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Annex to the Communication

”Winning the battle against global climate change”

Background paper

{COM(2005)35 final}

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1. INTRODUCTION

With the entry into force of the Kyoto Protocol international efforts to combat climate change enter a new phase. Thanks to efforts at EU and national level the EU has begun the process of reducing its greenhouse gas emissions and now needs to develop its medium and long term strategies for winning the battle against climate change, inside the EU and together with the international community. This Staff Working Paper accompanies and provides the analytical background for the Communication COM(2005)xxx responding to the request of the European Council at its March 2004 meeting to provide a report as input for a discussion on "medium and longer term emission reduction strategies, including targets".

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) constitutes a vital step in global efforts to combat climate change. Adopted by consensus at the third session of the Conference of the Parties (COP3) in December 1997, the Protocol has entered into force on the 16 February because of the recent decision by the Russian Government to ratify. Russia will join more than 120 other countries that have pledged to act on this issue. The Kyoto Protocol contains for the first time legally binding emissions targets for developed countries, for the period up to 2012.

The international community has planned to start negotiations during 2005 on commitments and policies for the period from 2012 onwards. Although a formal negotiating process on future action on climate change has not yet started at UNFCCC level, the international debate among research institutions, climate modelling departments, businesses, NGOs and governmental bodies is already ongoing. Several EU Member States have already announced or proposed national mid- and long-term climate targets highlighting the need for a common view. In particular all sectors of the economy would benefit in their investment decisions from clear indications on how EU climate policy is likely to evolve.

1.1. Progress in implementing the EU's commitment

In 2002, the greenhouse gas emissions of the 25 Member States (EU-25) are estimated to have been 9.0 % lower than in the base year. Aggregated projections for the EU-25 'with existing domestic policies and measures' show that the following Member States expect to reach their Kyoto targets: Czech Republic, Estonia, Hungary, Latvia, Poland, Slovakia, Sweden and the United Kingdom. Similarly, aggregate EU-15 projections suggest that 'with additional policies and measures', the projected use of the Kyoto mechanisms will be sufficient to reach the collective EU-15 Kyoto target. In those Member States not yet on track, further reductions will be necessary in particular requiring the effective implementation of additional policies and measures.

At Community level, significant progress has been made over the past year in terms of the adoption and implementation of a number of key common and coordinated policies and measures (CCPM) arising from the European Climate Change Programme (ECCP). Examples are the EU Emissions Trading Scheme (ETS), which takes off on 1 January 2005, the Directive linking project-based mechanisms to greenhouse gas emissions trading, the Council Decision for monitoring Community greenhouse gas emissions, the Directives on the promotion of electricity from renewable enery sources, and on co-generation, the Directive n bio-fuels, the Direcive on the energy performance of buildings, the proposal for a Regulation on fluorinated gases, the proposal for a framework Directive on eco-efficiency requirements for energy-using products, the proposal for a Directive on energy end-use efficiency and energy services.

The measures that the Commission had committed itself to proposing in the period 2002-2003 have now been put forward, with the exceptions of a comprehensive framework on infrastructure use and charging in the transport sector and the Integrated Pollution Prevention and Control (IPPC) reference document on generic energy efficiency techniques. Many of the proposals have already been adopted by the EU institutions.

Cost-effectiveness has been the starting point for the identification and design of policies within the European climate change programme (ECCP) and will remain a key criterion for all future EU action reaching far beyond the Kyoto horizon of 2012. However, mitigation costs are only one side of the sustainable policy balance-sheet. The costs of inaction, or the benefits of climate mitigation, have not yet received the same level of attention in quantitative model based approaches, but the potential magnitude of these costs is staggering.

1.2. The EU's long-term objective

The Kyoto Protocol is only a first step towards addressing the climate problem[1]. Further action is necessary to reach the ultimate objective of the UNFCCC. Article 2 of the UNFCCC sets out the ultimate objective of the Convention as follows: "The ultimate objective of this Convention [...] is to achieve [...] stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner."

On the basis of the results of IPCC, the European Council has translated this global, politically agreed objective into a measurable and verifiable target[2] and reached political consensus that an increase of 2°C of the earth's average temperature above pre-industrial levels is the maximum 'safe' level that can be envisaged. Recent studies have underpinned the 2°C temperature target. Significant impacts on ecosystems and water resources are likely even with a temperature increase of between 1 and 2°C, and the risks of net negative impacts on global food production occur between 2-3°C global warming. Climate impacts on ecosystems,[3] food production, or water supply[4] are projected to increase significantly once the global temperature increase exceeds 2°C. Assessing climate impacts of global mean temperature rise as the prime parameter, scientists confirm previous reports that, globally aggregated, the danger level begins once global mean temperature rises 2°C above pre-

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[1] An overview on climate data is provided by Baumert, K, Pershing, J. 2004. Climate Data: Insights and Observations. World Resources Institute. Washington.

[2] 1939th Council meeting, Luxembourg, 25 June 1996: "... the Council believes that global average temperatures should not exceed 2 degrees above pre-industrial level and that therefore concentration levels lower than 550 ppm CO_2 should guide global limitation and reduction efforts...".

[3] Green, R E, Harley, M, Miles, L, Scharlemann, J, Watkinson, A and Watts, O (2003) *Global Climate Change and Biodiversity*. Summary of Papers and Discussion. University of East Anglia, Norwich, UK.

[4] Parry, M, Arnell, N, McMichael, T, Nicholls, R, Martens, P, Kovats, S, Livermore, M, Rosenzweig, C, Iglesias, A and Fischer, G (2001) '*Millions at risk: defining critical climate change threats and targets'*. Global Environmental Change 11: pp 181–3.

industrial levels.[5] According to these studies, the long-term average rate of global warming should not exceed 0.2ºC per decade.

This long-term objective of a maximum global temperature increase of 2°C over the pre-industrial level guides the EU's internal and external climate change policy. The EU global temperature limit of 2°C above pre-industrial levels has since been reaffirmed in various Environment Council conclusions and the 6th EAP, and should be considered as an overall long-term objective to guide global efforts to reduce climate change risks, in accordance with the precautionary principle.

The 2°C target was based on the best scientific evidence available at the time and is associated with a CO_2 stabilisation level of 550 parts per million by volume (ppm). This limit was deduced mostly from impacts studies that were assessed in the IPCC Second Assessment Report, and strikes a balance between impacts (that will still be considerable if the 2°C is reached) and the political and economic feasibility of emissions reductions.

Achieving this target will be major challenge. Figure 1 depicts the Common Poles Image (CPI) baseline for global emissions divided into nine regions. It illustrates that in a 'business as usual' scenario global emissions will increase steadily, leading to almost a doubling of current emission levels by 2050. An important part of this rise will be caused by a relatively limited number of large countries, mostly in Asia and, to a lesser extent, the Middle East, Africa and Latin America, given their currently lower levels of economic development and expected future trends. The strong growth in emissions from countries in these regions can be contrasted with relatively stable emissions in the EU, Japan and Oceania. As a result of this, Europe's contribution to global greenhouse gas emissions (including countries that are not Member States of the EU) is expected to drop from 14 % in 2000 to less than 8 % in 2050.

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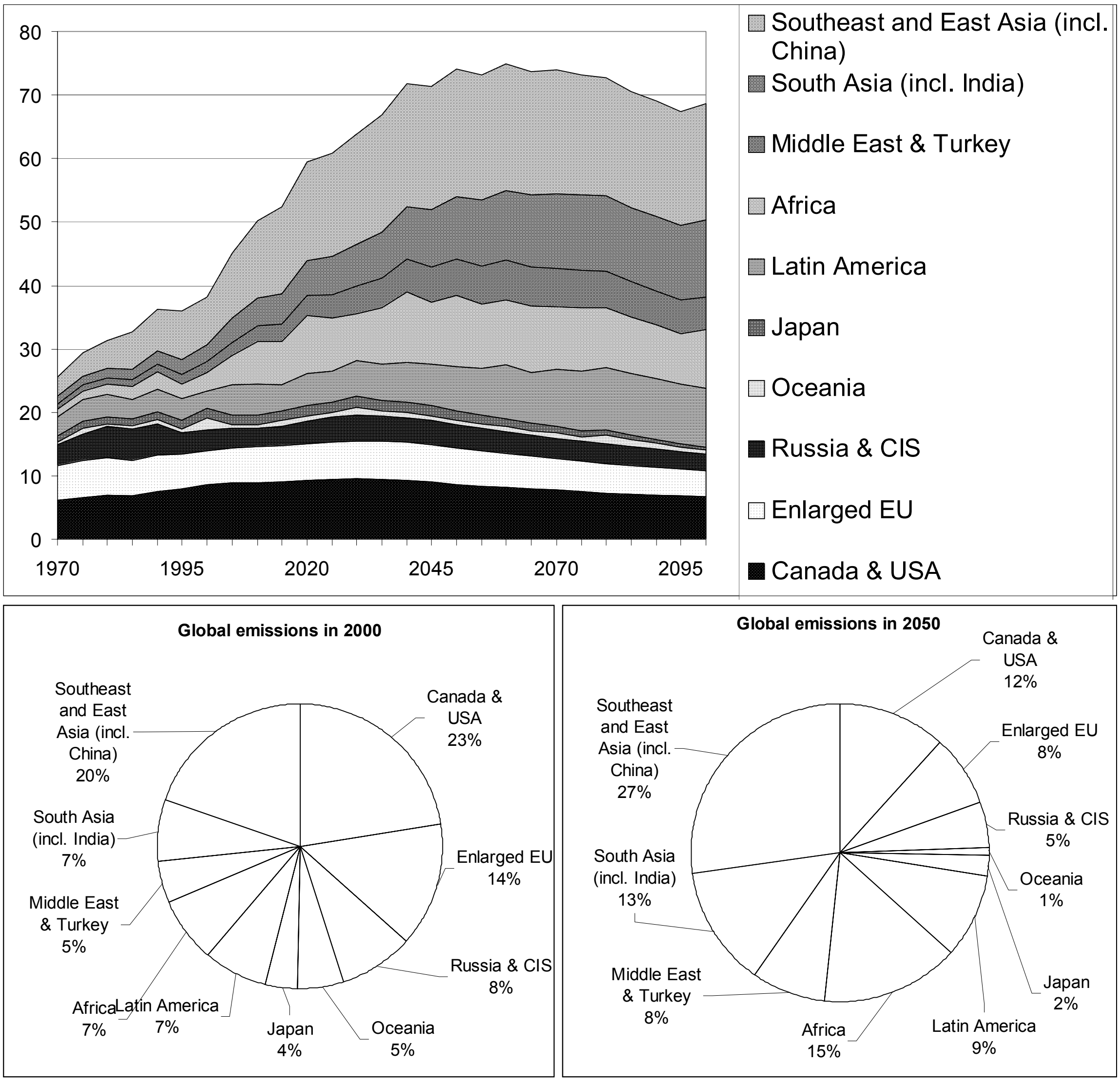
[5] WBGU: *Climate Protection Strategies for the 21st Century: Kyoto and beyond* Special Report; Berlin 2003.

