instrument	Effectiveness*	Cost-effectiveness	Policy instrument	Effectiveness*	Cost-effectiveness
Appliance standards	High	High	Tax exemptions/ reductions	High	High
Building codes	High	Medium/ High	Public benefit charges	Medium/High	High
Procurement regulations	High	Medium	Capital subsidies, grants	Medium/ High	High/ Medium
Energy efficiency obligations and quotas	High	High	Mandatory labelling and certification	High	High
Demand-side management programs	High	High	Voluntary labelling and certification	Medium /High	Medium
Energy performance contracting/ ESCO support	High	Medium	Voluntary and negotiated agreements	Medium	Medium
Co-operative procurement	High	High	Public leadership programs	High	High
Energy efficiency certificate schemes	High	High	Education and information programs	Medium/High	High
Kyoto Protocol flexible mechanisms	Medium	Medium	Mandatory audit and energy management	High, but variable	Medium
Taxation (on CO_2 or fuels)	Generally low	Medium	Detailed billing and disclosure programs	Medium	Medium

Note: *includes ease of implementation; feasibility and simplicity of enforcement; applicability in many locations; and other factors contributing to overall magnitude of realized savings

These policies, while applied in many industrialized countries with favourable results, have rarely been pursued aggressively. As a result, in most developed countries, the energy consumption in buildings is still increasing. Although some of this growth is offset by increased efficiency of buildings and major energy-consuming appliances, overall consumption continues to increase due to the growing demand for amenities, such as new electric appliances and increased comfort. The decoupling of energy use from economic growth is only observed for space heating demand. The limited overall impact of policies so far is due to several factors: (i) slow implementation processes; (ii) the lack of regular updating of building codes (requirements of many policies are often close to common practices, despite the fact that CO_2-neutral construction without major financial sacrifices is already possible) and appliance standards and labelling; (iii) inadequate funding and provision of other resources for programmes, and (iv) insufficient enforcement. In developing countries and economies in transition, implementation of existing energy efficiency policies is compromised by the 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.

6.6 Developing countries

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 be valuable in promoting reductions in growth of carbon dioxide emissions in the buildings sector and improving the welfare of the population. The transfer of knowledge, expertise and know-how from developed countries to developing ones can facilitate the adoption of the low-carbon options in these regions, such as integrated design, building energy management systems, PV, high-insulation building materials, efficient appliances and lighting, and solar cooling. However, for the poorest people this can only be facilitated by making the capital available too. 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 a long-lasting impact.

6.7 Co-benefits and links to sustainable development

Often a tension exists between the main development agenda of developing countries (poverty alleviation and increased access to energy) and climate change mitigation. Energy efficiency and utilisation of renewable energy in buildings offer a large portfolio of options where synergies between sustainable development and GHG abatement can be identified. The chief of these for the least developed countries are safe and efficient cook-stoves that, while cutting GHG emissions, significantly reduce mortality and morbidity (presently approximately 1.6 million annual premature deaths are attributed to indoor air pollution in developing countries, mainly among children and women). Safe and efficient cookstoves also reduce the workload for women and children who typically gather the fuel for traditional stoves and the demands placed on natural resources scarce and declining in many rural areas.

Improved energy efficiency in buildings in urban areas in developing countries results in a substantial savings in energy-related investment, since efficiency is less costly than new supply, thus freeing up funds for essential infrastructure investments. Energy efficiency also enhances the affordability of increased energy services, and is generally the least-cost way of bringing about local environmental improvement. If technologies that utilise locally available renewable resources in an efficient and clean way are used broadly, this provides access to “free” energy to impoverished communities for many years and contributes to meeting other Millennium Development Goals.

Improved energy efficiency and utilisation of renewable energy in buildings can reduce fuel poverty and increase access to energy services for poor households in industrialized as well as developing countries. There is increasing evidence that well designed, energy efficient buildings often have the co-benefits of promoting better occupant productivity and health. Most studies on the topic agree that energy-efficiency investments will have positive effects on employment, by creating new business opportunities and thus jobs via domestically produced energy-efficient technologies and services, and through the economic multiplier effects of spending in other ways the money saved on energy costs. The European Commission estimates that a 20% reduction in EU energy consumption by 2020 can potentially create (directly or indirectly) as many as one million new jobs in Europe. Providing energy-efficiency services is a well-established branch of industry in a number of developed countries. Improved energy security and system reliability through improved end-use energy efficiency and building-level energy generation technologies rank among the top energy policy goals of many countries.

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

Policies to implement the Montreal Protocol have generally reduced the use of halocarbons, thus providing greenhouse gas benefits. However, the Montreal Protocol was designed to address ozone-depeleting substances, not contributors to global climate change. In the buildings sector, halocarbons are used as the working fluid in most vapor-compression cooling equipment, and as an expanding agent in some solid-foam and spray-on foam insulation materials. The Special report on Ozone and Climate has identified many cost-efficient policies to reduce HFC emissions without delaying the phase out of CFCs.

Policies designed for objectives unrelated to greenhouse gas emissions can have important impacts. For example, tax policies that encourage the building of larger and more expensive houses to replace existing ones, as is the case in the United States, encourages increased energy use. Subsidy of driving, through public investment in roads and highways and the absence thereof in public transport, impact, not only impact transport energy use but also can encourage housing located far from work.

6.9 Technology research, development, deployment, diffusion and transfer

There is a broad array of accessible and cost-effective technologies and know-how that can abate GHG emissions in buildings to a significant extent that have not as yet been widely adopted. These include high-efficiency lighting and appliances, passive solar and integrated design practices and point to the need for the strengthening of policies to promote their deployment. At the same time, research and development is needed in such areas as high-performance control systems,[14] advanced window glazings, 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 heat, coolth, and electricity to buildings.

Demonstrations of these technologies and systems, and training of professionals are necessary steps toward bringing technologies to market.

[14] 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.

6.10 Long-term-outlook: actions needed

The large share of building-related GHG emissions (33%) makes that mitigation in the residential and commercial sectors an essential component of climate change policies**.** Substantial improvements in existing buildings are possible through renovations, changes in operating conditions and occupant behaviour, and equipment change-out. The basic approach in achieving a ambitious emission reduction targets involves the aggressive adoption and implementation of policies such as those identified Table TS.11.

Very large-scale reductions are possible in new buildings as compared with existing ones, although their overall effect takes longer so become visible in the market. To achieve these in the longer term, new approaches to integrated design and operation of buildings need be taught, spread, and put into large-scale practice as soon as possible. Such training is currently not available to majority of architects and building engineers. Even ambitious policies aimed at building shell improvements introduced in the near future will take long time to exert their full impact due to the long turn-over of buildings, therefore long-term GHG reduction in buildings requires a start in the near-term.

Because of the importance of non-technological opportunities in buildings, an ambitious GHG reduction may require a cultural shift towards a society that embraces climate protection and sustainable development among its fundamental values, leading to social pressure to construct and use buildings that have much reduced environmental footprints.

In sum, while there are many practical and cost-effective technologies and practices available today for buildings-and new options likely to emerge from ongoing research, development, and demonstration-achieving a lower carbon future will require very significant efforts to enhance programs and policies for energy efficiency in buildings and low carbon energy sources, well beyond what is happening today.

7. Industry

7.1 Status of the sector, development trends and implications

Energy-intensive industries: iron and steel, non-ferrous metals, chemicals and fertilizer, petroleum refining, cement, and forest products, account for more than half of the sector's energy consumption in most countries.
Since energy use in other sectors grew faster, the industrial sector's share in global primary energy use declined from 40% in 1971 to 36% in 2002. Developed nations accounted for 51% of this total while transition economies and developing nations accounted for 12% and 37%, respectively.

However, the phenomenal growth of energy-intensive industries observed during the 20th century is expected to continue as population and GDP increase
Much of that energy-intensive industry is now located in developing countries. Overall, developing countries accounted for 42% of iron and steel production, 57% of nitrogen fertilizer production, 78% of cement manufacture, and about 50% of aluminium production in 2003. Many facilities (for aluminium, cement and fertiliser 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 investments in developing countries to achieve energy efficiency and emissions reductions.

Though large scale production dominates these energy-intensive industries in developed countries and in some developing countries, small and medium sized enterprises (SMEs) also have significant shares in many developing nations

7.2 Emission trends (global and regional)

Total GHG emissions from the industry sector were about 10.6 GtCO2equiv in 2002.
Energy-related CO_2 emissions from the industrial sector grew from 5.9 Gt CO_2 in 1971 to 8.5 Gt CO_2 in 2002 .Industry also emits CO_2 from non-energy uses of fossil fuels and from non-fossil fuel sources. In 2000, these were estimated to total 1.7 Gt CO_2. In 2002 developed nations accounted for 53% of total emissions while developing nations' share was 47% (see table TS.12). Most of the industrial sector's CO_2 emissions are from energy-intensive industries: iron and steel, non-ferrous metals, chemicals and fertilizers, petroleum refining, cement, and forest products.

Industrial processes also emit other GHGs, including HFCs from chemical processes; PFCs from aluminium smelting and semiconductor processing; SF_6 from use in electrical switchgear and magnesium processing, and CH_4 and N_2O from chemical industry sources and food industry waste streams. Total emission from these sources is was about 0.4 Gt CO_2 eq in 2000 [medium evidence,medium agreement].

Table TS.12 Industrial Sector Energy-Related CO_2 Emissions 10 World Regions, 1971-2002.

	Energy-Related Carbon Dioxide emissions from industry ($MtCO_2$)		
	1971	**1990**	**2002**
Pacific OECD	530	639	790
North America	1,533	1,493	1,536
Western Europe	1,404	1,176	1,104
Central and E. Europe	398	485	241
Former Soviet Union	963	1,465	822
Centrally Planned Asia	572	1,559	2,197
Other Asia	138	448	823
Latin America	170	326	424
Sub Saharan Africa	118	180	200
Middle East and N. Africa	63	238	393
World	5,887	8,008	8,530

Source: Price et al., 2006

Emissions projections for 2030 under SRES-B2 and -A1 scenarios show a range of energy-related industrial CO_2 emissions from 14 to 20 Gt CO_2 .(see Table TS.13). The highest average growth rates in industrial sector CO_2 emissions are predicted for developing countries. Growth in the regions of Central and Eastern Europe, Former Soviet Union, and Centrally Planned Asia are envisioned to slow to an average annual rate of 0.3 to 1.5% in the B2 scenario, and 0.5 to 2.3% in the A1 scenario for the period 2000-2030. CO_2 emissions are expected to decline in the Pacific OECD, North America, and Western Europe regions for A1 and for B2 after 2010. For non-CO_2 GHG emissions from the industrial sector to 2020 *globally*, emissions are projected to increase by a factor of 1.8, from 470 $MtCO_2$ eq. (130 MtC eq.)in 1990 to 860 $MtCO_2$ eq (230 MtC eq.) in 2020, assuming no further action is taken to control these emissions. Mitigation efforts led to a *decrease* in non-

CO_2 GHG emissions between 1990 and 2000, and many programs for additional control are underway. *Regional* projections of rates of growth in emissions from 1990 - 2020 range from no-growth in emissions in Central and Eastern Europe and the Former Soviet Union, to a factor of nearly 8 in sub-Saharan Africa, albeit from a very low base.

Table TS.13 Projected Industrial Sector Energy-Related CO_2 Emissions and Emissions of Non-CO_2 Gases. Source: Price et al., 2006; U.S. EPA, 2006b.

	SRES A1 Scenario Energy-Related Carbon Dioxide ($MtCO_2$)				SRES B2 Scenario Energy-Related Carbon Dioxide ($MtCO_2$)				Emissions of Non-CO_2 Gases (MtCO2 eq.)	
	2000	2010	2020	2030	2000	2010	2020	2030	2010	2020
Pacific OECD	1,193	1,170	1,169	1,137	894	980	836	688	62	87
North America	1,901	1,876	1,783	1,651	1,867	1,916	1,899	1,725	160	204
Western Europe	1,254	1,276	1,228	1,160	1,351	1,270	1,154	1,063	103	118
Central and E. Europe	520	594	614	600	293	327	380	424	20	22
Former Soviet Union	1,496	1,766	1,850	1,856	1,107	1,093	1,146	1,208	28	31
Centrally Planned Asia	2,244	3,322	4,145	4,483	2,329	2,803	3,261	3,630	146	209
Other Asia	934	1,506	2,087	2,858	924	1,312	1,699	2,154	50	121
Latin America	833	1,532	2,099	2,426	635	950	1,146	1,254	25	32
Sub Saharan Africa	453	856	1,322	1,577	263	260	345	665	8	11
Middle East and N. Africa	786	1,342	1,888	2,224	547	791	888	1,080	16	23
World	11,613	15,240	18,183	19,973	10,210	11,703	12,755	13,892	619	860

Source: Price et al., 2006; U.S. EPA, 2006.
Note: Columns may not sum to total because of independent rounding.

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

Historically the industrial sector has achieved reduction in emissions intensity through adoption of energy efficiency and specific mitigation technologies, particularly in energy-intensive industries. For example, China reported a reduction in energy use per tonne of steel from 29.3 GJ in 1990 to 23.0 GJ in 2000. Not in the text so either we keep this drop the example. The aluminium industry reported >60% reduction in PFC emission intensity over the period 1990-2004 and the ammonia industry reported >50% reduction in energy intensity for 1960 to present. One company reported a 24% reduction in refining energy intensity between 1992 and 2004.

Low technical and economic capacity of SMEs pose challenges for the use of sound environmental technology, though some innovative R&D is taking place in these sectors.

A wide range of measures and technologies have the potential to reduce industrial GHG emissions. These technologies can be grouped into categories of energy efficiency, fuel switching, power recovery, renewables, feedstock change, product change and material efficiency. (Table TS.14). 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.

Table TS.14 Selected Examples of Industrial Technology for Reducing Greenhouse Gas Emissions (not comprehensive). Technologies in italics are under demonstration or development

Sector	Energy Efficiency	Fuel Switching	Power Recovery	Renewables	Feedstock Change	Product Change	Material Efficiency	Non-CO_2 GHG	CO_2 capture and storage
Sector wide	Energy management systems and practices, Motor systems,Efficient boilers and burners, Heat recovery, Efficient lighting & HVAC	Coal to natural gas	Cogeneration	Biomass, Biogas (anaerobic digestion, gasification), PV wind turbines	Recycled inputs				CO_2/O_2 combustion
Iron & Steel	Smelt reduction, Near net shape casting, Scrap preheating, Efficient furnace, Dry coke quenching	Natural gas, oil or plastic injection BF	Top-gas pressure recovery, By-product gas combined cycle	Charcoal	Iron/Steel Scrap	High Strength steel	Recycling, High strength steel, Reduction process losses	n/a	Hydrogen reduction, Oxygen use in blast furnace,
Non-Ferrous Metals	Inert anode, Efficient cell designs				Metal Scrap		Recycling, thinner film and coating	PFC-controls	
Chemicals	Efficient furnaces, Process integration, Membranes, Reactive distillation	Natural gas	Pre-coupled gas turbine, Pressure recovery turbine, hydrogen recovery		Recycled plastics, bio-feedstock	LLDPE?? high-performance plastics	Recycling, Thinner film and coating, Reduction process losses	Control technology for N_2O, PFC, CFC and HCFC	Ammonia, Ethylene oxide

Cement	Precalciner kiln, Roller mill, fluidized bed kiln	Waste fuels, Biogas, Bio-mass	Drying with gas turbine, power re-covery	Biomass fuels, Bio-gas	Slags, poz-zolanes??	Blended cement Geo-polymers??		n/a	CO_2/O_2 com-bustion in kiln
Glass	Cullet preheating Oxyfuel furnace	Natural gas	Air Bottom-ing Cycle	n/a	Increased cullet use	High-strength thin con-tainers	Re-usable containers	n/a	CO_2/O_2 com-bustion
Pulp & Paper	Efficient pulping, Efficient drying, Shoe press, Con-debelt drying	Bio-mass, Landfill gas	Black liquor gasification combined cycle	Biomass fuels (bark, black liq-uor)	Recycling, Non-wood fibers	Fiber ori-entation, Thinner paper	Reduction cutting and process losses	n/a	CO_2/O_2 com-bustion in lime kiln
Electron-ics	Continuous melt silicon growth		RTO-power recovery	n/a				PFC, SF_6 controls	
Food	Efficient drying, Mem-branes		Anaerobic digestion, Gasification	Biomass, By-products, Solar dry-ing			Reduction process losses, Closed water use		
Non-metallic minerals	Roller kiln	Landfill gas	n/a	Biogas, Wood	Wood chips in clay	Hollow bricks			

The mitigation potential for 2030 at costs lower than US$ 100/tCO2 eq is in the order of 10 to 30% of the baseline. In 2030, under the A1B scenario, estimated mitigation potential for the industrial sector, essentially all at costs less than US$ 50/tCO2 eq, is 3.6-6.9 GtCO2 eq (0.98-1.9 GtC eq) or about 15 to 30% of the baseline. Mitigation potential in 2030 under the B2 scenario is somewhat less, 2.6-5.5 GtCO_2 eq (0.71 -1.5 GtC eq) or about 13 to 33 % of baseline. Most of the mitigation potential is located in the steel, cement, and petroleum refining industries, and in the control of non-CO_2 gases, and much of the potential is available at costs of <US$20/t$CO_2$ eq. (limited evidence/low agreement). In both scenarios about 0.35GtCO_2 eq is from the control of non-CO_2 gases, the balance from the control of CO_2.

7.4 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) can be vulnerable to climate change.

7.5 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 (much evidence/high agreement). In many areas of the world, GHG mitigation is not demanded by either the market or government regulation. In these areas, companies can afford to invest in GHG mitigation only to the extent that these investments are compensated by lowered energy or raw material costs, or some similar benefit. 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 to access and absorb information about available options.

Experience with Voluntary Agreements (VAs) for energy efficiency improvement and reduction of energy-related GHG emissions by industry, which have been implemented in industrialized countries since the 1990s, has been mixed. The most effective agreements are those that set realistic targets, include sufficient government support - often as part of a larger environmental policy package, and include a real threat of increased government regulation or energy/GHG taxes if targets are not achieved. Numerous companies are participating in GHG emissions reporting programmes as well as taking voluntary actions to reduce energy use or GHG emissions through individual corporate programmes, non-governmental organization (NGO) programs, and industry association initiatives.

Many countries, both developed and developing, have financial schemes available to promote energy saving in industry. According to a WEC 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.

Policies that reduce the barriers to the adoption of cost-effective, low-GHG emission technology (e.g. lack of information, absence of standards, unavailability of affordable financing for first purchases of modern technology) can be effective. Industry needs a stable transparent policy regime, addressing both economic and environmental concerns, to reduce the costs of capital, because energy efficiency and other forms of GHG mitigation technology can provide attractive rates of return, but they tend to increase initial capital costs, which can be a barrier, particularly in developing countries where capital availability is limited. Industry GHG mitigation decisions, many of which have long-term consequences, will continue to be driven by consumer preferences, costs, competitiveness, and government regulation.

However, a drawback to financial incentives is that they are often also are 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 list of equipment, only innovative technologies), or use a direct criterion of cost-effectiveness.

Several established or evolving national, regional or sectoral CO_2 emissions trading systems exist e.g. in the EU, the UK, Norway, Denmark, New South Wales (Australia), Canada, and several U.S. States. The further refinement of these trading systems could be informed by evidence which suggests that in some important aspects participants from industrial sectors face a significantly different situation than 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.

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

Non climate policies can affect GHG emission both positively and negatively. Policies aimed at balancing energy security, environmental protection and economical development can have 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 it 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 restructuring through the adoption of industrial development pathways that minimize the need for future mitigation (medium evidence, high agreement). 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 the broader national strategies for development, is consistent with sustainable development objectives. Energy intensive industries are now commiting 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.

6.7 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.

6.8 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, e.g. development of an inert electrode to eliminate process emissions from aluminium manufacture and use of hydrogen to reduce iron and non-ferrous metal ores. Technology development is an essential step in producing significant reductions in industrial GHG emissions. However, these 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, and ideally their roles should be complementary. Because of the large economic risks inherent to technologies with the main purpose of GHG emission mitigation, government programmes are likely to be needed 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 risk and capture the rewards of commercialization.

In addition to the funding of R&D, government information, energy audits, reporting, and benchmarking programmes promote technology transfer and diffusion by making industrial enterprises aware of the potential for energy savings and the technology available to achieve those savings. 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.

8. Greenhouse gas mitigation options in agriculture

8.1 Status of the sector, development including production and consumption, and implications

Technological developments have allowed remarkable progress in land productivity, increasing per-capita food availability despite a consistent decline in per-capita agricultural land. 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 progressively increased in developing countries, whilst remaining constant in the developed world.

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.

The absolute area of global cropland has grown to ca. 1400Mha, an overall increase of 8% since the 1960s (5% decrease in developed countries, and 22% increase in developing countries). This trend is predicted to continue into the future, with an additional 500 Mha converted to agriculture from 1997-2020, mostly in Latin America and Sub-Saharan Africa.

Globally, the cropland to grazing land ratio has remained stable at 0.44 since 1961, although there are regional differences. While for the group of developed countries this ratio has decreased slightly (from 0.56 to 0.53) from 1961 to 2002, it has shown a slight increase in the developing countries, from 0.36 to 0.39, during this period.

Economic growth and changing lifestyles in some developing countries, notably in China, 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 (60% by 2020) are forecast, mostly in developing regions such as South and Southeast Asia, and Sub-Saharan Africa.

8.2 Emission trends

Agriculture accounts for an estimated 14% of total global anthropogenic emissions of non-CO_2 GHGs and its net CO_2 exchange with the atmosphere is nearly balanced. Agriculture accounts for 84% of anthropogenic N_2O emissions (2825 Mt CO_2 eq. in 2000), 47% of anthropogenic CH_4 emissions (2778 Mt CO_2 eq. in 2000) and <1% of anthropogenic CO_2 emissions (40 Mt CO_2 eq. in 2000).

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 some gains in soil C are possible in the short term). Despite increases in absolute emissions, improved management practices and emerging technologies may permit a reduction in emissions per unit of food produced.

Without additional policies, agricultural N_2O and CH_4 emissions are forecast to increase by 35-60% and 40-50%, respectively, up to 2030, thus accelerating with respect to the observed 14% increase from 1990 to 2005. Emissions of CO_2, mainly from land use change, especially deforestation, are forecast to be stable or declining up to 2030. Combined with the increasing adoption of conservation tillage practices and increasing crop productivity, CO_2 emissions from soils might decrease. With the only exception of the European Union, where emissions of agricultural greenhouse gases are expected to continue decreasing, all other regions, most notably The Middle East and North Africa and Sub-Saharan Africa, are expected to show important increases.

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

The global technical agricultural mitigation potential by 2030, considering all gases, is estimated to be around 5500-6000 Mt CO_2 eq. yr^{-1}, with economic potentials of 1900-2100, 2400-2500, and 3100-3300 Mt CO_2 eq. yr^{-1} at carbon prices of < 20, <50 and < 100 US\$ t CO_2 eq.$^{-1}$, respectively.

Improved agricultural management can reduce net GHG emissions, often affecting more than one GHG. These practices include: cropland management (agronomy, nutrient management, tillage/residue management, water management including irrigation and drainage, rice management, agro-forestry, land cover/use change); grazing land management and pasture improvement (grazing intensity, increased productivity, nutrient management, fire management, species introduction), management of organic soils; restoration of degraded lands (erosion control, organic amendments, nutrient amendments); livestock management (improved feeding practices, dietary additives, breeding and other structural changes); manure/biosolid management (improved storage and handling, anaerobic digestion, more efficient use of nutrients); and bio-energy (energy crops, solid, liquid, biogas, residues). The effectiveness of these practices varies, depending on factors such as climate, soil type, and farming system.

The economic mitigation potential at the range of prices of CO_2 equivalents for each SRES scenario is shown in Table TS.15 below.

Table TS.15 *Estimates of the global agricultural GHG mitigation potential by 2030 under different assumed prices of CO_2 equivalents.*

Scenario	0-20	0-50	0-100	>>100 (technical potential)
	Price range (USD t CO_2 eq. $^{-1}$)			
	Mt CO_2 eq. yr^{-1}			
B1	1900	2400	3100	5500
A1b	2000	2400	3300	5700
B2	2000	2500	3300	5800
A2	2100	2500	3300	6000

The most prominent mitigation options in agriculture (with potentials shown in Mt CO_2 eq. yr^{-1} for technical potential by 2030) are improved cropland management (1440), improved grazing land management (1360), restoration of cultivated organic soils (1260) and degraded lands (690). Lower, but still significant mitigation potential is provided by rice management (279), livestock management (220) and manure management**.** Details are provided in Figure TS.29

In addition to GHG emission reduction, agricultural land can provide feed stocks (e.g. crop residues, dung, dedicated energy crops) for bio-energy production. Although the mitigation potential is counted in the user sectors, the economic potential of biomass energy from agriculture is estimated to be 640, 2240 and 16000 Mt CO_2 eq. yr^{-1} at costs below 20, 50, 100 USD t CO_2 eq.$^{-1}$, respectively. At costs < 20 USD t CO_2 eq.$^{-1}$, bio-energy could mitigate about 30% as much GHG as all other agricultural GHG measures combined, at costs < 50 USD t CO_2 eq.$^{-1}$ the figure is 90-100% of all other measures combined, but at costs < 100 USD t CO_2 eq.$^{-1}$, agriculturally derived bio-energy could mitigate nearly five times the GHG of all other agricultural measures together. Bio-energy competes with other land-uses for available land. An additional mitigation of 770 Mt CO_2 eq. yr^{-1} could be delivered by 2030 by improved energy efficiency in agriculture. This potential is not included in the table above as this potential might also be counted under buildings and transport.

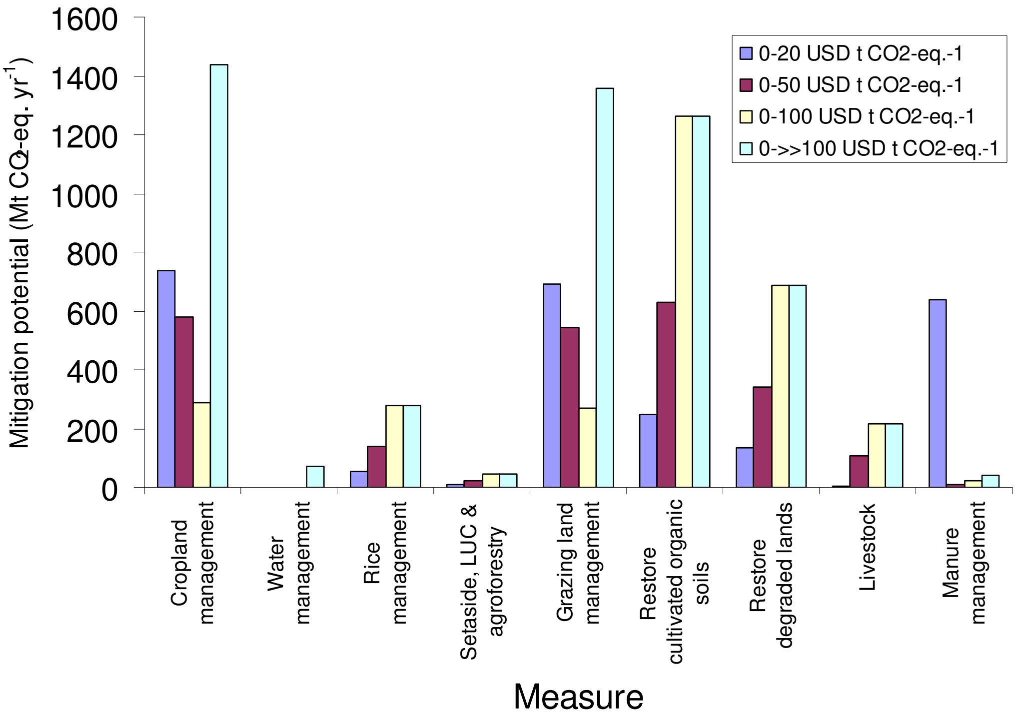


Figure TS.29 Potential for GHG agricultural mitigation at a range of prices of CO_2 eq. (B1 scenario shown, though the pattern is similar for all SRES scenarios)

The estimates of mitigation potential for the next 20 years are lower than those in the IPCC SAR and TAR (which projected to 2050), because of the different time scale and greater awareness of potential barriers to adoption. In the medium-term, much of the mitigation potential is derived from soil C accrual (atmospheric CO_2 removal), but this benefit will diminish as soil C approaches maximum levels, and long-term mitigation will rely increasingly on reducing emissions of N_2O, CH_4, and CO_2 from energy, the benefits of which persist indefinitely

8.4 Interactions of mitigation options with vulnerability and adaptation

Agricultural actions to mitigate GHGs could (a) reduce vulnerability (e.g. if carbon sequestration reduces risk of drought) or (b) increase vulnerability (e.g. if heavy dependence on biomass energy makes the energy supply more sensitive to climatic extremes). Policies to encourage mitigation and / or adaptation in agriculture may need to consider these interactions. Adaptation-driven actions, also, may either (a) favor mitigation (e.g. residue return 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 yield leading to increased nitrous oxide emissions). Strategies that simultaneously increase adaptive capacity, reduce vulnerability and mitigate climate change could be favoured over those with conflicting impacts.

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

Many recent studies have shown that actual levels of GHG mitigation are far below the potential for these measures. Very little progress in implementation has been made and little is expected by 2010 because of costs of implementation and other barriers, including: pressure for agricultural land, demand for agricultural products, competing demands for water as well as various social, institutional and educational barriers. Carbon sequestration in Europe, for instance, is likely to be negligible by the first Commitment Period of the Kyoto Protocol (2008-2012), despite significant technical potential. Many of these barriers may not be overcome without policy/economic incentives.