Figure 1: Projected baseline emissions of world regions, 1990 and 2050



Source: Common POLES IMAGE baseline data

An important conclusion to be drawn from Figure 15 is that significant reductions in greenhouse gas emissions in the EU or in Annex I countries alone, will not be sufficient to achieve the level of reductions required to attain the 2°C target. An effective future multilateral climate change regime will require all major emitters to contribute by limiting or reducing their greenhouse gas emissions. Without the participation of other developed countries and key emitters among developing countries, substantial cuts in EU emissions alone will fail to achieve the 2°C target.

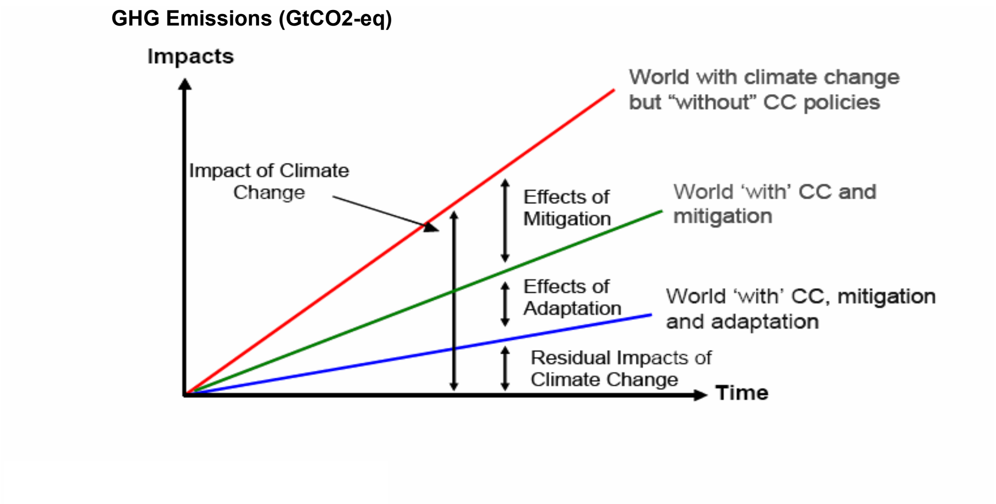
2. FUTURE CLIMATE CHANGE POLICY: DECISION MAKING UNDER UNCERTAINTY

In order to allow for fully informed societal decisions, a comprehensive assessment of benefits and costs should be undertaken to determine the economically optimal mix between mitigation, adaptation and the residual impacts of climate change over a long time period. Gaps in scientific understanding render such an exercise impossible and climate change policies have to be developed and implemented on the basis of partial information and under uncertainty.

Far more than a decade of scientific work has been spent estimating the economic benefits and costs of climate change policies. The focus tends to be on costs, and in particular mitigation costs, because such costs are tangible, have market value, occur mainly in the short- and medium term, and are perceived to be subject to less uncertainty. In most circumstances, particularly when the decision to pursue a climate policy has been taken, looking at costs only is sufficient for a cost effectiveness analysis of policy alternatives aiming at similar outcomes, so an informed choice can be made in favour of the most cost-effective option.

In contrast, there are only a limited number of often incomplete estimates on the benefits of climate policies. This is further complicated by the fact that the magnitude of the benefits depends on action taken to mitigate and adapt to the consequences of climate change.

Figure 2: Impacts grow over time



Source: Estimating Non-Market Impacts of Climate Change and Climate Policy[6]

Current and future policy decisions in the EU need to be guided by the robust scientific conclusion that climate change is now a reality and that, during the 21st century, without future action, global average surface temperature will continue to rise at rates without precedent over the last 10,000 years. However, there are still considerable scientific uncertainties.

Obviously, the higher the concentration target chosen, the less the likelihood that the 2°C target can eventually be achieved. Emission profiles are sensitive to assumptions used in models, such as carbon cycle feedbacks and climate sensitivity.

Scientific studies tell us that this relates to the atmospheric concentrations of greenhouse gases in the range of 550 ppm CO_2 eq. The Intergovernmental Panel on Climate Change

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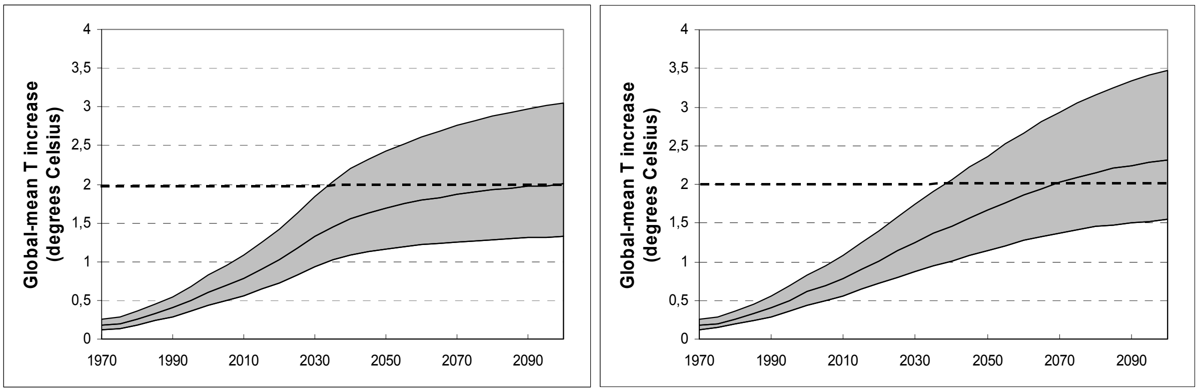
[6] Rothman, D., B. Amelung, and P. Polomé (2003), "*Estimating Non-Market Impacts of Climate Change and Climate Policy*", Paper prepared for the OECD Project on the Benefits of Climate Policy, 12-13 December 2002, Paris, ENV/EPOC/GSP(2003)12/FINAL.

(IPCC) estimates the range of climate sensitivity to be between 1.5 and 4.5°C, with a median value of 2.5°C.

Figure 3: Global mean temperature rise since pre-industrial levels, 550 ppm (left) and 650 ppm (right), assuming different climate sensitivities (1.5, 2.5 and 4.5)



Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025

Figure 3 above shows the range of temperature increases that could be reached with greenhouse gas stabilization levels of 550 ppm and 650 ppm respectively. In principle, the 550 ppm concentration level could meet, or at least stay close to, the EU 2°C target for the maximum global temperature rise for median to low climate sensitivity. The 650 ppm concentration level only does so if climate sensitivity is towards the lower end of the range, so is less likely to meet the EU target. If climate sensitivity is high, the EU target will not be met under either concentration level. Figure 4 reflects more recent scientific studies estimating climate sensitivity. It shows that there is very little likelihood of keeping within the 2°C target with greenhouse gas concentrations levels beyond 450 ppm CO_2 equivalent.

There are still key uncertainties about how much climate forcing is due to natural factors and how much is human-induced, and particularly about the global effects of local air pollution. Taking the example of aerosols, the direct effects (negative radiative forcing = cooling the atmosphere) and indirect effects (positive radiative forcing = heating the atmosphere) are not yet completely understood on a global scale. The latest indications suggest that the cooling effect of aerosols may have "masked" part of the current greenhouse gas effect and therefore that climate sensitivity, defined as the global mean temperature for a doubling of CO_2, is likely to be greater than 3°C, i.e. towards the higher end of the IPCC TAR estimate.

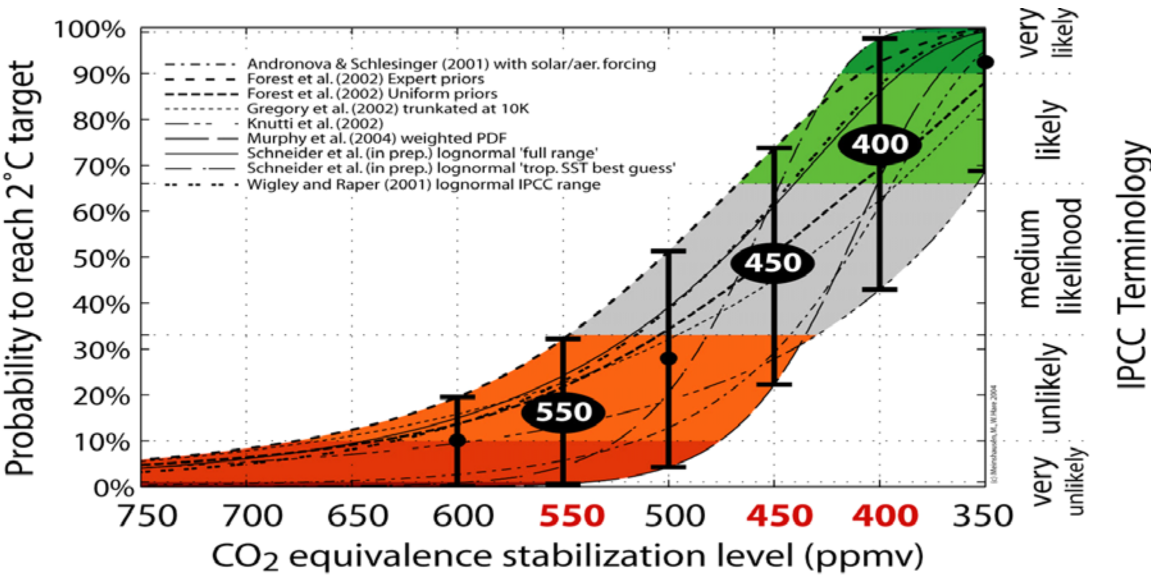
Further uncertainties relate to regional climate change trends, economic development patterns, assumptions underlying the wide range of emissions scenarios, technological progress, population growth, and governance structures and factors associated with model projections. There are also uncertainties relating to climate sensitivity, climate forcing, and feedback processes. In particular, the mechanisms, quantification, time scales, and likelihoods associated with large-scale abrupt/non-linear changes (e.g., ocean thermohaline circulation) are not sufficiently well understood.

However, since 1996, climate science has improved significantly as more models have been developed and more realistic scenarios have been used, as reported in the IPCC TAR and subsequently. In general, impacts will increase as temperatures rise.

Because of these uncertainties about climate sensitivity and other factors, it is important to keep any greenhouse gas stabilisation goals under review. Considering the inertia of the climate and socio-economic systems, there is a narrow window of opportunity within the next couple of decades in which to shift global emissions to a pathway consistent with the EU 2°C target.

The strategy of waiting for more scientific certainty does not appear to be sound. By the time uncertainty is sufficiently resolved, the opportunity to apply important policy levers may have been lost. The precautionary principle suggests that the international community needs to pursue a hedging strategy ("buying insurance"), keeping open the option that it might be possible to reach an even lower concentration at a later stage.

Figure 4: The probability of reaching the 2°C target



Source: B. Hare and M. Meinshausen[7]

3. The Benefits of Limiting Climate Change – The Costs of Inaction

3.1. Evidence of climate change today

The evidence for climate change is now overwhelming and there is widespread scientific consensus that it is already taking place. Over the past 100 years, the global average temperature has risen by about 0.6°C and the European average temperature by 0.95°C. Global temperature is expected to increase by another 1.4 to 5.8°C by the year 2100, and by 2.0 to 6.3°C in Europe - a rapid and profound change that will continue unless additional action is taken. Scientists tell us that globally the ten warmest years on record all occurred after 1991. Looking further ahead, recent simulations[8] indicate that in 2071 every second European summer is likely to be as warm as the summer of 2003, which in most parts of

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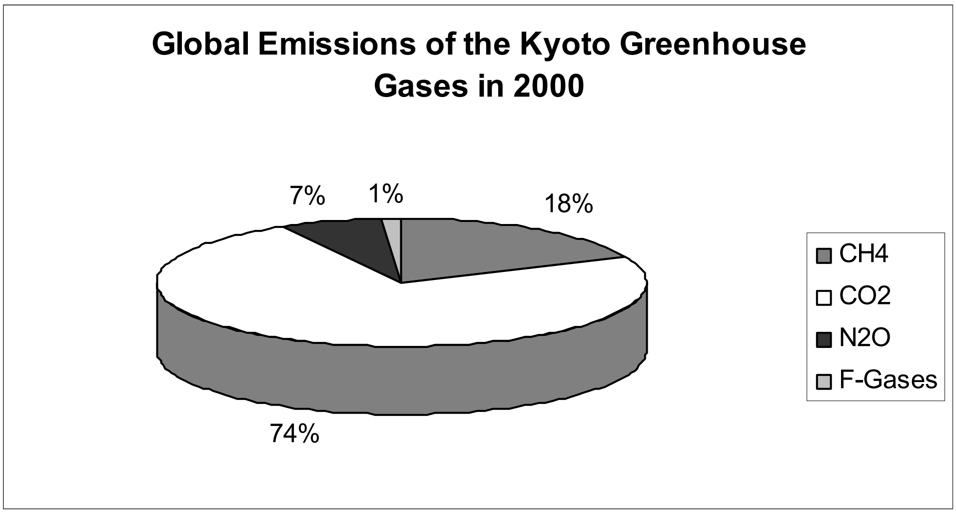
[7] B. Hare, M. Meinshausen (October 2004) PIK Report No.93: *How Much Warming are we Committed to and How Much Can be Avoided?* http://www.pik-potsdam.de/publications/pik_reports.

[8] Schär, C., P.L. Vidale, D. Lüthi, C. Frei, C. Häberli, M. Liniger and C. Appenzeller, 2004 : *The role of increasing temperature variability for European summer heat waves*. Nature, in press.

Europe was the hottest ever. Even if only the minimum predicted increase takes place, it will still be larger than any century-long trend in the last 10,000 years.

The principal reason why average temperatures are rising is a century and a half of industrialization: the burning of oil, gasoline, and coal, the cutting down of forests,[9] and certain forms of agriculture. Human activities have been increasing the atmospheric concentrations of greenhouse gases and aerosols since the pre-industrial era. The key greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases, i.e. hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6), all of which are covered by the Kyoto Protocol, and also tropospheric ozone (O_3). Figure 5 shows the shares of total emissions accounted for by the Kyoto Protocol gases. The atmospheric concentrations of key anthropogenic greenhouse gases reached their highest recorded levels in the 1990s, primarily due to the combustion of fossil fuels, agriculture, and land-use changes (see Table 1).

Figure 5: Shares of greenhouse gas emissions



Source: Common POLES IMAGE baseline data, provided by RIVM

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[9] Addressing deforestation as a specific issue in some regions seems to be vital; it is estimated to release approx.1.7 GtC/yr i.e. the equivalent of 25% of global fossil emissions.

Table 1: 20th century changes in the Earth's atmosphere

Atmospheric concentration of CO_2	280 ppm for the period 1000–1750 368 ppm in the year 2000 (31 ±4% increase).
Atmospheric concentration of CH_4	700 ppb for the period 1000–1750 1,750 ppb in the year 2000 (151 ±25% increase).
Atmospheric concentration of N_2O	270 ppb for the period 1000–1750 316 ppb in the year 2000 (17 ±5% increase).
Tropospheric concentration of O_3	Increased by 35 ±15% in the period from 1750 to 2000, varies by region.
Stratospheric concentration of O_3	Decreased between 1970 and 2000, varies with altitude and latitude.
Atmospheric concentrations of HFCs, PFCs, and SF_6	Increased globally over the last 50 years.

Source: IPCC Synthesis Report of the Third Assessment Report - Summary for Policy Makers

The effects of these changes in the atmosphere are already measurable today:[10]

- the global mean sea level increased at an average annual rate of 1 to 2 mm during the 20th century;
- the widespread retreat of non-polar glaciers has been observed during the 20th century;
- the duration of ice cover of rivers and lakes decreased by about 2 weeks over the 20th century in mid- and high latitudes of the Northern Hemisphere;
- the extent and thickness of Arctic sea ice has decreased by 40% in recent decades during late summer and early autumn, and snow cover has decreased in area by 10% since global observations became available from satellites, in the 1960s;
- permafrost soil has thawed, warmed, and degraded in some mountainous, polar and sub-polar regions;
- El Niño events have become more frequent, persistent, and intense during the last 20 to 30 years compared with the previous 100 years;
- coral reef bleaching has increased in frequency, especially during El Niño events;

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[10] IPCC Synthesis Report of the Third Assessment Report - Summary for Policy Makers.

– weather-related economic losses have risen by an order of magnitude over the last 40 years, partly because of socio-economic factors and partly because of climatic factors.

3.2. Likely future impacts

The above changes give serious warning of more profound changes in the future. Without comprehensive climate action beyond the emission controls introduced by the Kyoto Protocol, global greenhouse gas emissions will follow a continuously rising trend. Thus, without further policy induced emissions constraints, concentration levels and related average temperature will continue to increase. According to model-based estimates and projections, if no further action is taken to control emissions, concentrations of greenhouse gases in the atmosphere may increase from 425 ppm CO_2 equivalent today to 935 ppm CO_2 equivalent or more by 2100. This could cause global temperature to rise by more than 3°C by 2100.

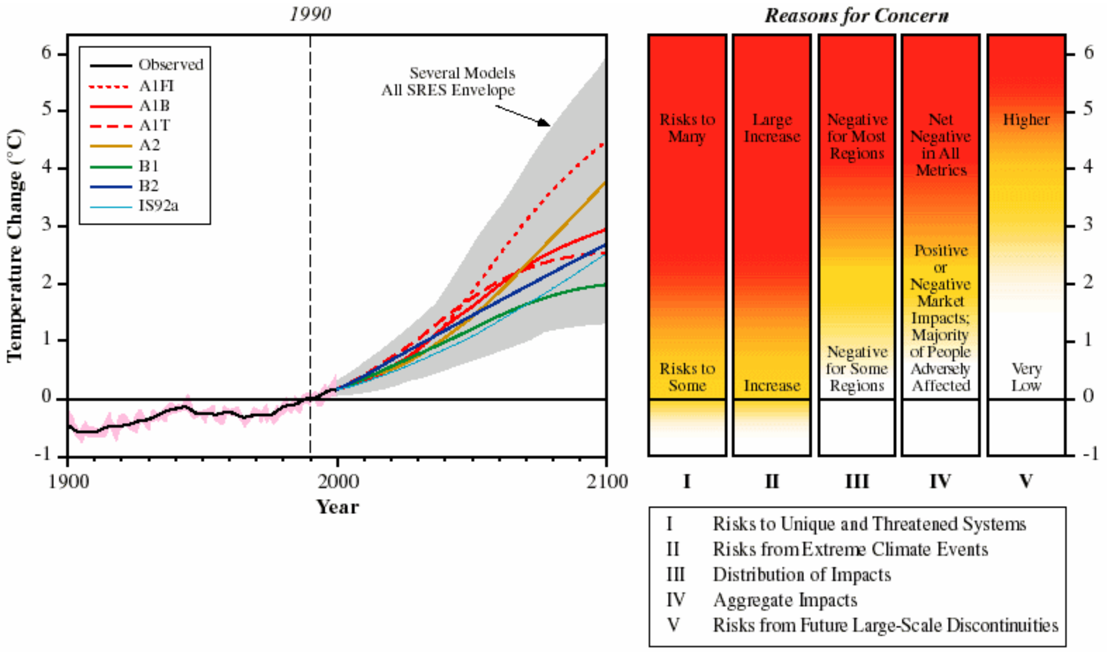
The Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) gives an overview of the projected change for the 21st century. All global regions will have to face serious impacts on their economies and ecosystems. Impacts on weather will include higher maximum temperatures, more heat waves, increased summer drying with the risk of drought, or increase in tropical cyclone peak wind intensities and more intense precipitation events.