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 constrains confidence in future global projections. 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. For example, agro-forestry undertaken to produce fuel wood, 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.

8.7 Co-benefits of greenhouse gas mitigation policies

Agro-ecosystems are inherently complex and very few practices yield purely 'win-win' outcomes; most involve some trade-offs. The co-benefits and trade-offs of a practice may vary from place to place because of differences in climate, soil, or the way the practice is adopted. In producing bio-energy, for example, if the feedstock is crop residue, that may reduce soil quality by depleting soil organic matter; conversely, if the feedstock is a densely-rooted perennial crops, that may replenish organic matter and thereby improve soil quality.

Most of the 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. For example, agro-forestry helps females, otherwise devoted to fuel wood and fodder collection, participate in local decision-making and frees children to attend school. Agro-forestry also provides greater biomass (fuel-wood, fodder) and helps the livestock sector. However, for some mitigation options, the impact on sustainable development is still uncertain. 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.

8.8 Technology research, development, deployment diffusion and transfer

Many of the mitigation strategies outlined for the agriculture sector employ existing technology. For example, increases in crop yields and animal productivity will reduce emissions per unit of production. 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 methane capture systems − all of which reflect existing technology. However, some strategies involve new use 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 methane suppressant is still new and not fully defined.

8.9 Long-term outlook/systems transitions, decision making

By 2050, many existing and emerging practices could be adopted to reduce greenhouse gas emissions, but their net effect is uncertain because of the counteracting effects of higher food demands, and uncertainties from coming social, economic, and climate changes.

Global food demands may double by 2050, leading to intensified production practices (e.g. increasing use of N fertilizer) that could offset the effects of mitigation practices. Forecast increases in consumption of livestock products, likewise, amplify CH_4 and N_2O emissions if livestock numbers increase. Thus, while mitigation practices can significantly reduce emissions per-unit of agricultural product, these gains may not offset the effects of higher total production.

Projecting long-term mitigation potentials is also hampered by other uncertainties. For example, the effects of climate change are unclear; yields and soil C sequestration could increase with elevated CO_2 and warmer temperatures (at least in some regions), but the effects may be offset by accelerated soil C decay, changes in precipitation, and unpredictable adaptive responses. Some studies have suggested that technological improvements could potentially counteract the negative impacts of climate change on cropland

and grassland soil carbon stocks, implicating technological improvement as a key factor in future GHG mitigation.

9. Forestry

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

Forestry is one of the important sectors when addressing climate change in the broader context of global change, land use planning and sustainable development. Hundreds of millions of households depend on the goods, services and financial values provided by forests. Land-use changes can negatively affect those that most closely depend on forest resources for their livelihoods. Currently, forest management does not consider future impacts of climate change.

Globally the forest area has continued to decrease, but at a decreasing rate: between 2000 and 2005 the net area loss was 7.3 million ha/yr, in the 1990s it was 8.9 million ha/yr[1]. Forest planting, landscape restoration and natural expansion of forests have reduced the net loss of forest area. Despite this, gross deforestation continues at an alarming rate, 13 million ha a^{-1} globally, mainly as a result of converting forests to agricultural land. Still, the global forest cover amounts to about 4000 million ha, which is about 30 percent of the world's land area. Africa and South America continued to have the largest net loss of forests (Figure TS.30).

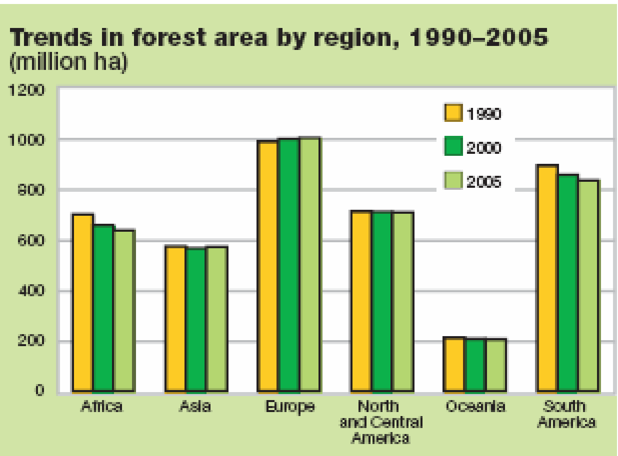


Figure TS.30

Production of wood and non-wood forest products is the primary function for 34% of world forests. Official data show that global wood harvest has remained steady since 1990 at approximately 3 billion m^3/yr and that globally harvest is far below the yearly increment. Undoubtedly the actual amount of wood removals is higher, as informally and illegally removed wood is not recorded. Forest plantations were estimated in 2000 to account for only 5% of global forest cover but supply 35% of global roundwood.

9.2 Emission sources and sinks; trends

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. In the years following clear-cut harvest or other major disturbances, the losses from decay of residual dead organic matter exceed the carbon uptake by regrowing trees. For most of the immature and mature stages of stand development, stands are carbon sinks, and at very old ages, ecosystem carbon will either decrease or continue to slowly increase with accumulations mostly in dead organic matter and soil carbon pools.

Deforestation is the major contributor to greenhouse gas emissions from land use, land-use change and forestry. Since 1990, deforestation in the tropics and forest regrowth in temperate and parts of the boreal zone remained the major factors responsible for emissions and removals respectively. New estimates support the previously-found increase in the terrestrial carbon sink in the 1990's over the 1980's, but the new sink estimates and the rate of increase is estimated to be smaller than previously reported. Projected future trends in emissions and removals vary greatly making it difficult to define baselines.

Global net emissions from land-use change in the tropics are estimated to be 4 ± 1 GtC /yr. This includes emissions from conversion of forests (71%) and loss of soil carbon after deforestation (20%), emissions from forest degradation (4.4%), emissions from the 1997-1998 Indonesian exceptional fires (8.3%), and sinks from regrowth (-3.3%).

Large year-to-year and decadal scale variation of regional carbon sinks is reported, making it difficult to define distinct trends**.** The variation reflects the effects of climatic variability, both as a direct impact on vegetation and through the effects of wild fires and other natural disturbances, as well as the effects of (historic) management. It also results from other aspects of global change including socio-economic factors. (see fig TS.31)

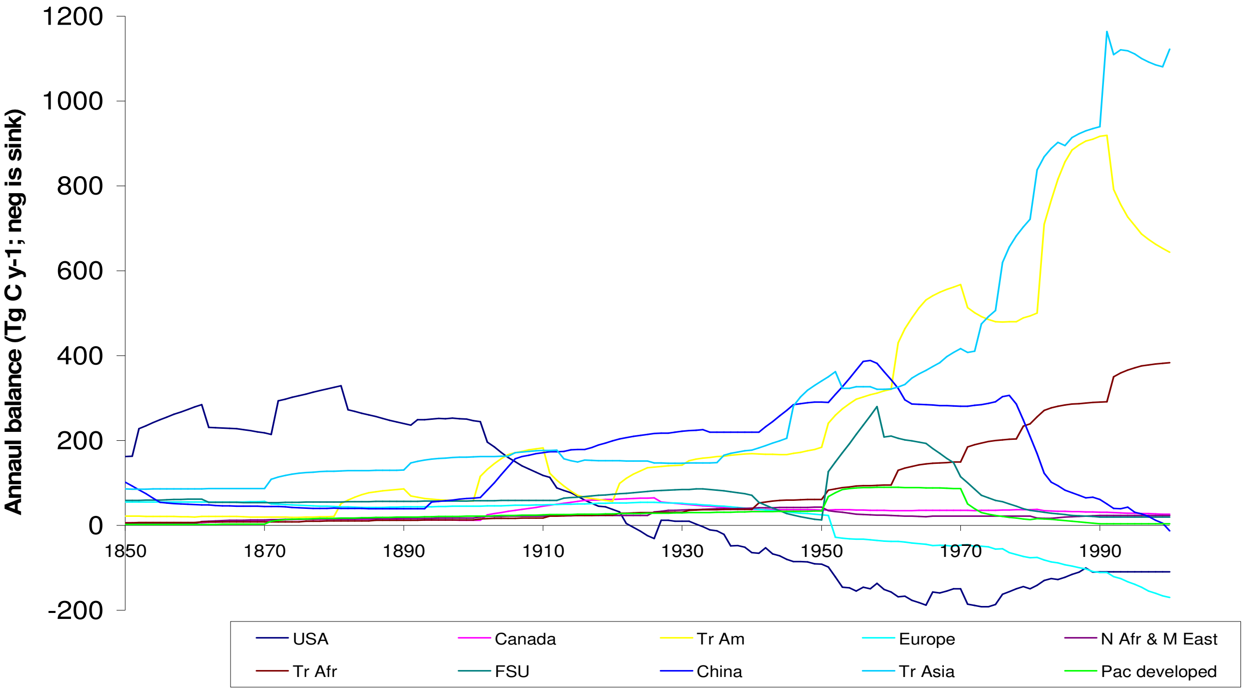


Figure TS.31. Net sink or source of the LULUCF sector over time per continent, historically. Positive = source.

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

Mitigation in the forest sector needs to be assessed on a system wide basis in view of possible important interactions (see Fig. TS.32). Assessment of mitigation options requires integration across land-use sectors, across forest ecosystems and forest product use (including bioenergy), and over several time scales because analyses with narrowly defined boundaries (in sectors, space or time) may arrive at conclusions that do not maximize the benefit for the atmosphere.

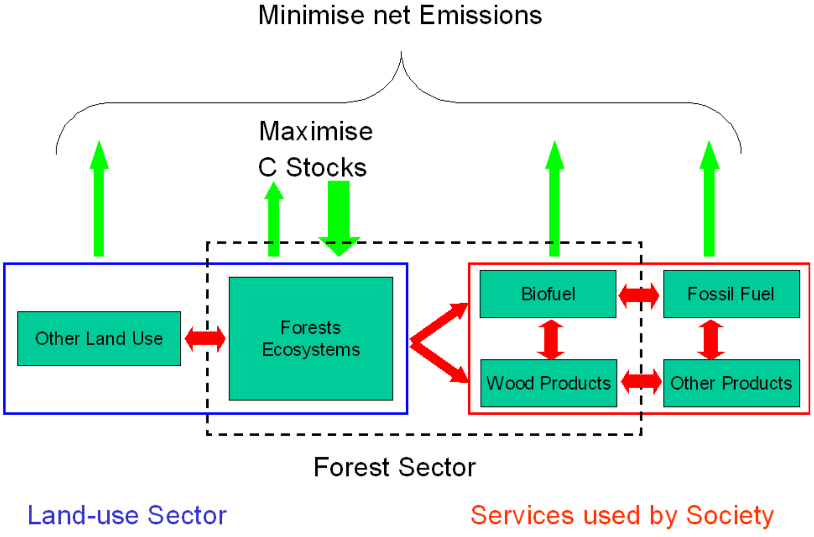


Figure TS.32. Mitigation strategies aimed at maximizing carbon storage in forest ecosystems need to be assessed with regard to their impacts on net GHG emissions across all sectors. The optimum strategy may change as the system boundaries are expanded from forest ecosystems, to the entire forest sector, to all services provided by the forest sector, and ultimately to all land-use decisions.

The choice of mitigation options in a portfolio will depend on the boundaries and time horizon over which the assessment is made. In the short-term (< 5 years) avoiding deforestation is the most attractive option, but over longer time frames the role of forestry and the forest sector in providing a sustainable supply of timber, fibre and energy can be increasingly enhanced. Forest management practices aimed at increasing carbon stocks can affect the net GHG balance of other sectors. For example stopping all forest harvest activities results in increases in forest carbon stocks, but reduces the amount of timber and fibre available to meet society's needs which would result in higher emissions outside the forest sector.

Options available to reduce emissions by sources and/or increase removals by sinks in the forest sector are grouped into four general categories (Figure TS.33):

1. <u>Maintaining or increasing the forest area</u> through the avoidance of deforestation and through afforestation/reforestation;
2. <u>Increasing the stand-level carbon density</u> (tonnes of carbon per ha) using planting, site preparation, tree improvement, fertilization, uneven-aged stand management, or other silvicultural techniques that contribute to sustainable forest management;
3. <u>Increasing the landscape-level carbon density</u> using longer forest rotations, forest conservation, fuel management, protection against fire and insects, and
4. <u>Increasing carbon stock in wood products and enhancing product substitution</u> using forest-derived biomass to substitute products with high fossil fuel requirements and increasing the use of biomass-derived energy to substitute fossil fuels.

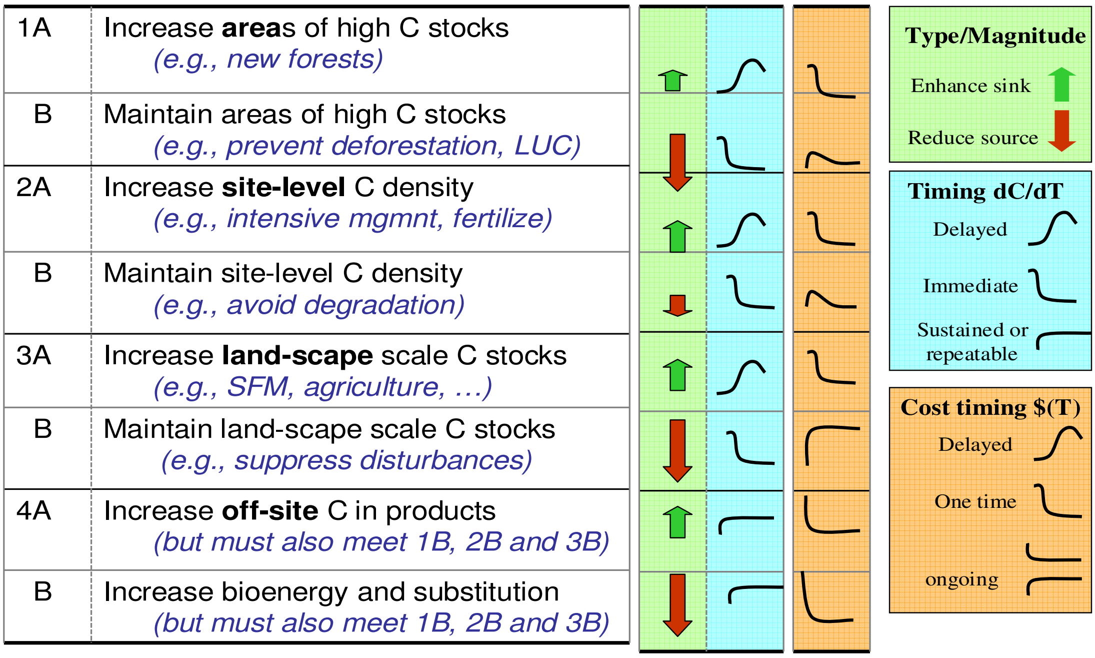


Figure TS.33 Conceptual diagram of the options available in the forest sector and their characteristics in affecting the sink. The stylised graphs in the two right hand columns indicate respectively when effects will appear and when costs would be incurred (immediatel, or later and in what pattern).

Wood for bioenergy is a globally important energy carrier. Forest biomass and 'waste' products can be used to produce energy either directly (e.g. harvesting residues, processing wastes, construction and demolition waste) and via intermediate biofuels (e.g. wood pellets, bioethanol, biogas). In its non-industrial version, much of the global population depends on it for domestic heating and cooking. The forest industry is already a large user of bioenergy, and interest is growing in the use of logging residues or additional fellings for more widespread use of bioenergy. The climate benefit of using biomass is that the carbon emissions associated with fossil energy use are prevented. The use of forest residues in the electricity sector, replacing fossil fuels, can lead to avoided CO_2 emissions in the order of 0.8-4.9 $GtCO_2eq$ in 2030.

Minimising net greenhouse gas emissions in the forest sector includes consideration of both forest ecosystem carbon stocks (increased by aforestation, avoided deforestation and agroforestry) and the ability of these systems to provide wood products to meet society's needs. Wood products derived from sustainably managed forests address the issue of saturation of forest carbon stocks: the annual harvest can be set equal or below the annual forest increment, thus allowing forest carbon stocks to be maintained or to increase. Wood products stocks tend to be small compared to carbon stocks in the forest but they can reduce emissions by providing an alternative to materials such as concrete or steel which are associated with higher GHG emissions.

Regional modeling assessments project a gradually increasing mitigation potential of forestry measures globally (Figure TS.34 and Table TS.16). By 2030 the economic potential of a combination of measures in afforestation, avoided deforestation, forest management, agroforestry and bioenergy, could yield on average an additional sink of around 3.1 $GtCO_2eq/yr$ at costs <

US$ 100/tCO2 eq (medium confidence). About 50% of this (1.5 $GtCO_2$ /yr) can be achieved at costs under 20 $/tCO_2$. This sink enhancement/emission avoidance will be located in the tropics for 65% (high confidence), be found mainly in above ground biomass carbon pool, and for 10% achieved through bio energy (medium confidence). In the short term this potential is much smaller, with 1.2 Gt CO_2eq in 2010 (high confidence).

Top-down global models generally give higher global economic potentials with an average of 12.9 $GtCO_2$eq/yr , all price levels, in 2030, for 36% (4.6 $GtCO_2$ eq/yr)_achievable at costs under 20$/t CO_2 .
The regional assessments are based on a wide variety of studies with different assumptions. The global top down modeling efforts provide a very large potential that does not sufficiently take into account local specific barriers, leakage, risk and institutional barriers. A large uncertainty still surrounds these mitigation estimates.

Regional modelling estimates are much lower than in TAR which gave a potential of 11.7 $GtCO_2$eq/yr in 2010) (Figure TS.35). However, the latter could be regarded as a technical potential.

Table TS.16. Economic mitigation potentials in forestry as assessed from regional modeling studies broken down by cost classes.

	region	Potential in MtCO2 eq in 2030 Baseline*: B2	In cost class: <0 US$/ton CO2eq (%)	In cost class: 1-20 US$/ton CO2eq (%)	In cost class: 20-50 US$/ton CO2eq (%)	In cost class: 50-100 US$/ton CO2eq (%)
Forestry (inl the bio energy effect)	global	3147				
	North America	555		20	40	40
	EU 25 + 2+3	124		20	40	40
	Former Soviet Union	206		30	30	40
	Africa	491	10	50	30	10
	OECD Pacific	141	5	30	40	25
	Caribbean, Central and	903	10	50	30	10
	Centrally planned asia	235		30	30	40
	Other Asia	491	10	50	30	10

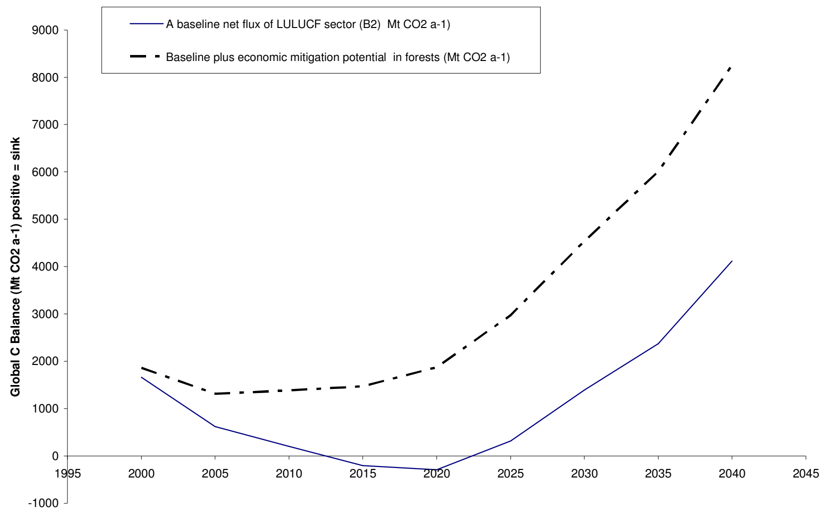


Figure TS.34. The wedge: A hypothetical projection of the baseline of the global LULUCF sector (B2) and the economic potential of curbing of this baseline by additional measures in the forestry sector alone at a carbon price of around 20US$/tCO2. Note that large uncertainty surrounds both the baseline, as well as the effect of the measures. Naturally, choosing another baseline would have an impact on the size of the curbing as well, however, literature does not allow such a dynamic approach.

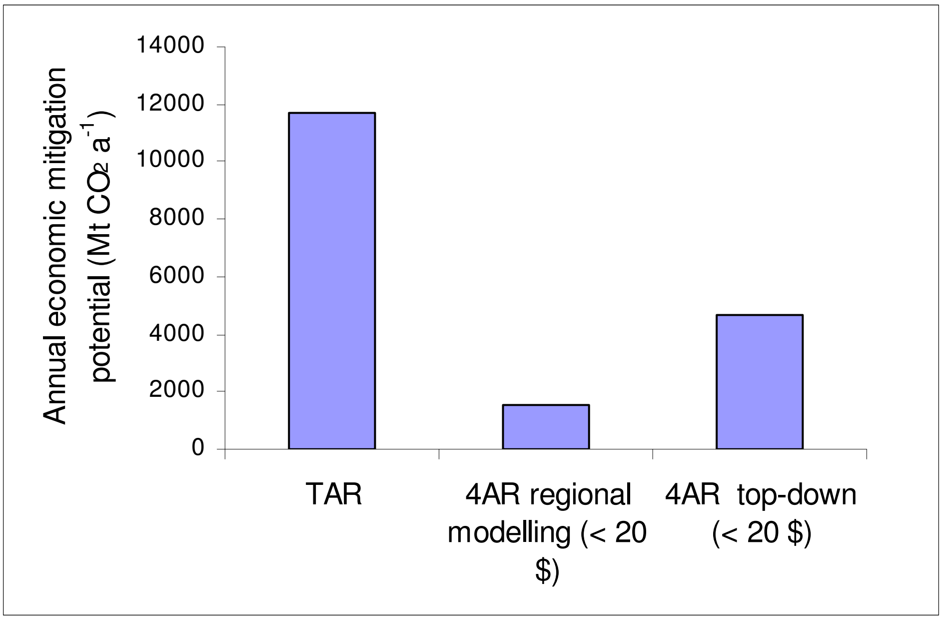


Figure TS.35. Comparison of results as presented for forestry mitigation potential in TAR (biological potential), with the two estimates of the current chapter (economic potential < 20$ US/tCO_2)

There are uncertainties about the practical implementability of the global potential estimate (< 20 US $/tCO2) of 1.5 - 4.6 Gt$CO_2$ /yr. The market potential is probably a small fraction of these numbers due to several institutional barriers and risks. The economic potential does not take these into account yet. Also possible leakage between regions is not accounted for.

9.4 Interactions of mitigation options with vulnerability and adaptation

Forests are likely to be impacted by projected climate change which could reduce its mitigation potential. However, forest land can be managed to reduce vulnerability to climate change. The literature on the interaction between forestry mitigation and climate change is in its infancy. A primary management adaptation option is to reduce as many ancillary stresses on the forest resource as possible. Maintaining widely dispersed and viable populations of individual species minimizes the probability that localized catastrophic events will cause 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 the vulnerability to climate change.

Forestry mitigation projects provide adaptation co-benefits to other sectors. Examples include agroforestry in reducing rainfed crop income variability to drought, mangroves reducing vulnerability of coastal settlements, and shelterbelts halting desertification.

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

No single cook-book recipe can be given to guide mitigation policies in the forestry sector. Multiple and location specific strategies are required. The optimum choices depend on the current state of the forest, the dominant drivers of forest change, and the anticipated future dynamics of the forest within each region. Participation of all stakeholders and policy makers is necessary to promote mitigation projects. Within each region combined consortia of stakeholders and policy makers can design the optimal mix of measures that tackles the ongoing emissions, protects the carbon stocks, be it in the above ground biomass, soil organic carbon, wood products or through provision of biomass for bio energy. Integration of mitigation in the forestry sector into land use planning could be important in this respect.
Climate mitigation policies in forestry have been generally most successful where they both align with and amplify underlying economic objectives or where there is sufficient political will, financial resources and regulatory capacity for effective implementation

One of the main barriers for implementing carbon sequestration projects in the LULUCF sector has been the uncertainty over regulations**.** Few forestry mitigation projects have been undertaken since 2000. Clean Development Mechanism (CDM) afforestation and reforestation (A/R) was not operational before September 2004, when the first call for methodologies was issued by the CDM Executive Board. Projects in Annex I countries are subject to fewer limitations. In principle, all land-use related activities are eligible for crediting, starting from 2008. Furthermore, the credits generated do not expire, because host country governments will remain responsible for the maintenance of the carbon stocks once built up on their territories.

Understanding of the complexity of the effects of land-surface change on the climate system in formulating the policy for climate change mitigation in the forest sector is very important. To fully consider the climatic effect of changing land surface and managing carbon stocks in the biosphere would require complex modelling tools not yet available and the present analysis therefore continues to focus on carbon.

9.6 Integrated and non-climate policies

Taken together, non-climate policies have had minimal impact on slowing tropical deforestation, the single largest contribution of land-use change to global carbon emissions. Available evidence suggests that policies that seek to alter forestry activities where sufficient regulatory and institutional capacity are not available, have had limited effectiveness. Nevertheless, there are promising examples where many developing countries with adequate resources and political will have been able to slow deforestation, raising the possibility that with sufficient institutional capacity, political will and sustained financial resources, it may be possible to scale up these efforts. Well-constructed carbon markets or other environmental service payment schemes aimed at providing a countervailing financial incentive to overharvesting and forest conversion may offer considerable promise in this regard.

Non-climate forest policies have a long history of successful creation of plantation forests on both public and private lands in developing and developed countries. The underlying financial incentives to establish plantations are often positive but the establishment of virtually all significant plantation estates has relied upon government support, at least in the initial stages. This is due, in part, to the non-liquidity of the investment, the high cost of capital establishment and long waiting period for financial return.

Non-climate forest policies may affect both the sequestration and stocks of carbon in managed forests. Industrialized countries generally have sufficient resources to implement policy changes in public forests but there may be limited opportunities for increasing sequestration through changed management practices (e.g., by changing species mix, lengthening rotations, or accelerating replanting rates) if these forests are already managed to relatively high standards. Governments typically have less authority to regulate land use on private lands, and so have relied upon providing incentives to maintain forest cover, or to improve management. These incentives can take the form of tax credits, subsidies, cost sharing, contracts, technical assistance, and environmental service payments. The lack of robust institutional and regulatory frameworks, trained personnel and secure land tenure has constrained the effectiveness of forest management in many developing countries. Over longer time frames, the role of forestry and the forestry sector in providing a sustainable supply of timber, fibre and energy can be increasingly enhanced at the same time increasing mitigation potential.

Carbon will remain one of multiple goals that drive land-use decisions. Within each region, local solutions have to be found that optimize all goals and aim at integrated and sustainable land use. Developing the optimum regional strategies for climate change mitigation involving forests will require complex analyses of the synergy and trade-offs in land-use between forestry and other land uses, the trade-offs between forest conservation (carbon storage) and harvesting forests to provide society with carbon-containing fiber, timber and bioenergy resources, and the trade-offs among utilization strategies of harvested wood products aimed at maximizing storage in long-lived products, recycling, and use for bioenergy. Important environmental, social and economic ancillary benefits can be gained by considering forestry mitigation options as an element of the broad land management plans. Environmental payment schemes for forest services (e.g. recognizing carbon value) can provide incentives to change to more sustainable patterns of forest management. Attractive carbon prices and simplified rules and guidelines, favourable national land use policies and capacity building could promote large-scale CDM type of forestry mitigation programmes.

9.7 Technology research, development, deployment, diffusion and transfer

Technologies for mitigation in the forestry sector are generally commercially available, but not always easily accessible in developing countries. R&D for forest inventory, remote sensing and ecological modeling is important for making mitigation actions more effective in the future. The deployment, diffusion and transfer of mitigation technologies are key to improving the economic and social viability of the different mitigation options.

10. Waste management

10.1 Status of the sector, development trends, and implications

Waste generation is related to population, urbanization, and affluence. Current total global rates of post-consumer waste generation are estimated to exceed 900 Tg ($9*10^{11}$ kg) per year and have been increasing in recent years, especially in developing countries with rapid population growth and urbanization. In the most highly developed countries, a current goal is to decouple waste generation from economic driving forces such as GDP; recent trends suggest that rates of post-consumer waste generation/capita may be peaking in the highly developed countries as a result of recycling, reuse, waste minimization, and other initiatives. Effective GHG mitigation, improved public health, and pollution prevention are all important co-benefits of effective and sustainable waste management practices. While there is extensive infrastructure in place for waste and wastewater management in developed countries, it is a significant and costly challenge to improve the waste and wastewater infrastructure in developing countries.

The major technologies for waste management are mature and readily deployable, including sanitary landfilling with leachate and gas management, composting, and incineration and other thermal processes. In the context of integrated waste management, the choice of a particular technology is a function of many competing variables, including cost, available land area, waste quantity and characteristics, regulatory constraints, economic incentives, collection and transport issues, and policy considerations. Recycling initiatives, both public and private, are currently reducing GHG emissions by decreasing the mass of waste requiring disposal-recycling could be expanded in many countries to achieve additional reductions. Recycling benefits are difficult to quantify globally because of varying baselines and definitions; however, local reductions of 30-50% have been achieved. In developing countries, waste scavenging and informal recycling are common practices, and there is a great need to improve conditions for those who make their living from waste.

With respect to wastewater, only about 60% of the global population has access to some form of sanitation (sewerage, septic tanks and latrines). For wastewater treatment, almost 90% of the population in developed countries but less than 30% of the population in developing countries is served by the existing wastewater treatment infrastructure. Similar to solid waste, there are numerous existing technologies for wastewater collection, transport, recycling, aerobic and anaerobic treatment, and use of sludges.