These impacts will have serious economic implications. Crop yields will decrease as mean and peak precipitation increases. Agricultural and rangeland productivity will suffer in drought- and flood-prone regions. Damage to a number of crops will increase, as will the risk of forest fire. Ground shrinkage could damage building foundations. Water supply will also be affected: there will be less of it and quality will decline. There will also be less hydro-power potential in drought-prone regions. There will be shifts in tourist destinations. Demand, for electric cooling will increase, but energy supplies will be less reliable (See Chapter 4).

Climate change will have different cost and competitiveness implications for different economic sectors. It will have a bearing on all three pillars of the Strategy for Sustainable Development as defined in Lisbon and Gothenburg: the economic, the social and the environmental.

In its Third Assessment Report, the IPCC introduced the concept of “reasons for concern” in order to facilitate political decisions on what level of climate change would constitute dangerous interference. Figure 6 below summarises the reasons for concern about projected climate change impacts.

Figure 6: The risks of adverse impacts from climate change increase with the magnitude of climate change[11]



Key to magnitude of negative impact and degree of risk

Neutral or small negative or positive impacts or risks ⬜
Negative impacts for some systems or low risks 🟨
Negative impacts or risks that are more widespread and/or greater in magnitude. 🟥

Source: 'Climate Change 2001: Working Group II: Impacts, Adaptation and Vulnerability' IPCC, Summary for Policy Makers

The assessment of impacts or risks in Figure 6 takes into account only the magnitude of change and not the rate of change. Global mean annual temperature change is used in the figure as an approximation for the magnitude of climate change, but projected impacts will be a function of a number of factors, including the magnitude and rate of global and regional changes in mean climate, extreme events and socio-economic conditions.

For this reason, it is also important to consider the likely effects of climate change in detail. The major effects include:

– impacts of sea level rise, including the loss of coastal land/wetlands and the increased costs of sea level protection;

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[11] The risks of adverse impacts from climate change increase with the magnitude of climate change. This effect is illustrated in this figure, which highlights the magnitude of the negative impact and the risk of this occurring in relation to increased temperature change. The left side of the figure displays the observed temperature increase relative to 1990 and the range of projected temperature increase after 1990 as estimated by Working Group I of the IPCC for scenarios from the Special Report on Emissions Scenarios (SRES). The right side displays five causes for concern from climate change risks in the period to 2100. Risks from large-scale discontinuities only start to become significant above a 3°C temperature change. Risks to unique or threatened systems and risks from extreme climate events are projected to be significant and widespread for changes of 2 to 3°C. Above 2°C temperature increase, the vast majority of market impacts are predicted to be negative and most regions will suffer adverse affects.

- impacts on agriculture;
- impacts on energy use (heating and cooling);
- impacts on human health from cold and heat ;
- impacts on human health from disease, secondary effects;
- impacts on eco-systems (loss of productivity and bio-diversity);
- impacts on water resources, water supply and water quality;
- impacts from drought;
- impacts from flooding;
- impacts from storm damage and extreme weather (including infrastructure costs);
- socially contingent effects (arising from multiple stresses and leading to migration, famine, etc);
- impacts from major events (e.g. loss of thermo-haline circulation, collapse of West-Antarctic Ice Sheet, methane hydrates).

Sea level rise

By 2100, a sea level rise of 0.09 to 0.88 m, with a central value of 0.48 m, is predicted to occur.[12] Sea level rise will cause flooding, coastal erosion and the loss of flat coastal regions. Coastal protection is possible, though this leads to adaptation costs. Rising sea levels will increase the likelihood of storm surges and landward intrusion of salt water, and endanger coastal ecosystems and wetlands. Estimates for the European Union, where the coastline is about 89,000 km long, indicate that some 68 million people could be affected by sea level changes.

At global level, the effect is potentially more extreme. Populations that inhabit small island states such as the Maldives or low-lying coastal areas like the Bangladesh delta are at particular risk of severe social and economic effects from sea level rise and storm surges. The loss of these areas could have potentially important secondary effects through migration and other social effects.

Agriculture

Parts of Europe, particularly central and northern Europe might actually benefit from increasing CO_2 concentrations and rising temperatures. The cultivated area could be expanded northwards, and growing seasons extended. In southern Europe, agriculture could be threatened by climate change due to increased water stress. During the heat wave in 2003, many southern European countries suffered drops in yield of up to 30%, while some northern European countries profited from higher temperatures and lower rainfall. Bad harvests could

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[12] IPCC Third Assessment Report (2001).

become more common due to an increase in the frequency of extreme weather events (droughts, floods, storms, hail), and pests and diseases.[13]

Global projections[14] estimate EU (and US) agricultural yield increases for up to 2°C temperature rise, but a decline beyond this level. But in subtropical and tropical areas damage from increased heat stress is already projected even with a 1.7°C temperature increase. Higher average temperatures of 2.5°C in 2080 could leave 50 million additional people at risk of hunger.

Energy

Energy use is likely to change with new average temperature ranges, with a combination of increases and decreases in demand for heating (both in terms of overall energy supplied, and to meet peak demands). Benefits from increased winter temperatures that reduce heating needs may be offset by increases in demand for summer air conditioning, as average summer temperatures increase. Shortage of water supply for cooling purposes of thermal power plants may arise during periods of droughts, affecting security of electricity supply.

Health - thermal stress

During the summer of 2003 there were more than 20 000 additional deaths in western and southern Europe attributable to heat, particularly among the elderly. Heat waves are projected to become more frequent and more intense during the twenty-first century, so the number of premature deaths due to heat will increase in the future.[15] However, rising temperatures reduce deaths from cold in winter.

Globally it is estimated that, without accounting for extreme events such as heat waves, an average temperature rise above 1.2°C will cause an increase in premature mortality of several hundred thousands.

Health - infectious disease

In Europe the number of tick-borne encephalitis cases increased in the Baltic region and central Europe between 1980 and 1995, and have remained high. Ticks can transmit a variety of diseases, such as tick-borne encephalitis (TBE) and Lyme disease (in Europe called Lyme borreliosis). It is not clear how many of the 85 000 cases of Lyme borreliosis reported annually in Europe are due to temperature increases over the past decades.

At global level, rising temperatures will put many additional people at risk of diseases like malaria, dengue and schistosomiasis. It is projected that a 2°C increase will put 210 million more people at risk of malaria, with a potential epidemic increase of 30-50% for dengue.

Ecosystems

Significant impacts on ecosystems and water resources are likely between 1 and 2°C, and the risks of net negative impacts on global food production occur between 2-3°C global warming.

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[13] European Environment Agency (EEA), *Impacts of Europe's changing climate An indicator-based assessment*, Report No 2/2004.

[14] Sources: Parry 1999, Hare 2003, IPCC TAR.

[15] See footnote no. 46.

Recent studies[16] indicate for instance that, with a rise of up to 1°C above pre-industrial levels, up to 10% of ecosystem areas worldwide will shift. Some forest ecosystems will exhibit increased net primary productivity, increased fire frequency and pest outbreaks. Some hotspots with high biodiversity and protected areas of global importance will begin to suffer climate-induced losses. Coral reefs will suffer increased bleaching. Range shifts of species and higher risk for some endangered species are likely. Most of these impacts are already starting to be evident today.

A rise of 1–2°C above pre-industrial levels will shift up to 15–20% of ecosystem areas worldwide. Some protected areas of global importance and hotspots are likely to suffer severe losses of both land area and species. The wildlife of arctic ecosystems will be harmed (e.g. polar bears, walruses). Bleaching events will probably be so frequent that coral reefs will not recover enough to prevent severe losses of biodiversity.

With a rise of more than 2°C above pre-industrial levels, the global share of ecosystems shifting due to climate change is likely to be above 20%, and even more than that in some regions. Global losses of coastal wetlands could exceed 10%. On a global scale, reefs will undergo major disruptions and species loss, but will possibly not disappear completely. A large number of species will be endangered by range shifts. There is a risk that some protected areas of global importance will lose most of their area due to climate change.

Water resources, water supply and water quality

Water resources are sensitive to climatic variations in almost all regions of the world. In central Asia, melting glaciers and shorter winters alter river flows. In mid-latitude regions, increased temperatures lead to higher demand for water, particularly for irrigation. Decreased rainfall and more variable rainfall increase the risk of drought. The implications for water supply are an increase in potential regions of water stress and water poverty. Above 2 to 2.5°C global average temperature increase, it is projected that an additional 2.4 to 3.1 billion people will be at risk of water stress.[17] Some scenarios suggest that 10% of the Earth's surface area would be subject to water stress.[18]

Water quality is also sensitive to higher temperatures, lower river flows, saline intrusion with sea level rise, and more storms. Low flows and higher temperatures are likely to decrease the dissolved oxygen in lakes and slow moving rivers, increasing stress on fish. Low flows are already a problem in southern Europe, and this could be exacerbated by climate change. An intense summer storm over London in 2004 caused sewers to overflow directly into the Thames estuary. The many local controls on water quality have hindered a global assessment of potential climate change damage.

Drought

One of the most serious effects of climate change will be to increase the risk and possibly the duration of droughts. Higher temperatures and erratic rainfall are the primary causes, while a shift in circulation patterns, such as extended periods of El Niños, could see droughts lasting

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[16] WBGU: *Climate Protection Strategies for the 21st Century: Kyoto and beyond* Special Report; Berlin 2003.

[17] Source: Parry et al, 2001.

[18] Alcamo, J. and Henrichs, T. (2002) *Critical regions: A model-based estimate of world water regions sensitive to global changes*. Aquatic Science 64: 352-362.

for years and possibly decades. Although the scenarios of future drought risk are as yet uncertain, the effects would be serious. The immediate consequences - water stress, food scarcity, reduced plant growth, disease - could lead to economic, social and even political stresses. The most severe consequences, such as famine, forced migration and disease epidemics need not be the irect consequences of a drought; however an increase in drought risk with climate change could push some sensitive ecosystems and economies beyond the threshold of sustainability. The global economic cost of drought has not been calculated. However, droughts in Africa have cost up to 8% of GDP, primarily due to loss of power production from hydroelectric plants.[19] Annual average losses in the United States due to drought are estimated at $6 to $8 billion.[20]

Floods

Between 1975 and 2001, 238 flood events were recorded in Europe. Over this period the annual number of flood events clearly increased. The number of people affected by floods rose significantly, with adverse physical and psychological human health consequences.[21] With 2.0-6.4°C temperature increases the damage from river floods will be several times higher than with no climate change. With 1.4°C temperature increase coastal floods are projected to increase the number of people at risk by 10 million, 3.2°C will put 80 million at risk.