The availability and quality of data are major problems for the waste sector. Solid waste and wastewater data are lacking for many countries, the reliability of existing data for many countries is questionable, definitions are not uniform, and interannual variability is often not well quantified. Consistent and coordinated data collection and analysis at the national level could greatly improve the quantification of both direct and indirect GHG mitigation for the waste sector.

10.2 Emission trends

Historic emissions and emission trends are summarized in Table TS.17. The waste sector contributes about 2-3% of total GHG emissions for Annex I and EIT countries and 4-5% for non-Annex I countries. Current annual emissions are about 800 Mt CO_2eq for landfill CH_4, about 400 Mt CO_2eq for wastewater CH_4, about 80 Mt CO_2eq for wastewater N_2O, and about 40 Mt CO_2eq for CO_2 from incineration of fossil carbon**.** In developing countries, rapid increases in population and urbanization are resulting in increased emissions.

Table TS.17 Trends for GHG emissions from waste according to UNFCCC national inventories and projections

	1990	1995	2000	2005	2010	2015	2020	2050
	Mt CO_2eq							
Landfill CH_4	760	780	780	820	880	950	1000	2900
Wastewater CH_4	360	400	420	440	460	480	500	
Wastewater N_2O	70	80	80	90	90	90	100	
CO_2 from Incineration	40	40	50	50	60	60	60	80

Notes: *Includes extrapolations for countries which did not report emissions. For 1995, total GHG emissions from waste reported to UNFCCC were approximately 1000 $MtCO_2eq$/yr; the numbers in the table total 1300 Mt CO_2eq for 1995.*

Landfill CH_4 is the largest GHG emission from this sector. Major differences exist between the developed countries of Europe, Asia, and N. America and the developing countries of Asia, Africa, and the LAC region. Although landfill CH_4 emissions are stabilizing and decreasing in many developed countries as a result of increased CH_4 recovery and use, waste diversion from landfills, and waste reduction due to recycling, landfill CH_4 emissions are increasing in developing countries due to urbanization, increased quantities of municipal solid waste, and, to some extent, the replacement of open burning and dumping by controlled (more anaerobic) landfills. Without additional measures, increases in emissions of 30-40% from 1990 up to 2020 are projected, mainly from the non-Annex 1 countries.

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

Effective waste management is synonymous with effective GHG mitigation. Collectively, a wide range of mature, effective, low- to high-technology waste management strategies can be implemented to mitigate GHG emissions from waste through landfill CH_4 recovery and utilization, improved landfill management practices, engineered wastewater management, and thermal processes for waste-to-energy. The importance of the waste sector for reducing GHG emissions has been underestimated because waste management decisions are often made locally without concurrent quantification of GHG mitigation co-benefits. A key issue for developing countries is the implementation of controlled vs. uncontrolled management of waste and wastewater. In addition, waste minimization, recycling,and re-use represent a growing potential for indirect reduction of GHG emissions through improved energy 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.

Landfill CH_4 emissions are directly reduced through active landfill gas extraction and recovery using vertical wells or horizontal collectors. In addition, utilization of landfill CH_4 offsets fossil fuels for industrial or commercial process heating, onsite generation of electricity, or production of a substitute natural gas. Landfill CH_4 recovery for energy use has been fully commercial since 1975, currently exceeds 105 Mt CO2eq/yr, and, in combination with the EU Landfill Directive limiting landfilling of organic waste, has been largely responsible for stabilizing landfill CH_4 emissions from developed countries. With incentives such as the continued availability of the CDM for increased landfill CH_4 recovery in developing countries, a reduction of up to 500 Mt/yr CO_2 eq by 2030 could be achieved at very low cost (<10 US$/t CO_2 eq) with larger mitigation potentials technically feasible. Both the CDM and JI could significantly reduce landfill CH_4 emissions by accelerating the introduction of existing technologies for landfill CH_4 recovery and utilization.

The economic reduction potential for reducing landfill CH_4 emissions is 2.3 $GtCO_2eq$ at costs <20 US$/$tCO_2eq$, of which around 500MtonCO_2eq at negative marginal costs for the year 2030 (see Table TS.18). 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. Additionally, thermal processes for waste-to-energy offer significant potential to reduce emissions but at a higher cost; this option may become more viable as energy prices increase. Because landfills continue to produce CH_4 for many decades, thermal processes can provide a complementary shorter-term mitigation measure.

Table TS.18 Economic reduction potential of CH_4 emissions from landfilled waste by level of marginal costs for total GHG emission reduction assessed for the year 2030[15].(Monni et al., 2006)

		USD/t CO_2 eq				
		<0	**<10**	**<20**	**<50**	**<100**
Category	**Region**	**Mton CO_2 eq reduced**				
Anaerobic digestion	OECD	0	0	1	5	5
	EIT	0	0	0	20	24
	Non-OECD	0	0	30	68	95
	Global	0	0	31	94	124
Composting	OECD	0	0	0	0	3
	EIT	0	0	0	6	19
	Non-OECD	0	0	0	58	81
	Global	0	0	0	64	102
Mechanical biological treatment	OECD	0	0	0	0	0
	EIT	0	0	0	0	0
	Non-OECD	0	0	0	0	19
	Global	0	0	0	0	19
LFG recovery - energy	OECD	27	43	41	23	22
	EIT	56	29	15	0	0
	Non-OECD	328	368	306	138	43
	Global	411	440	362	162	65
LFG recovery - flaring	OECD	0	6	1	0	0
	EIT	0	17	0	0	0
	Non-OECD	0	12	0	0	0
	Global	0	34	1	0	0
Waste incineration with energy recovery[a,b]	OECD	124	222	237	266	266
	EIT	0	101	156	156	140
	Non-OECD	0	0	166	515	653
	Global	124	323	558	936	1059
Total	OECD	151	270	280	295	296
	EIT	56	147	171	182	182
	Non-OECD	328	380	501	779	890
	Global	535	797	953	1255	1369

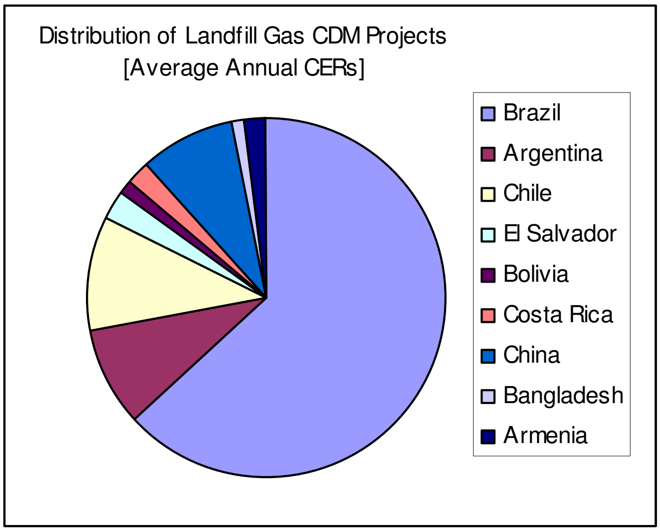
a This category includes all waste-to-energy thermal processes, e.g. gasification

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

Because landfill CH_4 is the dominant GHG emission from this sector, a major strategy is the implementation of standards that encourage or mandate landfill CH_4 recovery. In most developed countries, landfill CH_4 recovery has increased as a result of either direct regulatory mandates for landfill CH_4 recovery, or indirect mandates or financial incentives (e.g., tax credits) for use of renewable energy, including landfill gas.

In developing countries, it is anticipated that landfill CH4 recovery will increase significantly during the next two decades as controlled landfilling is phased in as a major waste disposal strategy; however, developing countries will require mechanisms such as CDM to assist with project financing. Gas recovery requires an engineered landfill with cover materials to minimize air intrusion during gas extraction in order to prevent internal landfill fires. Generally, in EIT and developing countries, the lack of financing is a major impediment to improved solid waste management**.** Joint Implementation (JI) and the Clean Development Mechanism (CDM) have already proven to be useful mechanisms for external investment from industrialized countries, especially for landfill gas recovery projects. The benefits are twofold: reduced GHG emissions via landfill CH_4 recovery and improved waste management practices including upgraded landfill design and operations. In terms of annual registered CERs for CDM projects, landfill gas recovery projects currently constitute about 15% of the total (May 2006). Most projects are located in the LAC region (88% of CERs), dominated by Brazil (8 projects; 63% of CERs); see Figure TS.36. Some projects are flaring gas while others are using the gas for on-site electrical generation or direct use projects (including leachate evaporation). Although eventual landfill gas utilization is to be encouraged, an initial flaring project under CDM can be desirable because it: a) simplifies the CDM process (fewer participants); b) lowers capital costs for project implementation; and c) permits definition of composite gas flow rates and gas quality prior to investment in gas utilization hardware.

Figure TS.36. Distribution of Landfill Gas CERs by Country showing share of Annual CERs for Projects Achieving Kyoto EB Registration (May, 2006).



10.5 Integrated and non-climate policies affecting emission 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 which address broad environmental objectives, encourage energy recovery from waste, restrict choices for ultimate waste disposal, promote waste recycling and reuse, and encourage waste minimization. In many developed countries, especially Japan and the EU, waste management policies are closely related to and integrated with climate policies. For example, the EU Landfill Directive requires a phased reduction in the quantity of landfilled biodegradable waste to 50% of 1995 levels by 2009 and 35% by 2016; landfill gas recovery is also mandated. As a result, there is greater reliance on incineration and other thermal processes, as well as on mechanical-biological treatment (MBT) to recover recyclables and decrease biodegradable organics prior to landfilling. In the U.K., the Non Fossil Fuel Obligation (NFFO), requiring a portion of electrical generation capacity from non-fossil sources, provided a major incentive for landfill-gas-to-electricity projects during the 1980's and 1990's. In Asia, China and Japan 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. In developed countries not signatory to the Kyoto Protocol, GHG mitigation from waste is primarily addressed by national or regional air quality regulations and, to some extent, by waste regulations which directly address soil or water quality. The U.S. has implemented regulations under the Clean Air Act (CAA) which require large landfills to capture and combust landfill gas. Also, periodic tax credits in the U.S. have provided an economic incentive for landfill gas utilization. Other drivers in the U.S. include state requirements that a portion of electrical energy be derived from renewables as well as green power programs that allow consumers to select renewable energy power providers. In general, the decentralization of electrical generation capacity via renewables can provide strong incentives for the development of on-site electrical generation from landfill CH_4.

Although policy instruments within 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 landfill taxes, tax credits for landfill gas recovery or energy from waste, other financial incentives for landfill gas recovery, and 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 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.

Policies and measures to promote waste minimization, reuse, and recycling indirectly reduce GHG emissions from waste. These include Extended Producer Responsibility (EPR), unit pricing (or PAYT/"Pay As You Throw"), and landfill taxes. Separate and efficient collection of recyclables is needed with both unit pricing and landfill tax systems. Because of limited data, differing baselines, and other regional conditions, it is difficult to quantify the global effectiveness of these strategies.

Effective GHG mitigation, improved public health, conservation of water resources, and the reduction of untreated discharges to surface water, groundwater, soils, and coastal zones are all important co-benefits of effective and sustainable waste and wastewater management practices. A key aspect of sustainable development is the selection of appropriate and sustainable technology for a particular country; moreover, developing infrastructure for waste and wastewater management is an integral part of urban planning in both developed and developing countries. Therefore, the broad implementation of waste and wastewater management strategies can greatly assist the achievement of sustainable development goals, provided the chosen technologies are sustainable in the local environment. There are many examples of abandoned waste and wastewater plants built in developing countries. Sustainable infrastructure for both waste and wastewater management in developing countries could provide multiple benefits for GHG mitigation and improved public health using existing technologies for improved waste and wastewater collection, transport, recycling, treatment, and disposal.

10.6 Technology research, development, and diffusion

In general, the waste sector is characterized by mature technologies which require further diffusion in developing countries. However, there are opportunities for technological improvements in several areas:

- Landfills: Improvements which are currently being deployed include optimization of landfill operations (bioreactors), increased landfill gas collection efficiency, and construction of landfill covers which optimize microbial oxidation of CH_4 and NMVOCs (biocovers).
- Thermal processes: New processes will include advanced waste-to-energy technologies including advanced combustion, gasification and pyrolysis in combination with improved separation technologies. Such technologies should make waste separation and pretreatment combined with energy production more competitive and increase their mitigation impact through higher efficiencies than current incinerators (10-20% net electrical efficiency).
- Recycling and waste minimization: Innovations in recycling technology and process improvements will result in increased use of secondary materials in production processes

10.7 Long-term outlook, systems transitions

To minimize future GHG emissions from the waste sector it is important to preserve local options for integrated and sustainable management strategies. These options may include recycling and waste minimization to limit use of virgin materials and fossil fuels, plus a wide range of sustainable and cost-effective waste management strategies. The benefits of improved waste and wastewater management in developing countries through infrastructure development confer many benefits for improved public health and safety, in addition to GHG mitigation. Recovery of energy from waste both offsets the use of fossil fuels and reduces emissions.

11. Mitigation from a cross sectoral perspective

11.1 Mitigation options across sectors

While many of the technological options mentioned in Chapter 4-10 concern the sector itself, or maybe another sector, some technologies reach across many sectors. The use of biomass and the switch from high carbon fuels to gas are examples that affect energy supply, transport, industry and buildings. Apart from potentials for technology cross-over, these examples also highlight possible competition for resources, such as finance and R&D support.

Competition over resources, but also other interactions and spillovers between sectors, over time, over regions, and markets complicate a bottom-up compilation of sectoral mitigation potentials. Table TS.19 has been compiled by a series of formal procedures to account for spillovers, such as reduction of the capacity needed in the power sector due to electricity saving in industry and the residential sector, and the effects of the use of bio-energy in one sector for the supply to other sectors. System-wide bottom-up approaches can provide more comprehensive summaries of aggregate potential, and can include the effects of common technologies (sensors, management systems, etc.), but these are not available on a global level.

Table TS.19 provides, as a rough bottom-up estimate, a total potential in 2030 of about 4 Gt CO_2eq at net benefits, with a large share in the building sector, and an additional potential of about 6 Gt CO_2eq at additional costs of less than 20 US$/t$CO_2$eq. These totals do not include transport and material efficiency improvements in industry. The estimates confirm the TAR finding of substantial opportunities at additional costs less than 100 US$/tC (27US$/tCO_2eq). The total bottom-up potential at costs less than 20 US$/t$CO_2$eq (10 Gt CO_2eq) is also within the range suggested by the top-down models for these carbon prices by 2030. The potential at costs up to 100 US$/t$CO_2$eq (18-25 Gt CO_2eq) appears consistent with the few top-down estimates for much higher carbon prices by 2030.

Table TS.19 confirms the observation in Chapter 3 that a large part of the long term mitigation potential is found in the power and industry sectors. While making the comparison with Chapter 3 it should be kept in mind that the top-down models in discussed in Chapter 3 generally allocate the CO_2 associated with electricity savings in households or industry to the energy supply sector. Hence it should not be a surprise that the bottom-up analysis for 2030 highlights the availability of a very significant potential in the building sector. Mitigation by agriculture is also important, with a share of about 18 % of the total at marginal costs less than 20 US$/t$CO_2$eq.

Apart from the mitigation options mentioned in the sectoral Chapters 4-10, other solutions to the enhanced greenhouse effect have been developed. However, options to remove CO_2 directly from the air e.g. by iron fertilization of the oceans, or to block sunlight, remain largely speculative, may have a risk of uncontrollable consequences and are generally uncosted. Blocking sunlight does not affect the expected escalation in atmospheric CO_2 levels, but could reduce or eliminate the associated warming. This disconnection of the link between CO_2 concentration and global temperature could have beneficial consequences, for example in increasing the productivity of agriculture and forestry, but with potential for unknown side effects, e.g. further acidification of the oceans.

Table TS.19: Estimated economic potentials for GHG mitigation at a sectoral level for different cost categories using the SRES B2 and IEA World Energy Outlook (2004) baseline (see notes)

Sector (in brackets 2030 emissions WEO/SRES B2 scenario)	**Mitigation option**	**Region**	**Economic potential < 100 US$/tCO$_2$eq**		**Economic potential at different cost categories in US$/tCO$_2$eq**			
			Low	High	<0	0 - 20	20 - 50	50 - 100
			Mton CO$_2$eq					
Energy supply (n.a.)	All options in energy supply excluding electricity savings in other sectors	OECD	200	1400	100	200	290	200
		EIT	300	500	60	80	150	150
		Non OECD	1700	3100	700	700	1000	-
		Global	2200	5100	850	1000	1400	350
Transport (10.6 GtCO$_2$-CO$_2$ only)	Total	OECD	1700					
		EIT	150					
		Non OECD	1100					
		Global	3000					
Buildings (15.0 GtCO$_2$-CO$_2$ only)	Electricity savings	OECD	750		750	-	-	-
		EIT	100		100	-	-	-
		Non OECD	1200		1200	20	-	20
	Fuel savings	OECD	950	1000	750	100	150	-
		EIT	500	550	300	250	10	-
		Non OECD	150	500	250	100	-	-
	Total	OECD	1700	1700	1500	100	150	-
		EIT	600	700	400	250	10	-
		Non OECD	1400	1700	1400	100	-	20
		Global	3700	4100	3200	450	150	20
Industry (13.4 GtCO$_2$-CO$_2$ only; 1 GtCO$_2$eq non-CO$_2$ emissions in 2020)	Electricity savings	OECD	400		100		100	200
		EIT	100		30		30	50
		Non OECD	900		200		200	450
	Other savings, including non-CO$_2$ GHG	OECD	300	900	300		200	50
		EIT	150	400	80		200	20
		Non OECD	900	2900	550		1300	70
	Total	OECD	700	1300	400		300	250
		EIT	300	550	100		250	80
		Non OECD	1800	3800	750		1500	500
		Global	2800	5600	1300		2100	850
Agriculture (7.2 GtCO$_2$eq in 2020)		OECD	800			450	150	250
		EIT	150			50	50	80
		Non OECD	2300			1600	250	500
		Global	3300			2100	450	850
Forestry (n.a)		OECD	700		10	150	300	250
		EIT	150		0	40	40	60
		Non OECD	1900		150	850	550	350
		Global	2700		150	1100	900	650
Waste (1.5 GtCO$_2$eq)		Global	550	1300	700		200	
All sectors		OECD	5900	7700	1600	1300	1200	1000
		EIT	1700	2200	450	550	450	350
		Non OECD	10000	13800	2200	3900	3400	1300
		Global	18200	25000	4200	6500	5200	2700

Notes:

- Mitigation potentials for Buildings, Industry, Forestry, Agriculture and Waste compared to the SRES B2 baseline, for Energy and Transport compared to the WEO baseline.
- Mitigation options in energy supply, transport and buildings are for CO$_2$ only, due to limited availability of information on the other gases.

- When available the lowest and the highest range in mitigation potential is given. Potentials per cost category are based on the average of the high and low mitigation potential estimate. Mitigation options at costs >100 US$/t$CO_2$eq are not included here, but are reported in the source chapters. Only the numbers for waste are cut off at 50 US$/t$CO_2$eq. The transport mitigation potential includes an unknown amount with costs >100 US$/t$CO_2$eq. Results in the industry cost category <20 US$/t$CO_2$ are included in the 0-20 US$/t$CO_2$eq category.
- Total figures include only the categories for which data were available, causing e.g. deviations between the sum of regions and the global total. The total potentials for all sectors per cost category thus exclude transport, for which no costs specification is available.
- Without the electricity savings in buildings and industry, the energy supply sector could mitigate more than indicated here (see Chapter 4 for details). Transport mitigation potentials include light duty vehicles, biofuels and aviation only. Because the literature on mitigation in buildings for some regions did not cover high cost options, the building sector has a number of missing values. Industry is exclusive of material efficiency improvements, other than through recycling. Mitigation targeted at heating and cooling is included in the building and industry sector only; combined heat and power is not included.

11.2 Mitigation costs across sectors

No single sector or technology will be able to successfully address the mitigation challenge, suggesting a diversified portfolio based on a variety of criteria.

The various short- and long-term models come up with differing cost estimates, the variation of which can be explained largely by approaches and assumptions regarding 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. Top-down assessments agree with the bottom-up results in suggesting that carbon prices around 20-25 US/tCO_2$ eq (US$80-120/tC) are sufficient to drive large-scale fuel switching and make both CCS and low-carbon power sources economic as the technologies mature. Incentives of this order might also play an important role in avoiding deforestation.

Achievable concentrations will be influenced by the timing and stability of such prices. Global modelling studies suggest that efficient pathways towards stabilisation near

- 3.5W/m^2 (multigas) / 450ppm (CO_2 only) would require global carbon prices to rise gradually and predictably, exceeding such levels not later than 2030 and probably much earlier, and to continue rising later
- 4.5W/m^2 (multigas) / 550ppm (CO_2 only) could be compatible with such prices being deferred until after 2030.

Studies by the International Energy Agency suggest that a mid-range pathway, which returns emissions to present levels by 2050, would require global carbon prices to rise to 25 US$/t$CO_2$ by 2030 and be maintained at this level.

In all cases, short-term pathways towards stabilisation would also require numerous additional measures around energy efficiency, technology development and the avoidance of investment in very long-lived capital stock. Studies of trajectories under uncertainty emphasise 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 16 US$trillion investment out to 2030 and the options for stabilisation will be heavily constrained by the nature and carbon intensity of this investment.

Effects of the measures on GDP or GNP by 2030 vary accordingly. For the 550ppm CO_2 pathways and 20-30 $/t$CO_2$ prices, modelling studies suggest that gross world product would be at worst some 0.5% below baseline by 2030, depending on policy mix and incentives for innovation and deployment of low-carbon technologies. Effects for the more stringent targets around 450ppm CO_2 are more uncertain, with most studies suggesting costs less than 1.0% global output for a 15-35 % reduction in CO_2, with the estimates heavily dependent on approaches and assumptions.

The gap between bottom-up costs estimates and estimates of costs from top-down models has narrowed, partly because some of the top-down models have introduced more bottom-up features, especially experience curves incorporating effects from learning-by doing. The results from hybrid modelling confirm that the costs arising tend to fall between those of purely top-down and bottom-up models - though the relative paucity of purely top-down models applied limits the scope for meaningful comparison, and the studies emphasise the costs depend heavily upon the technology assumptions.

As regards portfolio analysis of government actions, a general finding is that 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-efficiency. 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, e.g. by recycling revenues from permit auctions to support energy-efficiency and low-carbon innovations.

11.3 Technological change across sectors

As already mentioned, a major development since the TAR has been the inclusion in many top-down models of induced technological change. Using different approaches, modelling studies suggest that allowing for induced technological change may lead to substantial reductions in carbon tax rates and CO_2 permit prices as well as GDP costs, compared to most of the models in use at the time of the TAR and when technological change was assumed to be included in the baseline and largely independent of mitigation policies and action. The degree to which costs are reduced hinges critically on the assumptions about the returns to climate R&D expenditures, spillovers between sectors and regions, crowding out of other R&D, and, in models including learning by doing, assumed learning rates.

However the models are often very abstract with little technological detail and a very stylised specification of spillover effects. Their empirical basis is very weak; they are highly deterministic and usually fail to account for the major uncertainties. Finally their treatment of policy instruments is very limited.

Major technological shifts like carbon capture and storage, advanced nuclear and hydrogen require a long transition as learning by doing accumulates and markets expand. Improvement of end-use efficiency offers thus 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 11.1. Other options and sectors may play a more significant role in the second half of the century.

11.4 Spill-over effects from mitigation in Annex 1 countries on non-Annex 1 countries

Spillover 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 expressed as the increase in CO_2 emissions outside the countries taking domestic measures divided by the emissions reductions in 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. Model 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 are in the range of 5-20%, with one study reporting ranges between 25 and 130% related to specific assumptions regarding increasing returns in the energy-intensive sector. Studies on the energy-intensive industry itself 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.

As far as existing mitigation actions are concerned, the empirical evidence seems to indicate that competitive losses 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 so far not been quantified in a reliable manner.

Perhaps one of the most important ways in which spillovers from mitigation action in one region affects the others is through its effect on world fossil-fuel prices. When a region reduces its fossil fuel demand as a result of mitigation policy, it will reduce the world demand for that commodity and so put downward pressure on the prices. Depending on fossil-fuel producer's response, 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 who are taking the abatement measures. Oil price protection strategies may limit income losses in the oil producing countries.

11.5 Co-benefits of mitigation

Numerous recent studies have demonstrated significant benefits of carbon mitigation strategies on human health, mainly because they also reduce other air-bourne emissions, e.g. SO_2, NO_x and particulate matter. This results in the prevention of tens of thousands of premature deaths in Asian and Latin American countries annually, and several thousands in Europe. However monetisation 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 mitigation costs.

In addition, benefits of avoided emission 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 greenhouse gas reduction policy in which substantial advantages accrue even if the impact of human induced climate change turns out to be less than current projections shows.

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 of the costs of air pollution control. An integrated approach is needed to address those pollutants and processes where trade-offs exist. This is, for instance, the case for NO_x controls for vehicles and nitric acid plants, which may increase N_2O emissions, or the increased use of energy efficient diesel vehicles, which emit relatively more fine particulate matter.

11.6 Adaptation and mitigation

There can be synergies or trade-offs (for example access to scarce resources) between policy options that can support adaptation and mitigation. Synergy potential is high for biomass energy options, land use management, and agricultural irrigation and other 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 policies could potentially provide both significant adaptation benefits while also working to provide mitigation benefits, mostly in the form of sequestration activities. However, in other cases there may be trade-offs. The growth of energy crops may affect food supply and forestry cover, thereby increasing the vulnerability to impacts of climate change.

12. Sustainable Development and Mitigation

12.1 Addressing Sustainable Development Concerns

The concept of sustainable development was adopted by the World Commission on Environment and Development. There is general agreement that sustainable development involves a comprehensive and integrated approach to economic, social and environmental processes. Discourses of sustainable development, however, have historically focused primarily on the environmental and economic dimensions. The importance of social, political and cultural factors - for example, poverty, social equity, governance - is only now getting more recognition. From a climate change perspective, this integration is essential in order to articulate development trajectories that are sustainable.

There are complexities however in pursuing sustainable development: definitional ambiguity or vagueness of what sustainable development is and the fact that the term can be used to support cosmetic environmentalism. In response to these two concerns, it has been argued that vagueness may constitute a form of constructive ambiguity that allows different interests to engage in the debate, and the concept to be further refined through implementation. Implementation at the macro and sectoral level is beginning to be quantified through improved monitoring and analytical techniques and standards are being developed and implemented in order to be able to verify claims about sustainable practices. At the sector level, green certification, monitoring tools, and emissions registries are some of the ways that progress towards sustainable development is being measured and reported by industry and government entities.

The issues and cases discussed in this chapter suggest that the challenge of implementing sustainable development is not confined to the developing countries. The nature of the challenge in industrialized countries, however, tends to be different than in developing countries.

12.2 Synergy between sustainable development and mitigation

There is a growing literature on the two-way nature of the relationship between climate change and sustainable development. The notion is that policies that pursue sustainable development and climate change mitigation can be mutually reinforcing; that climate change mitigation can have ancillary benefits or co-benefits which will contribute to the sustainable development goals and that sustainable development can create conditions that will reduce vulnerability to climate change and levels of GHG emissions.

Decisions about technology, investment, trade, poverty, biodiversity, community rights, social policies, or governance, which may seem unrelated to climate policy, may have profound impacts upon emissions, the extent of mitigation required, and the cost and benefits that result. Conversely, climate policies that implicitly address social, environmental, economic, and security issues may turn out to be important levers for creating a sustainable world.

Much of the literature emphasizes the degree to which climate change mitigation can have effects, sometimes called ancillary benefits or co-benefits, which will contribute to the sustainable development goals of the jurisdiction in question. This amounts to viewing sustainable development through a climate change lens. It leads to a strong focus on integrating sustainable development goals and consequences into the climate mitigation policy framework, and on assessing the scope for such ancillary benefits. For instance, reductions in greenhouse gas emissions might reduce the incidence of death and illness due to air pollution and benefit ecosystem integrity - both of which are elements of sustainable development. The challenge then becomes ensuring that actions taken to address global environmental problems help to address regional and local development .

It has further been argued that sustainable development might decrease the vulnerability of all countries, and particularly of developing countries, to climate change impacts, thereby contributing to both mitigation and adaptation efforts. Framing the debate as a development problem rather than an environmental one may better address the immediate goals of all countries and particularly developing countries and their special vulnerability to climate change, while acknowledging that the driving forces for emissions are linked to the underlying development path.

It is important to recognize that the sustainable development and climate change relationship is not always mutually beneficial. Climate change mitigation can be the cause of other environmental problems, and development that is sustainable in many other respects may increase GHG emissions.

The capacity to develop and implement climate response strategies is essentially the same as that required to develop and implement policies across a wide variety of domains and to implement sustainable development trajectories In translating capacity into actual mitigation or adaptation activities, however, these capacities may become more specific.

12.3 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.

Developed nations possess comparative advantages in technological and financial capabilities in mitigation of climate change. As the impacts of climate change in these countries are manageable, priority mitigation areas for countries in this group may lie in improving energy efficiency, building new and renewable energy and carbon capture and storage facilities, and to foster a mutually remunerative low-emissions global development path through provision of technological and financial resources to the developing world. However, in industrialized countries, climate change continues to be regarded mainly as a separate, environmental problem that is to be addressed through specific climate change policies.

Economies in transition as a single group do not exist. Nevertheless, central and eastern Europe and the Commonwealth of Independent States do share some common features in socioeconomic development and in climate change mitigation and sustainable development. Measures to decouple economic and emissions growth might be especially important for this group.

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, financial and technological assistance may be needed to support these countries to pursue a low carbon path of development.