Impacts from storm damage and extreme weather events

Extreme weather events are also likely to increase, with cold spells, heat waves, drought, floods, storms and tropical cyclones. Changes in both frequency and severity are possible, though these may not be linearly dependent on average climate.

In Europe, 64 % of all catastrophic events since 1980 are directly attributable to weather extremes: floods, storms and droughts or heat waves. These account for 79 % of economic losses caused by catastrophic events. Economic losses from weather related events have increased significantly in the last 20 years, from an annual average of less than €6.5 billion to about €14.3 billion. This is due to increased wealth and more frequent events. Four of the five years with the largest economic losses in this period have occurred since 1997. The average number of annual weather disasters in Europe doubled in the 1990s compared with the previous decade, while non-climatic events such as earthquakes remained stable. Projections show an increasing likelihood of extreme weather events, which means that increasing levels of damage are likely.[22]

Socially contingent or secondary effects

There is an emerging consensus that widespread climate change may increase socially contingent effects[23] through a combination of multiple stresses. This is unlikely to affect Europeans directly, but may well have effects on Europe as a whole. Stresses from climate

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[19] Benson, C. and Edward J. Clay. 1998. '*The impact of drought on Sub-Saharan African economies: a preliminary examination.*' *Technical Paper, 401.* Washington, D.C.: World Bank.

[20] Http://www.magazine.noaa.gov/stories/mag51.htm.

[21] See footnote no. 46.

[22] See footnote no. 46.

[23] The classification of socially contingent damages is used to describe those large scale dynamics related to human values and equity that are poorly represented in damage estimates based on cost values, e.g. regional conflict, poverty.

change may converge on a number of vulnerable areas, for example in Africa, leading to potential regional conflict, poverty, famine, and migration.

It is clear that climate change will have a disproportionate impact on developing countries because these countries are more vulnerable than developed countries. Their economies rely more heavily on climate-sensitive activities; they are close to environmental tolerance limits; and they are poorly prepared to adapt to climate change. In contrast, richer societies tend to be better able to adapt and their economies are less dependent on climate. Under the upper range of IPCC projections of climate change, the impacts are likely to adversely affect achievement of the Millennium Development Goals (as agreed at the World Summit of Sustainable Development at Johannesburg).

Catastrophic disruption

A number of major effects could occur (potential catastrophes or major climate discontinuities). These include climate feedbacks that strongly accelerate climate change (by exceeding specific temperature thresholds), irreversible changes to the climate system, or effects that result in the sudden and rapid exacerbation of certain impacts that require unachievable rates of adaptation. The temperature changes at which these thresholds would be passed are not all clearly defined as yet, due to scientific uncertainties. At temperature rises above 2°C there is an increased risk of a range of severe large-scale events, such as shutdown of the ocean thermohaline circulation. However, some thresholds could be passed at global average temperature changes below 2°C, such as the irreversible melting of the Greenland ice sheet leading to a sea-level rise of 0.3 meter per century (to a maximum of 7 metres) with sustained local warming of 3°C (Arctic warming).

3.3. Estimating the costs of inaction

The sections above summarise the physical effects of climate change if no further action is taken. It is important also to assess the benefits of potential stabilisation targets[24], expressed either in relation to CO_2 concentrations (e.g. 450, 550, and 650 ppm CO_2 equivalent concentrations) or to temperature change (e.g. a limit of a 2˚C rise above the pre-industrial level). Reducing greenhouse gas emissions generates benefits in the form of avoided damages from climate change. The potential benefits depend to a large degree on estimates of (i) the availability and costs of adaptation technologies and policies, and (ii) the sensitivity of the climate to rising concentrations of greenhouse gases in the atmosphere. According to the Intergovernmental Panel on Climate Change *"comprehensive, quantitative estimates of the benefits of stabilization at various levels of atmospheric concentrations of greenhouse gases do not yet exist."*

There are three broad reasons for this:

- there is a "cascade of uncertainties", from GDP and population growth and the increase in emissions this triggers to the (regionally varying) changes in climate to the possible effects of these changes and their timing;

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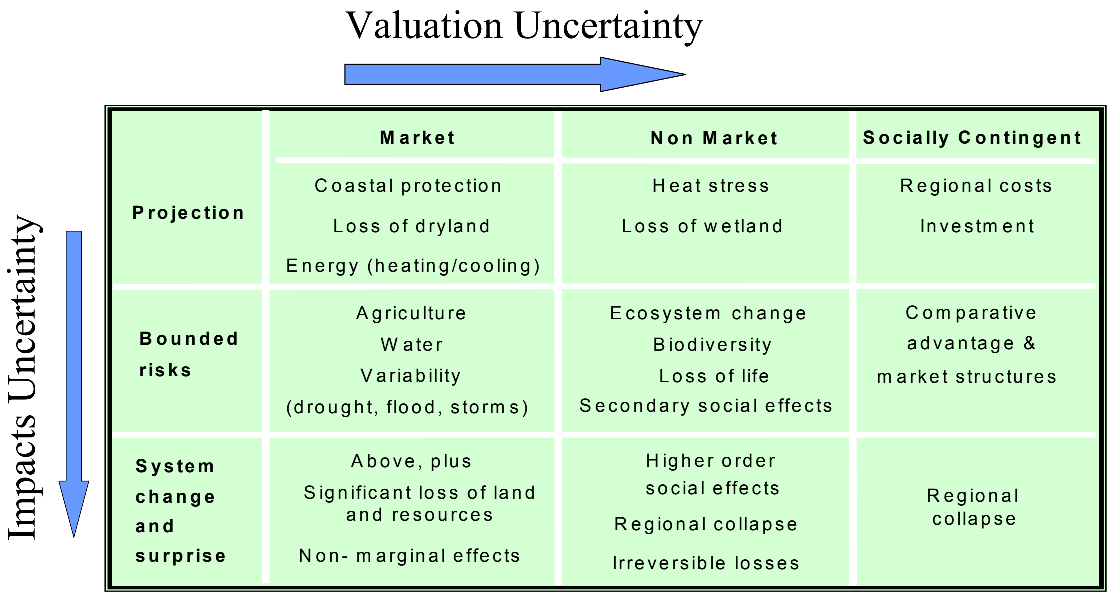
[24] Given historical and current emissions, the world is already committed to some level of warming and climate change.

- the impacts cannot all readily be expressed in money terms. Apart from impacts on economic activity, climate change is likely to have impacts in terms of additional human lives lost due to severe weather events and losses in biodiversity. Global income inequality may increase, and there may be forced large-scale changes in human settlement patterns, potentially triggering social and institutional instability;

- The main benefits of climate policies will occur only in the distant future. Choosing a rate for discounting benefits occurring in a distant future is an ethically-charged decision involving inter-generational equity.

- some regions (such as Russia and Canada) potentially benefit from moderate amounts of climate change, once they have successfully adapted to the changed climate. In addition, policy-makers have to decide how to value benefits accruing outside their borders. So there is a need to estimate the net costs of climate change. This might even hold within the EU.

Figure 7 shows the increasing uncertainty with respect to climate change impacts (vertical axis), and the uncertainty in valuing different types of impacts (horizontal axis). The scientific confidence and understanding of effects is best for the top left-hand area of the matrix.



	Market	**Non Market**	**Socially Contingent**
Projection	Coastal protection Loss of dryland Energy (heating/cooling)	Heat stress Loss of wetland	Regional costs Investment
Bounded risks	Agriculture Water Variability (drought, flood, storms)	Ecosystem change Biodiversity Loss of life Secondary social effects	Comparative advantage & market structures
System change and surprise	Above, plus Significant loss of land and resources Non- marginal effects	Higher order social effects Regional collapse Irreversible losses	Regional collapse

Figure 7: Risk matrix of increasing uncertainties in estimating the costs of inaction

Source: Downing and Watkiss, 2003[25]

While major advances have been made in recent years in the valuation of climate change, and work is ongoing in e.g. the OECD[26], concrete single scientific estimates of the global cost of inaction must be viewed with caution.

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[25] Downing, T., and Watkiss, P. (2003). *The Marginal Social Costs of Carbon in Policy Making: Applications, Uncertainty and a Possible Risk Based Approach*. Paper presented at the DEFRA International Seminar on the Social Costs of Carbon. July 2003. http://www.defra.gov.uk/environment/climatechange/carbonseminar/index.htm.

[26] OECD (2004), The Benefits of Climate Change Policies: Analytical and Framework Issues, Paris.

Recent work[27] on monetary values in the scientific literature on all possible impacts of climate change has concluded that these values are almost certainly only a part of the full cost of climate change. When all possible impacts are considered, a lower indicative estimate for the marginal damage costs might be €14 to 20 per tonne CO_2 with an upper indicative estimate of €80 Euro/tCO_2 and very possibly much higher,[28] based on current emissions (the value would increase in future years).

Recent work[29] has assessed the benefits associated with different stabilisation targets. The PAGE2002 has been used to examine a number of different stabilisation targets. The total damage values presented are based on all global damages over a time horizon up to 2200 and discounted back to a net present value. The analysis for a 'business as usual' run is based on the IPCC SRES A2 scenario. The model also assessed 550 ppm and 450 ppm CO_2 concentrations levels. These are broadly equivalent to 550 ppm and 650 ppm CO_2 equivalence (though PAGE includes stimulation of natural CO_2 using IPCC estimates of lower effective uptake of CO_2 by oceans as the temperature increases, so the model actually predicts higher increases). Instead of giving single estimates, PAGE builds up probability distributions of results by representing 31 key inputs, including discount rates and equity weighting, into the marginal impact calculations by probability distributions. For these runs, the mean values are for a mean discount rate of 2% pure rate of time preference (PRTP) and an elasticity of utility with respect to consumption of minus 1 (i.e. an equity weighted scenario). The value of a 2% PRTP is broadly consistent with a 4% social rate of time preference (assuming average GDP per capita growth of 2%). Note that the use of lower discount rates, or declining discount rate schemes, would give higher values than presented here.

The results show damage costs of €74 trillion from climate change under a baseline 'business as usual' scenario.[30] This falls by more than 40% to €43 trillion under a 650 CO_2 equivalent ppm stabilisation scenario, and by more than 55% to €32 trillion under a 550 CO_2 equivalent ppm stabilisation scenario.

The findings are broadly supported by recent studies[31] on responses to specific climate change scenarios. The scenarios assessed included three temperature change scenarios (<2˚C, 2-4˚C, >4˚C), but also included variables with respect to major events, socially contingent effects, discount rates, equity weighting, etc. Most experts believed that under conditions of low temperature change (2˚C), the costs would be low, most probably below €15/tCO_2. In contrast, for high temperature change (>4 °), the expert response was that costs would be high: probably in excess of €30/tCO_2 and possibly €80 to €140/tCO_2.

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[27] Tom Downing and Paul Watkiss in work for the UK Department of Environment, Food and Rural Affairs, on the Social Cost of Carbon, http://socialcostofcarbon.aeat.com/.

[28] There is no single value and that the range of uncertainty around any value depends on ethical as well as economic assumptions. These indicative values are based on a declining discount rate and include equity weighting.

[29] Chris Hope - Cambridge University - using the PAGE model as part of the support contract to DG Environment for *Modelling support for Future Actions – Benefits and Cost of Climate Change Policies and Measures.*

[30] Cumulative damages up to 2200 discounted total damage back to a net present value. Values are quoted in 2000 prices.

[31] Tom Downing - Stockholm Environment Institute (Oxford office) - as part of recent work on the social costs of carbon for UK Defra.

4. THE COSTS OF LIMITING CLIMATE CHANGE

4.1. The costs of adaptation

The above findings also indicate that it is already too late to escape a certain degree of climate change. Therefore it is already unavoidable that various regions, including in Europe, will have to adapt to certain impacts. This is part of the adaptation challenge, which will rise dramatically the more that climate change is allowed to occur. Even if necessary global action limits the temperature increase to 2°C, adaptation measures will still be necessary. Of course the need to adapt will increase dramatically if the temperature increases beyond 2°C, and this will exceed the adaptive capacity of many - if not all - countries. Damage from the changing climate will increase unless it is addressed by mitigation or adaptation.

The adverse effects of climate change will require the EU to adapt to the changing climate, but developing countries in particular will be most affected by climate change as they are most vulnerable and have least capacity to respond to the negative effects.

While developed countries can be expected to be more capable of setting out systematic programmes for adapting to climate change than developing countries, so far only a few systematic climate change adaptation programmes have been reported in OECD countries. A very comprehensive example of a systematic approach to adaptation is the UK Climate Impact Programme (UKCIP).[32] Set up already in April 1997 and funded by the Department for Environment, Food & Rural Affairs (Defra) the stakeholder-driven UKCIP helps organisations to assess how they might be affected by climate change, so they can prepare for its impact.

Adaptation to climate change will also require technological innovations and investment. New user-friendly climate impact assessment and planning tools for local and regional public and private sector actors are required in order to identify optimal adaptation strategies. Particularly vulnerable to climatic changes are low-lying areas close to the coast, river catchments and mountainous areas, areas with high risks of increasing numbers of storms and hurricanes. Economic sectors dependent on weather like agriculture and forestry are more at risk than other sectors.

Many climate impacts can be softened through early anticipation and adequate management (e.g. land use and urban planning, building codes). Important opportunities for reducing vulnerability to climate change occur when long-term public or private infrastructure investment decisions will have to be taken (e.g. tidal flood defences, dykes, and rainwater sewage systems). However, not knowing the overall mitigation effort required makes the search for appropriate adaptation technologies a moving target.

Another important aspect of adaptation is early prediction of more frequent and stronger natural disasters. The Commission is already involved in running an EU-wide early warning system for floods and forest fires. This will have to go hand in hand with improved management of natural disasters and the resulting damage. Private insurance might not adequately cover damages and losses of private property or might even be reduced over time. Governments will have to step in, either enforcing adequate coverage or providing solidarity funding.

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[32] See http://www.ukcip.org.uk/.

4.2. The costs of mitigation

Section 3 summarized the effects of climate change if no further action is taken. As well as considering how society can adapt to climate change, it is also important to assess the costs of potential stabilisation targets[33], expressed either in relation to CO_2 concentrations (e.g. 450, 550, and 650 ppm CO_2 equivalent concentrations) or to temperature change (e.g. a limit of a 2˚C rise above the pre-industrial level). Figures need to be interpreted with caution because tackling climate change entails action over many decades. Forecasting future technological developments and their costs is an uncertain exercise, and there are also choices to be made e.g. related to the value of the discount rate to be applied, a particularly sensitive parameter when dealing with events in the far future. Costs are also influenced by the amount of emission abatement that has to be undertaken to meet a particular target for atmospheric concentrations or temperature rise, and this depends on rates of growth of GDP and greenhouse gas emission intensities: over a period of 50 or 100 years. Minor changes in these factors can translate into major differences of effort needed to reduce emissions. While mitigation costs are certainly important, a discussion about costs, benefits and effects on competitiveness is necessarily more comprehensive, including effects on competitiveness arising from climate change impacts.

The European Council asked the Commission to consider the costs and benefits of medium- and long-term strategies, including targets, while not indicating which particular strategies and targets should be the subject of its analysis. Accordingly the Commission has not evaluated the benefits and costs of a finite number of policy alternatives, but rather looked at a broad range of strategies and targets in order to provide meaningful input for the European Council debate.

The Commission takes the view that post-2012 climate policy should aim to keep costs, including mitigation costs, low, and strengthen cost-effectiveness as one of the main pillars of the European Climate Change Programme. As a contribution to informed debate at the European Council the Commission has therefore identified and analysed the major factors that will influence mitigation costs for the European Union.

4.2.1. Pathways to stabilise the temperature increase

The emissions pathways in Figure 3 correspond to stabilising the total greenhouse gas concentration at 550 and 650 ppm CO_2 equivalent, for the set of six greenhouse gases covered by the Kyoto Protocol.

The range of temperature increases associated with any given concentration level reflects uncertainty over the 'climate sensitivity' parameter, which is defined as the global average temperature rise resulting from doubling CO_2 concentration. The 550 ppm CO_2 equivalent concentration level will result in a global mean temperature rise of less than 2°C for a low climate sensitivity value.[34] If climate sensitivity turns out to be higher, the 2°C target will not be met by following this stabilisation level. However, considerable global emission reductions

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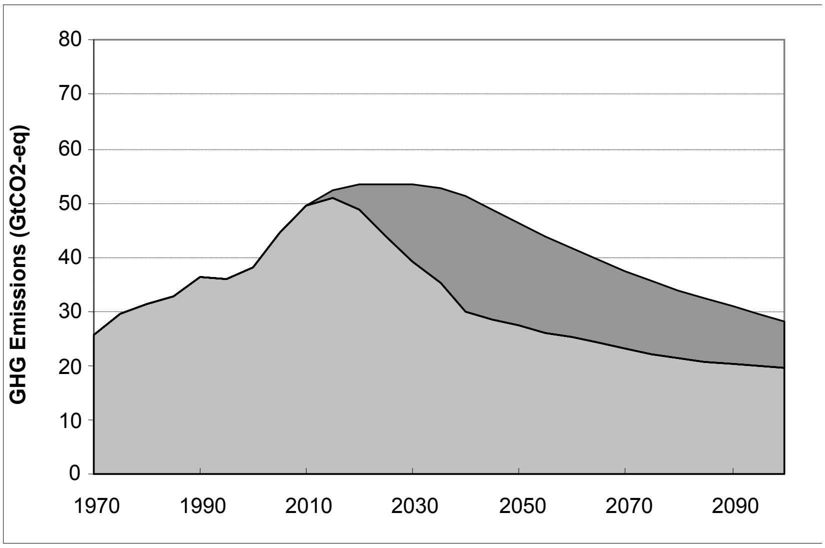
[33] Given historical and current emissions, the world is already committed to some level of warming and climate change.

[34] The Intergovernmental Panel on Climate Change estimates the range of climate sensitivity to be from 1.5 to 4.5°C, with a median value of 2.5°C.

are required in order to achieve even this pathway.[35] In 2025 global emission levels can still rise about 20% above 1990 levels under the 550 ppm pathway. However, global greenhouse gas emissions would need to peak around 2020, after which global emissions would need to fall substantially, up to 15-20% below 1990 levels by 2050.

The profiles of future global emissions in Figure 8 are examples. However, any profile to keep the 2°C target in reach would require keeping global emissions within a narrow window of 'allowed' emissions. All 2°C stabilisation scenarios show a peak in global emissions in the first half of the century and a steep decline after that. The later the global emissions peak is achieved, the steeper the emissions pathway will have to be in the second half of the century. However, early global action is more likely to address the inertia of both the climate and socio-economical systems. Setting the emission reduction target early provides certainty for business to guide long-term investments and technological change. Progressively larger emissions reductions over the next few years will prevent the need for more disruptive and more severe cuts later.

Figure 8: Global emissions pathways for stabilising greenhouse gas concentrations at 550 and 650 ppm CO_2 equivalent



Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025[36]

Note: 550 ppm pathway in light grey and 650 ppm pathway in dark grey

4.2.2. *Factors influencing the cost of different mitigation strategies*

Key factors influencing the cost of different abatement strategies are

- the level of ambition and the shape of the adjustment pathway
- the degree of participation

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[35] The abatement effort required under the constrained profile may be measured by the percentage change in anthropogenic greenhouse gas emissions from their 1990 level, and the baseline projection (i.e. the levels they would have been reached without specific abatement actions).

[36] Criqui, P, Kitous, A, Berk, M, den Elzen, M, Eickhout, B, Lucas, P, van Vuuren, D, Kouvaritakis N and Vanregemorter (2003) *'Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025'* A study commissioned by the EU Commission: p. 1-92.