For most other developing countries, adaptive and mitigative capacities are low and development aid can greatly help to reduce vulnerability to climate change and to keep/increase carbon storage in forest and soils through CDM. OPEC countries are unique in a sense that they may be adversely affected by development paths that reduce the demand for fossil fuels. Diversification of their economy is high on their agenda.

While the roles, responsibilities and powers assigned to the respective actors remains a hotly contested subject, it is widely acknowledged that the responsibility for the environment and sustainability has become a much broader project, no longer primarily the preserve of governments, but one involving civil society, the private sector, and the state. Greenhouse gas emissions mitigation, climate impacts adaptation, and sustainable development all depend on the institutional capability of humans in all arenas - the state, the market, and the community - to modify the practices of actors in each of those arenas.

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". The choice of policy instruments is affected by the institutional capacity of governments to implement the instrument on the ground.

Industry is a central player in environmental stewardship. Increasingly, the private sector has been recognized not only as a partner in implementation, but also as a stakeholder in policy design. Over the past 25 years, there has also been a progressive increase in the number of companies that are taking voluntary steps to address sustainability issues at either the firm or industry level. From the perspective of firms, there are both internal and external barriers to change. Although there has been progress, the private sector can play a much greater role in making development more sustainable.

Civil society can push policy reform through awareness-raising, advocacy and agitation. It can also pull policy action by filling the gaps and providing policy services. Interactions can take the form of partnerships that can provide citizens groups with a lever for increasing pressure on both governments and industry. It can also happen in the form of stakeholder dialogues. Deliberative public-private partnerships work most effectively when investors, local governments and citizen groups are willing to work together to implement new technologies, and produce arenas to discuss these technologies that are locally inclusive

Some conclusions emerge from examples that are cited in this chapter on specific opportunities to successfully integrate climate change into sustainable development policies

Development policies not explicitly targeting greenhouse gas emissions can influence GHG emissions in a major way. For example, six developing countries (Brazil, China, India, Mexico, South Africa and Turkey) have avoided approximately 300 million tons a year of carbon emissions over the past three decades, with many of these efforts being motivated by common drivers such as economic development and poverty alleviation, energy security, and local environmental protection

Decisions about fiscal policy, multilateral development bank lending, insurance practices, industrial policies, electricity market liberalization, energy security, forest conservation, for example, which may seem unrelated to climate policy, can have profound impacts upon emissions, the extent of mitigation required, and the costs and benefits that result. On the other hand, decisions about rural energy development for example will not have much influence on GHG emissions.

GHG emissions are influenced by, but not rigidly linked to economic growth, but policy choices can make a difference.
Sectors that are farther away from the production frontier - i.e., in sectors where effective production is close to the maximum feasible production with the same amount of inputs - have opportunities to adopt "win-win" policies, i.e., policies that bolster growth, meet other sustainable development goals, and also, incidentally, reduce GHG emissions relative to a baseline. 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 the trade-offs become apparent.
To have a lasting impact, however, what matters is not only that a "good" choice is made at a certain point in time, but also that the initial policy has persisted for a long time - several decades.
It is often not one policy decision, but an array of decisions that may be necessary to influence emissions, especially when considering large-scale and complex dynamics of human settlements. This highlights the issue of coordination across policies in several sectors, and at various scales.
National circumstances, including endowments in primary energy resources, but also institutions matter to determine how policies ultimately impact on GHG emissions. The development process is most effective when government, private sector and civil society partners participate equitable.
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Operational guidelines have been proposed for the integration of development and climate policies into future development pathways of developing countries. Operationalizing demands adherence to the following best practices: (i) commitment of publicly elected and/or regulatory bodies, (ii) involvement and support of key stakeholders, (iii) sound economic and environmental analyses that is conducted using simple and transparent tools, (iv) longer time frames for programs so that they can overcome market and funding cycles, (v) setting annual and cumulative targets to gage progress of mainstreaming, (vi) ensuring additionality over and above existing and other planned programs,. (vii) selection of an effective entity for implementation, (viii) education and regular training of key participants, (ix) monitoring and evaluation of mainstreaming results, and (x) maintenance of a functional database of a project's or program's sustainable development performance.

Figure TS.37 and the accompanying Table TS.20 provide insight into the relative magnitude of carbon emissions associated with non-climate policies in selected sectors.[16]
The figure shows the 2002 CO_2 emissions associated with selected significant sectors where non-climate actions could lead to either increases or decreases in GHG emissions. The size of the bar shows the significant opportunity, or not, for mainstreaming mitigation

The figure shows that the magnitude of associated emissions varies considerably. Electricity deregulation or privatization for instance can be practiced in any country and can impact the global electricity-related emissions which amounted to about 8 Gt CO_2. Policies such as public finance have a potentially larger influence on GHG emissions. Not all policy changes however have a large effect on the associated emissions. Emissions associated with some sectors, rural energy development for example, are small enough to be not considered for mainstreaming in comparison to their welfare benefits and global emissions.

[16] The global mitigation potential of non-climate actions is only sparsely reported in the literature. Data on other sectors, and mitigation potential will be added to this chart, after the completion of the SOD, to the extent the latter is reported in other AR4 chapters.

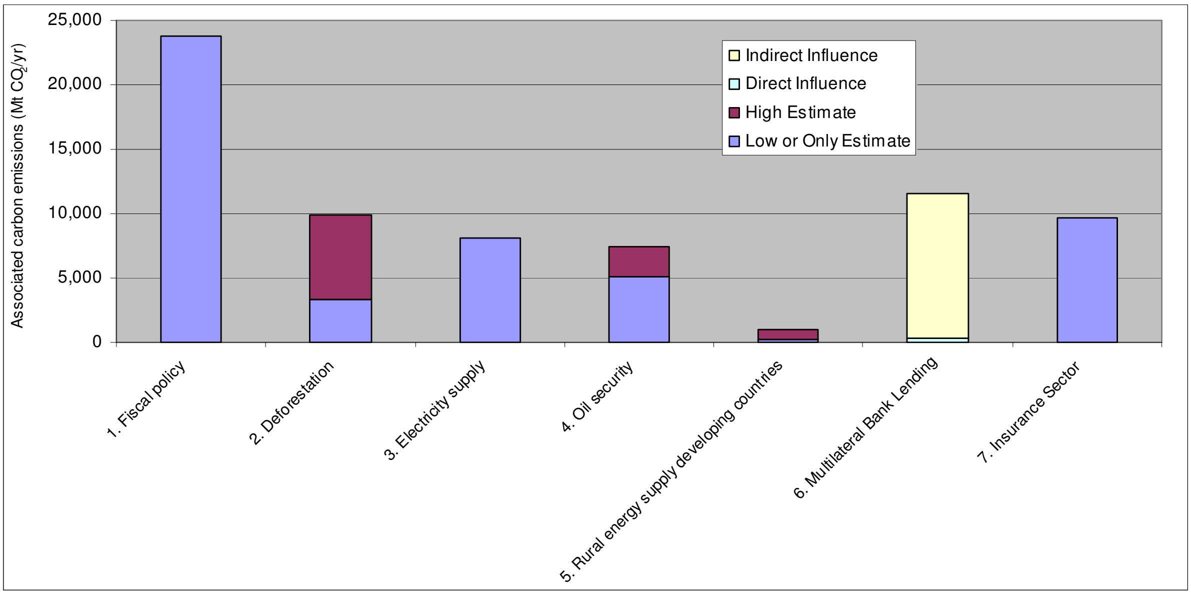

Figure TS.37: CO_2 emissions associated with sectors that could be targeted for non-climate actions (2002)

Table TS.20 Background of assessment of CO_2 flows associated with non-climate policies (as indicated in figure TS.37) [Degree of impact still to be added based on material from other AR4 SOD chapters.]

Non-climate policy area	Examples of non-climate actions	CO_2 emissions affected by policy
Public finance (Taxes/ subsidies)	Taxes and subsidies on energy and other resources that reduce fossil fuel use	All global emissions subject to taxes and/or subsidies
Electricity market liberalization	Reducing T&D losses through better transformers, improved management practices, portfolio standards, switching to less-carbon-intensive fuels	Global electricity sector
Energy security	Minimizing use of coal as a substitute, and increasing use of LCI fuels and reducing energy intensity of the economy	Emissions associated with net oil imports for countries that import over 75% and 50% of their primary oil supply respectively - one indicator of energy security
Deforestation	Reduced illegal logging and increased use of sustainable forestry management practices	Deforestation emissions
Rural energy use	Provision and use of improved cook stoves and LPG	Rural energy use in developing countries
Multilateral Bank Lending	Policy conditionalities, mainstreaming energy efficiency practices and technologies, increasing renewable energy lending, etc.	Emissions associated with energy loans by the World Bank, and emissions of all developing countries over which MDBs have indirect influence
Insurance	Premiums differentiated to reflect vehicle fuel economy or distance driven; liability insurance exclusions for large emitters; improved terms to recognize the lower risks associated with green buildings	Building and transportation energy: 90% in industrialized countries, 50% in FSU, and 20% in developing countries, and all bunkers

12.4 Implications of mitigation choices for sustainable development goals

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

The sustainable development benefits of mitigation options vary within a sector and over regions.

- Generally, mitigation options that improve productivity of resource use, whether it is energy, water, or land, yield positive benefits across all three dimensions of sustainable development. In the agricultural sector for instance, improved management practices for rice cultivation and grazing land, and use of bioenergy and efficient cookstoves enhance productivity, and promote social harmony and gender equality. Other categories of mitigation options have a more uncertain impact and depend on the wider socioeconomic context within which the option is being implemented.
- Energy efficiency options are almost always cost effective, improve energy security and reduce local pollutant emissions. Other energy options can be designed to (1) improve energy

security; (2) reduce local pollution and deleterious health impacts; (3) avoid displacement of local populations. Supply options may require more hard currency for imports of fuel and technology or higher capital investment for exploiting domestic resources.

- Policies that avoid deforestation have significant biodiversity, soil and water conservation benefits at the risk of loss of economic welfare. Forestation and bio-energy plantation policies can reduce wasteland and soil degradation, manage water runoff, retain soil carbon and benefit rural economies at the risk of loss of agricultural land and biodiversity. Policies that maintain soil carbon and encourage efficient use of fertilizers in agriculture have greatest synergy with sustainable development but those for water, rice, and set-aside land use change options are more uncertain.
- There are good possibilities for reinforcing sustainable development also in the waste management, transportation and building sectors.
- Some mitigation activities, particularly in the land use sector, have GHG benefits that may be of limited duration. A finite amount of land area is available for forestation, for instance, which limits the amount of carbon that a region can sequester. And, certain practices are carried out in rotation over years and/or across landscapes, which too limits the equilibrium amount of carbon that can be sequestered. The incremental sustainable development gains would thus reach an equilibrium after some decades unless biofuel options are resorted to.

Table TS.21: Sectoral Mitigation Options and Sustainable Development (Economic, Local Environmental and Social) Considerations: Synergies and Trade-offs

Sector and Mitigation Options	Potential SD synergies and conditions for implementation	Potential SD trade-offs
Energy Sector		
Energy efficiency improvement in all sectors (buildings, transportation, industry, and energy supply)	Almost always cost-effective, reduces or eliminates local pollutant emissions and consequent health impacts, improves indoor comfort and reduces building noise level, creates business opportunity and jobs, socially neutral and improves energy security Government and industry programs can help to overcome lack of information and principal agent problems Programs need to be implemented at all levels of government and industry Programs targeted at poverty reduction and gender empowerment needed to ensure that SD goals are met	Interaction between energy and other factors of production should be considered in assuring that these are complementary Important to ensure that low-income household energy needs are given due consideration, and that the process and consequences of implementing mitigation options are gender-neutral Indoor air pollution and health impacts of improving biomass cook stove thermal efficiency in developing country rural areas are uncertain
Fuel switching and other options in the transportation sector	Institutionalizing planning systems for CO_2 reduction through coordination between national and local governments is important for drawing up common strategies for sustainable transportation systems. CO_2 reduction costs may be offset by increased health benefits Promotion of non-motorized transport has large and consistent co-benefits	Switching fuels can incur tradeoffs Diesel engines are generally more fuel-efficient than gasoline engines and thus have lower CO_2 emissions, but increase particle emissions. Other measures (CNG buses, hybrid diesel-electric buses and taxi renovation) may provide little ancillary climate benefits.
Replacing imported fossil fuel with domestic alternative energy sources (DAES)	Important to ensure that DAES is cost-effective Reduces local air pollutant emissions. Can create new indigenous industries (e.g., Brazil ethanol program) and hence generate employment opportunities	Balance of trade improvement is traded off against increased capital required for investment Fossil-fuel-exporting countries may face reduced exports DAES construction may displace local populations and cause

		environmental damages to water bodies and biodiversity Important to ensure that IAES implementation is gender and income neutral
Replacing domestic fossil fuel with imported alternative energy sources (IAES)	Almost always reduces local pollutant emissions Implementation may be more rapid than DAES Important to ensure that IAES is cost-effective Economies and societies of fuel-exporting countries would benefit	Could reduce energy security Balance of trade may worsen but capital needs may decline Important to ensure that IAES implementation is gender and income neutral
Forestry Sector:		
Forestation	Can reduce wasteland, arrest soil degradation, and manage water runoff Can retain soil carbon stocks if soil disturbance when planting and harvesting is minimized Can be implemented as agroforestry plantations that enhance economic benefits and increase food security Can benefit rural economy, generate employment opportunities for women, and create rural industry May require joint management of community and forest lands Clear delineation of property rights would expedite implementation of forestation programs	Use of scarce land could compete with agricultural land and diminish food security Monoculture plantations can reduce biodiversity and increase risk of severe economic loss Conversion of floodplain and wetland could hamper ecological functions
Avoided deforestation	Can retain biodiversity, water and soil management benefits, and local rainfall patterns Reduce local haze and air pollution from forest fires If suitably managed, it can bring revenue from ecotourism Successful implementation may be achieved by providing alternative livelihood to local deforesters, enforcing laws to prevent migrants from encroaching on forest land, and joint forest management	Can result in loss of social welfare (economic). Reduced timber supply may lead to reduced timber exports and increased use of GHG-intensive construction materials Local dwellers and migrant labor may lose jobs
Bio-energy production	Can be practiced synergistically where crop residues (shells, husks, bagasse, and/or tree trimmings) are utilized.	Potential problem wih food security (location specific); competition can be re land, labour, finance and … (FAO, ….)