- the regime structure including the availability of flexible mechanisms
- the rate of technological progress
- the provision of a stable policy environment
- co-benefits for other policies

4.2.2.1. Level of environmental ambition and shape of adjustment pathway

An important factor in mitigation costs is the level of environmental ambition targeted post-2012. In addition the shape of the adjustment pathway – i.e. front-loading or back-loading of major reduction efforts – is also of crucial importance. Seen purely from the angle of keeping short-term mitigation costs low, a back-loading strategy that provides for only a moderate level of environmental ambition in the first decade post-2012 may appear preferable. Any such strategy will imply a steeper reduction pathway in later decades linked with higher mitigation costs and/or higher adaptation and residual damage costs.

The impact of the chosen ambition level is demonstrated in the study *"Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025",* which compares the economic costs of following pathways to two alternative stabilisation scenarios – 550 and 650 ppm CO_2 equivalent concentration levels – by 2025. Under the more ambitious 550 ppm strategy, costs for the EU-25 in 2025 are in the range of 0.9 to 1.8% of GDP as estimated under a partial equilibrium model (POLES). This corresponds to up to 0.5% under a general equilibrium model. Under the less ambitious 650 ppm strategy, costs for the EU-25 in 2025 are in the range of 0.1 to 0.2% of GDP (partial equilibrium) and up to 0.12% under general equilibrium.

The difference in the costs for pathways compatible with 550 and 650 ppm concentration levels is due to the difference in the level of global reductions necessary by 2025. Figure 8 indicates that a pathway towards 550 ppm requires deeper global reductions by 2025 than a pathway to 650 ppm.

The International Institute of Applied Systems Analysis[37] has assessed the GDP effects of a pathway to 400 ppm CO_2 only concentration level (comparable to a 500 ppm CO_2 equivalent concentration level) against two alternative baselines and concluded that the world GDP in 2025 may decline by some 0.6 to 1.1% and in 2100 may be some 0.3 to 1.7% lower.

Based on the IPCC's Third Assessment Report global costs of stabilizing CO_2 concentrations in 2100 range from 1 to 8 trillion US$ (discounted costs[38] over the period 1990 to 2100) for a concentration target of 550 ppmv CO_2 only. The costs of stabilizing concentrations at a level of 450 ppmv CO_2 only range from US$ 2.5 to nearly 18 trillion. The costs depend on the model used and the assumed emission trajectory. IPPC TAR results indicate that the average GDP loss for stabilizing concentrations depend on the assumed reference scenario. Stabilizing concentrations at 550 ppmv CO_2 only may lead to average GDP levels being 0.2 to 1.8%

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[37] N. Nakicenovic and K. Riahi, Model runs with MESSAGE in the context of the further development of the Kyoto Protocol, report submitted to the Secretariat of the German Advisory Council on Global Change, August 2003.

[38] Discount rates are not given in IPCC TAR but are likely to differ between the models used.

lower in 2050 than would otherwise be the case. Stabilizing concentrations at 450 ppmv CO_2 only might entail GDP losses of 1 to 4% in 2050.[39]

The IPCC TAR cost figures are likely to be both overestimated and underestimated for a number of reasons. The report did not take into account options to reduce other greenhouse gases besides CO_2, nor did the report take into account carbon sink enhancement or endogenous technological progress. Recent results indicate that discounted consumption losses for stabilizing greenhouse gas concentrations at around 550 ppmv CO_2 only might be around 0.2% (for the period 2000 to 2100) in a CO_2 reduction only case but less than 0.1% if a multi-gas approach is taken. For a concentration target of 450 ppmv CO_2 only global discounted consumption losses would be around 1.1% in a CO_2 only case and around 0.3% if some reductions in CO_2 would be substituted by cost effective reductions of other greenhouse gases.[40] Similarly, recent results from the MESSAGE model show that a multi-gas approach (that includes CH_4, N_20, fluorinated gases and carbon sinks) can reduce the marginal costs of stabilizing CO_2 concentrations at levels of around 450 ppmv CO_2 only by some 70 % to around 14 €/tCO_2 in the year 2100 assuming the median B2 scenario.[41][42] The IPPC TAR figures are underestimated in the sense that they are based on achieving a level of CO_2 only concentration with reductions in CO_2 emissions. Hence the costs for controlling other greenhouse gases to achieve a certain all gas concentration level are not taken into account.

4.2.2.2. The level of participation and regime structure

Factors closely linked to the level of environmental ambition are level of participation and regime structure, including differentiation of commitments. As already shown, it is of vital importance to realise environmental benefits and avert climate change to increase the level of participation in mitigation efforts.

While in the medium to longer term broad participation is absolutely necessary, there are many options that can be used over the next decade in a first stage of post-2012 policy to gradually increase participation. The study *"Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025"* analyses a range of architectures, and their economic effects up to 2025. Some of the architectures are based on a comprehensive global approach as of 2013 with all countries taking on targets, while others are based on the notion of increasing participation and moving to a global approach over several decades. The study examines in particular three versions of a three-stage approach. The first stage implies no emissions target, the second stage implies an intensity target (emissions per unit of GDP), and the third stage implies a Kyoto-type target of an absolute nature[43]. The study concludes that some developing regions may in fact not need to take on targets for a few more decades, but would only need to agree in principle to take on a target once certain pre-defined conditions apply to them.

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[39] Figure 8.18 TAR WGIII, page 548-549.

[40] Manne, A. and R. Richels (2004) The role of non-CO2 greenhouse gas and carbon sinks in meeting climate objectives, July 2004, Stanford University/EPRI, Stanford. www.stanford.edu/group/MERGE/EMF21.pdf.

[41] Rao, S. and K. Riahi (2004) The role of non-CO2 greenhouse gases in climate change mitigation: long-term scenarios for the 21th century, Draft to EMF-21, July 2004. IIASA, Laxenburg, Austria.

[42] The work of Manne and Richels (fn. 40) as well as Rao and Riahi (fn. 41) is against baseline emissions leading to atmospheric greenhouse gas concentrations in the range 700 to 750 ppmv.

[43] In the Commission study a rather simple regime structure was chosen compared to the plethora of approaches that can found in academic literature. For a survey see Bodansky, D. 2004. International Climate Efforts Beyond 2012: A Survey of Approaches. Pew Center on Global Climate Change. Washington.

The IPTS has undertaken scenario analysis with the POLES and GEM-E3 models to assess the environmental and competitiveness implications if there is insufficient progress in participation in the time horizon up to 2025. Three scenarios have been analysed:

(1) "Annex I freeze"

EU-25 reduces emissions by 2025 to 8% below 1990 level.

All other Annex I countries continue to be restricted to the Kyoto target by 2025. The US, by 2025, stabilizes absolute emissions at the 2012 level resulting from compliance with the intensity target.

JI and CDM is available beyond 2012.

(2) "EU freeze"

EU-25 reduces emissions by 2025 to 8% below 1990 level.

No other countries take on commitments beyond 2012.

JI and CDM is / is not available beyond 2012.

(3) "EU reduce"

EU-25 reduces emissions by 2025 to 20% below 1990 level.

No other countries take on commitments beyond 2012.

JI and CDM is / is not available beyond 2012.

Table 2: The effects of limited participation scenarios

	Annex I freeze	EU freeze (3)	EU reduce (3)
Carbon price in 2025	€ 7	€ 2 to 23	€ 2 to 55
Global reduction with respect to business as usual	7.3 %	3.3 %	3.9 %
Costs for the EU in % of 2025 GDP (partial equilibrium) (1)	0.04 %	0.01 to 0.03 %	0.02 to 0.06 %
Costs for the EU in % of 2025 GDP (general equilibrium)(2)	0.045 %	0.015 % to 0.78 %	0.02 % to 1.67 %

Source: IPTS, POLES and GEM-E3 models; Notes: (1) POLES model (2) GEM-E3 model (3) lower value=with JI/CDM, higher value=without JI/CDM

These figures need to be compared with EU costs in 2025, in the range of 0.89 to 1.81 % of GDP under the set of analysed regime structures aiming at a concentration level of 550 ppm CO_2 equivalent, and 0.11 to 0.27 % when aiming at 650 ppm CO_2 equivalent. The scenarios demonstrate the importance of the market mechanisms and suggest that, in the absence of broad participation, modestly ambitious steps among like-minded countries seem to be affordable to the EU economy, but will have only limited environmental effects. A conclusion that may be drawn from this analysis is that the studied approaches may be transitional strategies, while efforts to broaden participation are intensified.

4.2.2.3. The role of flexible mechanisms

Numerous studies have demonstrated the advantages in terms of lower mitigation costs of using market-based mechanisms to implement Kyoto targets from 2008 to 2012. This analysis is just as relevant for any target beyond 2012. While the absolute amount of savings will depend on the policy alternative adopted, studies generally estimate cost savings in the range of a third to a half of reasonable alternative policy instruments.

Of equal strategic value and importance is the continued use of market-based mechanisms at international level. The EU trading scheme is designed as a building block for an international carbon market. The Kyoto Protocol lays the foundation for three international market-based mechanisms – international emissions trading (in assigned amount units), joint implementation (JI), and the clean development mechanism (CDM). The latter two are project-based mechanisms.

The extent and types of market-based mechanisms available after 2012 will depend on which of the alternative forms of commitment are included in the post-2012 international policy architecture. Studies have concluded that allowance-type approaches like the EU trading scheme are superior to credit-based approaches like the project-based mechanisms. A post-2012 climate policy with low mitigation costs should preserve these market mechanisms, with an emphasis on allowance-type approaches, and further extend their use. At the same time the functioning of the project-based mechanisms (in particular the CDM) should be improved.

One other element in this context is the linking of the EU trading scheme with trading schemes in other countries. Directive 2003/87/EC allows such linkage already for the Kyoto commitment period, and it is of equal importance for climate policy post-2012 in order to keep mitigation costs low. Studies generally estimate higher cost savings from international market mechanisms than from EU market mechanisms.

The strategic importance of market mechanisms at international level is illustrated in the figures and tables presented in the annex. The volume of credits traded in 2025 will depend on the commitment scheme and may range from 1.5 to almost 6 billion tonnes. The international financial flows associated with these traded volumes are €50 to €800 billion in 2025, of which €7 to €230 billion would be outflows from the EU-25.