	Brings positive SD benefits. Planting crops/trees exclusively for bioenergy production also brings positive SD benefits similar to those noted for forestation, but requires that adequate agricultural land be available for planting bioenergy crops	
Forest Management	Most practices bring positive SD benefits.	Fertilizer application can increase N_2O production and nitrate runoff degrading local water quality Prevention of fires and pests has short term benefits but can increase fuel stock for later fires unless managed properly
Agriculture:		
Cropland mgmt. - Agronomy, and management of nutrient, tillage/ residue, and organic soils, and agroforestry	Environmental benefits are positive, but social and economic benefits are uncertain for these practices Improved nutrient management can enhance ground water quality and environmental health of the cultivated ecosystem	Tillage/residue management has positive environmental impacts but other impacts are uncertain
Cropland mgmt. - Water, Rice, and set-aside and land-use change	Environmental, economic, and social benefits are generally positive for these practices Largest water-using sector worldwide Perverse policies aid and abet water overuse	Short-run, changes in water policies would aggravate social cohesiveness and clash of divergent interests
Grazing land mgmt.	Improves livestock productivity, reduces desertification, and provide social security to the poor Requires laws and enforcement to ban free grazing as was done in China	
Livestock management	Mix of traditional rice cultivation and livestock management would enhance incomes even in semi arid and arid regions	
Waste Management:		
Recycling and Reuse	SD benefits increase with level and sophistication of implementation Requires laws, regulations, and/or programs to foster im-	There is a sizeable but undocumented unofficial market in waste collection and reuse by scavengers in many developing countries. While this does provide employment to a large number of people,

	plementation.	it is also prone to adverse health impacts on scavengers and is not a desirable employment option.
Biomass combustion	As above	Is itself a source of CO_2 emissions.
Biological treatment	Can be a potential source of fertilizer.	
Landfilling	Can lead to the creation of public spaces for recreation and other social purposes.	When not done properly can cause leaching that leads to soil contamination with potentially negative health impacts

13. Policies, Instruments and Co-operative Agreements.

13.1 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 , that is, environmental effectiveness, cost-effectiveness, distributional considerations, institutional feasibility, by which they can be evaluated.

There are a number of additional criteria which could be explicitly considered as well, such as effects on competitiveness, administrative costs and dynamic considerations. Criteria may be applied by governments in making ex-ante choices among instruments and in ex-post evaluation of the performance of instruments.

13.2 National Policies

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 instruments include: regulations and standards, emission 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 also can also affect GHG emissions. In general, climate change policies, if integrated with other government polices, can contribute to sustainable development in both developed and developing countries.

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 The literature provides a good deal of information to assess how well different instruments meet these criteria. Most notably, it suggests that:

- *Regulatory measures and standards* generally provide environmental certainty, but their environmental effectiveness depends on their stringency. They may be preferable when information or other barriers prevent firms and consumers from responding to price signals. However, they are generally viewed as inferior to price-based instruments in inducing innovation and technological change and provide less flexibility to stakeholders.
- *Taxes and charges* (which can be applied to carbon or all greenhouse gases) are given high marks for economic efficiency, but they cannot guarantee a particular level of emissions and may be politically difficult to implement and, if necessary, adjust. As with regulations, their environmental effectiveness depends on stringency. Uncertainty in the relationship between price and behaviour can make selecting the right level challenging, but conceptually taxes can be designed to be environmentally effective. As is the case with nearly all other policy instruments, care is needed to prevent perverse effects.
- *Tradable permits* are becoming increasingly popular as a mechanism to control conventional pollutants and greenhouse gases at the sector, national and international level. The volume of allowed emissions determines the environmental effectiveness of this instrument, while the distribution of allowances has implications for both economic efficiency and competitiveness. Experience has shown that banking provisions can provide significant temporal flexibility and that compliance provisions must be carefully designed, if it a permit system is to be effective. Un-

certainty in the price of emission reductions under a trading system makes it difficult, a priori, to estimate the total cost of meeting reduction targets.

- *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, but to date have generally yielded only modest results. On balance, it appears that the majority of voluntary agreements have achieved little emissions reductions beyond business as usual. The successful programs include, among other elements: clear targets, a baseline scenario, third party involvement in design and review and formal provisions of monitoring.
- *Financial incentives* are frequently used by governments to stimulate the diffusion of new, less GHG emitting technologies. While the economic costs of such programes are often higher than other measures, they are often critical to overcome barriers to the penetration of new technologies. 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.
- *Government support for research and development* is a special type of incentive, which can be an important measure to ensure that low GHG emitting technologies will be available in the long-term. To be environmentally effective, R&D needs to be supplemented with policies to promote technology deployment and diffusion. However, funding for many energy research programs, such as renewables has been flat or declining for nearly two decades, and there is little evidence to indicate that governments are capable of providing sustained support over 30-50 year time periods.
- *Information instruments*-sometimes called public disclosure requirements-may effect environmental quality by allowing consumers to make better-informed choices. While some evidence indicates information provision can be an effective environmental policy instrument, we know less about its efficacy in the context of climate change.

Applying an environmentally effective and economically efficient 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. In practice, climate related policies are seldom applied in complete isolation, as they overlap with other national polices relating to the environment, forestry, agriculture, waste management, transport and energy, and in many cases require more than one instrument.

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

While the preponderance of the literature reviews nationally based governmental regimes, corporations, sub-national governments, NGOs and civil groups play a key role, and are adopting a wide variety of actions to reduce emissions of greenhouse gases. There is no evidence indicating that independent actions by corporations, sub-national governments, NGOs or other civil groups can, by themselves, lead to significant national emission reductions, unless supplemented by national government policies. The literature suggests a number of reasons that lead corporations to act unilaterally, the most prominent of these are 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 have limited geographical scope, but often mirror efforts taken at the national level, and include renewable portfolio standards, energy efficiency programs, emission registries and sectoral cap and trade mechanisms. These actions are undertaken for a number of reasons, such as a desire to influence national policies, address stakeholder concerns, create incentives for new industries or to create environmental co-benefits. Many of the above actions may limit GHG emissions, stimulate innovative policies, encourage the deployment of new technologies and spur experimentation with new institutions.

13.4 International Agreements

The Kyoto Protocol has set a significant precedent as a means to solve a long-term international environmental problem. It'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 protocol has stimulated the development of emissions trading systems, which are an increasingly being applied, although a fully global system has yet to be implemented. In addition, the CDM has created a large project pipe-line and mobilized substantial financial resources, but it has faced methodological challenges regarding the determination of baselines and additionality.. However, the Kyoto Protocol has some limitations. For example, its effect on atmospheric GHG concentrations will be limited unless its first commitment period is followed-up by measures to achieve deeper reductions and the implementation of policy instruments by all major emitters.

Numerous options are identified in the literature for achieving emission reductions both under and outside of the Convention and its Kyoto Protocol, for example, by expanding the scope of market mechanisms, including through sectoral and sub-national crediting agreements and by enhanced international R&D technology programmes. Sectorally focused market mechanisms are attractive because they can contribute to sustainable development and attract additional investments and participants and may be more cost effective than project based mechanisms; although they are generally less efficient than broad based market policies. As in the case of project based mechanisms like CDM, there may be methodological challenges in setting baselines and determining additionality. International R&D programmes can induce cost savings, build national capacity and create goodwill. However, they may benefit only a few sectors and may target the wrong technologies. There is no evidence that investments in R&D activities will achieve the same level of emission reductions as quantitative emission objectives, such as those of the Kyoto Protocol, unless supplemented with policies to promote technology adoption and diffusion. Integrating elements such as technology development and cap and trade programmes in an agreement is possible, but comparing the efforts made by different countries would be very complex and resource consuming.

There is a broad consensus in the literature that a successful agreement will have to be environmental effective, fair/equitable, flexible (accommodate changes while providing adequate investment certainty), scientifically sound, economically efficient, institutionally feasible and lead ultimately toward universal participation and a more sustainable development path.
A great deal of new literature is available on potential structures for and substance of future international agreements. As has been noted in previous IPCC reports, because climate change is a global commons problem, any approach that does not include a large portion of the world, and at a minimum the world's major emitters, will be more costly and less environmentally effective - in other words, a second best approach..

Proposals relating to possible future agreements
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.

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 of implementing measures. However, given both their importance and the divergent views on what constitutes appropriate goals, reaching agreement is expected to be difficult.

The choice of the long term ambition influences significantly the necessary short term action and therefore the design of the international regime. For example, if the goal is set at low levels of stringency (e.g. 650 ppmv CO_2), a technology focused approach that only reduces emissions in the future would be sufficient. For more stringent stabilization goals (e.g. 400 ppmv CO_2), strong incentives for short term emission reductions would be necessary.

Options for the design of international regimes can incorporate goals for the short, medium and long-term stabilization of the climate system. One option is to set a goal for long-term GHG concentrations or a temperature stabilization goal.. Such a goal might bebased 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_2 concentration or temperature levels is an agreement on specific long term actions such as a technology R&D and diffusion target - e.g., "eliminating carbon emissions from the energy sector by 2060"). An advantage of such a goal is that it might be linked to specific actions. .

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.

Participation

Participation of states in international agreements can vary. At one extreme, participation can be universal; at the other, participation could just be limited to two countries. Actions to be taken by participating countries can be differentiated both in terms of when such action is undertaken, and what the action will be. States participating in the same "tier" would have the same (a broadly similar) type 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 also choose the tier into which they are grouped.

An agreement can have static participation or may change over time. In this 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.

Some have argued that an international agreement needs to include only the major emitters to be effective, since the largest 15 countries (including the EU25 as one) make up 80 percent 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 in a globally successful solution to climate change, and thus agreements must specifically target developments 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 are vulnerable to climate and must be included in any agreement.

Regime stringency: linking goals, participation and timing

Independent of the design of the international regime, greenhouse gas emissions would need to be reduced substantially during the next century to achieve low and medium stabilization levels (i.e. 450 and 550 ppm CO_2 eq.). For low and medium stabilization levels, developed countries as a group would need to reduce their emissions significantly below 1990 levels by 2020 (on the order of -10% to -40%) and to still lower levels by 2050 (-40% to -95% below 1990 levels). Under most of the considered regime designs for low and medium stabilization levels developing country emissions need to deviate from their baseline emissions within the next few decades. For many countries, the difference in reductions needed to reach certain greenhouse gas stabilization targets (e.g. 450, 550, 650 ppm CO_2eq.) is larger than the difference between the various design approaches that meet a particular stabilization target. Hence, the choice of the long-term ambition level may be more significant than the design of the emissions reduction regime.

The total global costs are highly depending on the baseline scenario, marginal abatement costs estimates, participation level (size of the coalition) and assumed concentration stabilisation level (see also Chapters 3 and 11). The total global cost do not vary significantly for the same global emission level, however costs will vary with the 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 may be higher (see also Chapter 3). Regional abatement costs are dependent on the allocation regime, particulary timing, but the assumed stabilisation level and baseline scenario are more important.

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 greenhouse gases and sectors as well as multiple countries through emission trading and/or project based mechanisms .

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), 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. However, there is a trade-off between costs and certainty in achieving an emissions level.

Market mechanisms

Market based approaches offer a cost effective means of addressing climate change if broadened to include additional countries and sectors. The EU ETS is by far the largest effort to establish such a scheme, with over 11,500 plants allocated and authorized to buy and sell allowances. At this early stage, several factors have influenced the price of carbon, including: the stringency of the emission caps, the external supply of project-based credits, relative fuel prices, weather and regulatory features. Market liquidity and prices have been affected because not all registries in new member countries are on line, the international transaction log is in not functioning, and market players still do not understand fully their need for credits. Full international trading would provide market players with information thus far absent from decision making, i.e., the actual cost of mitigation in a range of economic activities.

Financial arrangements

Governments, multilateral organizations and private firms have established nearly 4 billion USD in carbon funds for carbon reduction projects**.** This new source of funds, if efficiently managed, could generate between 400 and 800 Mt CO_2 eq. of credits, assuming a price of between 5-10 USD per tonne of CO_2 eq. Given that such funding has only come about in the last few years, it compares very favourably with funding provided by the Global Environmental Facility which has provided approximately 2.5 billion USD for projects since its inception ten years ago. This positive development needs also to be reconciled with financial flows due to foreign direct investments which often go to GHG intensive industries and development assistance programms which for energy amount to approximately 1 billion USD per year.

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. For example, a tax is considered one of the most efficient economic instruments to address climate change because it offers a flexible incentive to promote changes in behaviour, induce development of more efficient technologies, and lead to the adoption of cleaner energy technologies. 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 marginal abatement cost across countries is economically efficient, it may not be politically feasible in the context of existing tax distortions.

Non-climate policies and links to sustainable development

There is considerable interaction between policies and measures taken at the national and subnational level and with acitions 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. These include: policies focused on poverty; land use and land use change; energy supply and security; international trade, air pollution, structural reforms, and trade liberalization and population policies. New research on future international agreements could focus on understanding the inter-linkages between climate policis, non-climate policies and sustainable development and how to accelerate the adoption of exist technology and policy tools.

Finally, an assessment of international climate change agreements from the literature, applying the criteria, given in the Introduction, is presented in Table TS.22.

Table TS.22: Criteria for assessing international agreements on climate change

Approach	Environmental effectiveness		Cost effectiveness		Distributional / equity issues		Institutional feasibility	
National emission targets and emission trading	Can be effective, depending on participation, stringency and compliance.	+	Highly efficient and cost effective; increases with broad participation and multiple gases and sectors	+	Depends on participation and initial allocation	**?**	Requires capacity to prepare robust national GHG inventories and mechanisms to ensure compliance /enforcement	+
Sectoral agreements	Not all sectors amenable to such agreements, limiting overall effectiveness. Additional risks of leaving out sector due to political difficulties	?	Lack of trading across sectors may limit overall efficiency, although may be cost-effective within individual sectors. Within-sector competitiveness concerns alleviated since sectors treated equally at global level.	0	All countries would be treated equally, which may run counter to the concept of “common but differentiated responsibility”	-	Requires many separate decisions and agreements. Within individual sectors, may require cross-country institutions to manage agreements	-
Coordinated policies and measures	Individual measures can be effective, but uncertain whether desired emission levels are met; success will be a function of stringency.	?	Risk of designing a policy package that is not efficient and does not fit all specific national circumstances. Cost- effectiveness of individual policies enhanced with coordination.	?	Coordination could allow for differentiation although if policies identical, could run counter to the concept of “common but differentiated responsibility”	-	Designing package that suitably stringent while meeting all national concerns may be difficult; high level of institutional agreement required , with multiple separate decisions	0
Technology cooperation	Can be effective, depending on rate of technology uptake and extent of new technology developed. Potential concern that technology emerges too late to achieve low stabilization levels	-	Studies are divided about the economic efficiency of postponing reductions to the future. Cost effectiveness historically low based on economic costs of R&D subsidies, and historic failure for government to pick winning technologies	?/-	Issues of intellectual property often subject to equity disputes; potential problem with large-scale transfer and diffusion of most advanced technology; does leave all countries the right to develop	-	Requires many separate decisions and agreements; often best handled by private sector - where less extensive systems exist to promote diffusion to lower income countries	-
Development oriented actions	Can be effective, but results uncertain. Some development policies may have negative effect on climate (e.g., producing electricity using local coal may increase energy security but increase climate damages)	?	Should be efficient and cost-effective, as climate change measures are supportive of economic development; should create synergies	+	Inasmuch as development is a key priority, synergies have positive feedback on social development and international equities	+	Institutional structures for development policies mostly in place, although capturing climate benefits not usually a priority for existing institutional systems	0