The choice of the European Union to set up an EU-wide trading scheme in greenhouse gas allowances is a significant investment to keeping greenhouse gas mitigation costs low while gradually moving to a low-carbon economy. Implementing this scheme requires major efforts by both the public authorities and private actors. This investment will pay off over many years in terms of avoided mitigation costs. A low-cost post-2012 climate policy needs to preserve and extend the use of markets at EU level. The review of Directive 2003/87/EC planned in June 2006 will be an important step in the European Union's post-2012 climate policy development.

4.2.2.4. The rate of technological progress

Technology is an important factor in keeping mitigation costs low. In the short-term mitigation costs may be higher than necessary if certain technological solutions are not applied. In the medium to long term, research, development and dissemination efforts in low and zero-carbon technologies and techniques are crucial to allow the realisation of more ambitious mitigation strategies at moderate cost.

Key technologies were identified in a previous chapter. An important element is the incentive structure for technological development when choosing which instruments will achieve post-2012 strategies and targets. Allocation rules under the EU trading scheme, to take one example, should not discourage but rather promote technological development and dissemination.

The importance of technological development is demonstrated by the substantial change the world energy balance needs to undergo in order to move to a sustainable energy system as illustrated for a 550 ppm pathway in tables 3 and 4 below.

Table 3: World energy balance in a pathway compatible with a 550 ppm concentration level

POLES - 550ppmv profile WORLD	2000	2010	2020	2030	y.a.g.r 2000-2030
Population (M)	6102	6855	7558	8164	1.0%
Per capita GDP (95$/cap)	6786	8513	10506	12590	2.1%
GDP (G$95PPP)	41407	58350	79400	102788	3.1%
Energy Intensity of GDP (toe/M$95)	239	206	160	113	-2.5%
Primary energy (Mtoe)	9902	11996	12730	11621	0.5%
Carb intensity of energy (tCO2/toe)	2.38	2.42	2.27	1.78	-1.0%
CO2 emissions (MtCO2)	23574	29064	28934	20669	-0.5%
Other GHGs emissions (MtCO2e)	9197	9302	10320	11195	0.7%
Primary Energy Supply (Mtoe)					
Solids	2348	2835	2175	867	-3.3%
Oil	3517	4248	4545	3907	0.4%
Gas	2148	2889	3555	2856	1.0%
Others	1889	2024	2456	3992	2.5%
of which					
Nuclear	660	800	1036	2249	4.2%
Large Hydro + Geoth	236	291	353	421	1.9%
New Renewables	171	252	498	845	5.5%
World Oil Price ($95/bl)	26.5	23.7	25.5	24.5	-0.3%

Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025

Table 4: World energy balance in a pathway compatible with a 550 ppm concentration level compared to the reference case

550ppmv profile / Reference	2000	2010	2020	2030
Energy Intensity of GDP (toe/M$95)	0%	-0.8%	-12.9%	-32.4%
Primary energy (Mtoe)	0%	-0.8%	-12.9%	-32.4%
Carb intensity of energy (tCO2/toe)	0%	-0.4%	-10.2%	-31.7%
CO2 emissions (MtCO2)	0%	-1.2%	-21.8%	-53.9%
Other GHGs emissions (MtCO2e)	0%	-13.3%	-19.2%	-23.1%
Primary Energy Supply (Mtoe)				
Solids	0%	-3.0%	-41.9%	-81.9%
Oil	0%	0.6%	-10.6%	-33.4%
Gas	0%	-1.5%	-6.3%	-35.8%
Others	0%	0.8%	23.0%	89.8%
of which				
Nuclear	0%	-0.6%	31.3%	158.4%
Large Hydro + Geoth	0%	1.3%	4.3%	8.2%
New Renewables	0%	7.3%	65.7%	130.0%
World Oil Price ($95/bl)	0%	-0.1%	-11.2%	-29.9%

Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025

Work undertaken in the context of the Commission's World Energy, Technology and Climate Policy (WETO) Outlook has also underlined the importance of technological development. At the same time the work does indicate that technological development by itself, without any pull incentives for dissemination, will have only limited effects on greenhouse gas emissions.

Table 5: Impacts of the Technology Stories on electricity generation and CO_2 emissions (as compared to WETO Reference in % by 2030)

	Electricity generation						**Total**
	based on						
changes as compared to Reference in 2030	**Gas**	**Coal**	**Nuclear**	**Renewables**	**Total generation**	**CO2 emissions**	**CO2 emissions**
Gas case	21.6%	-12.2%	-5.3%	-10.5%	0.3%	-7.2%	-1.6%
Coal case	-16.0%	15.0%	-6.5%	-10.2%	1.1%	0.3%	0.0%
Nuclear case	-7.1%	-8.1%	77.5%	-9.9%	0.6%	-7.3%	-2.8%
Renewable case	-12.3%	-8.8%	-2.4%	132.0%	-2.2%	-8.9%	-3.0%

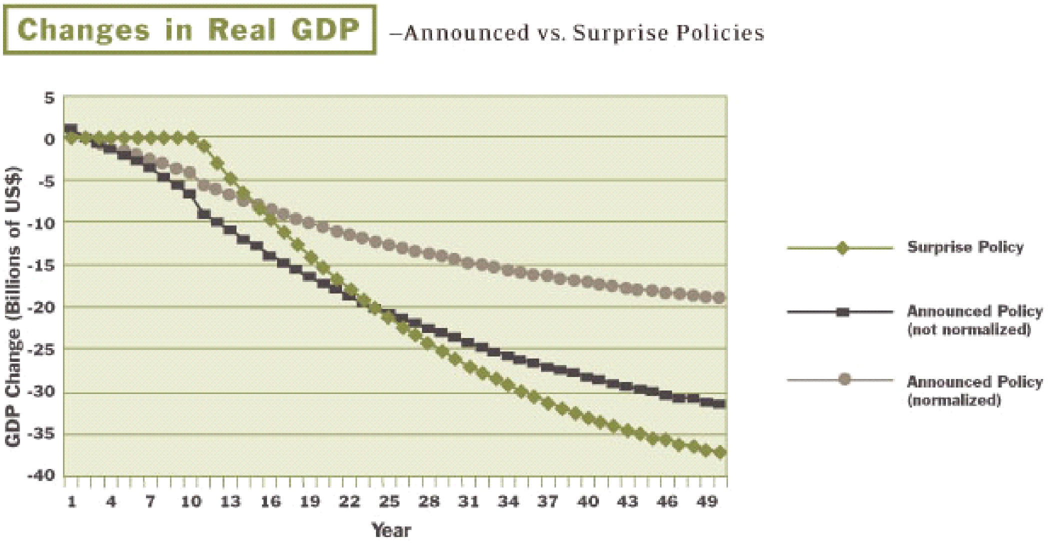
Source: World Energy, Technology and Climate Policy Outlook

4.2.2.5. Provision of a stable policy environment

Related to technology is also the issue of providing stable signals. While the pathways chosen to respect the ultimate objective of the UNFCCC may differ in the degree of effort over the next decade or two, it is important for policy to limit the uncertainty for investors in key technologies. An innovator or investor in a low-carbon technology targeting a certain carbon price level faces several risks. Competing innovators may develop and bring to market cheaper and more efficient technologies on a shorter time scale. New scientific evidence arising in the future may necessitate more or less stringent mitigation strategies. Most of these risks can and should not be neutralised by policy.

One risk that has hampered the development and dissemination of low and zero-carbon technologies so far is uncertainty about the entry into force of the Kyoto Protocol as the starting point for international climate policy. This lasted from 1997 to 2004. Studies have shown that gradual and predictable implementation of policy can smooth adjustment processes, reduce abatement costs, and be brought into line with medium-term investment cycles of long-lasting infrastructure and equipment. In contrast, uncertainty about the continuation of policies in the future or rapid "shock-therapy" adjustment processes can turn out to be unnecessarily costly. A recent study[44] refers to the value of prior announcements and quotes simulations that have shown that the GDP loss of a carbon tax of $ 25 per tonne is reduced by over a third if the tax is announced 10 years prior to introduction (see Figure 9).

Figure 9: The effect of prior announced policies.



Note: The normalized announced policy case involves the same cumulative emissions reductions as in the surprise case. The other announced policy case involves higher cumulative reductions.

Source: Goulder L. (2004), Induced Technological Change and Climate Policy, Pew Center on Global Climate Change, Arlington, Virginia.

4.2.2.6. Co-benefits from reducing greenhouse gas emissions

The response to climate change and the changes it will induce in the world's energy and transport systems, shows promise in terms of the economic, social and environmental pillars of sustainable development, in particular:

– a better and more secure energy future;

– employment and innovation;

– reductions in air pollution and related health effects, and other environmental burdens.

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[44] Goulder L. (2004), *Induced Technological Change and Climate Policy*, Pew Center on Global Climate Change, Arlington, Virginia.

A better and more secure energy future

The IEA's World Energy Outlook paints a sobering picture of how the global energy system is likely to evolve from now to 2030. In the reference 'business as usual' case, world energy demand - and CO_2 emissions - will be approximately 60% higher than today. Global primary oil demand is projected to grow by 1.6% per year, reaching 121 mb/day in 2030. Major oil and gas importers, most OECD countries, but also India and China, will become more and more dependent on imports from distant and often politically unstable parts of the world. Rising oil demand will have to be met by a small group of countries with large reserves.

Consequently, the risks in terms of energy security are expected to grow in the coming decades. With ever increasing demand and with supply problems, ranging from geo-political instability to overstretched supply chains, future trends in oil prices and related energy prices, are a major source of uncertainty, and economic risk. While this is not a new observation, the recent surge in oil prices and the concerns about its impacts on the world's economic performance in terms of consumer confidence, inflation and business climate, have brought back the memory of the oil shocks of the seventies and early eighties.

The IEA's World Alternative Policy Scenario analyses the global impact of environmental and energy-security policies, resulting in a faster deployment of clean and efficient technologies. While not requiring increased overall investment, it would indeed lead to substantial reductions in energy demand (10%), oil demand (11%) and import, and CO_2 emissions. This IEA scenario does not include certain technological options such as carbon capture and storage, or other major changes in the way energy is produced and used.

A development path in line with the 2°C target would certainly encourage alternative technologies (energy efficiency, renewables, carbon capture and storage) that would significantly reduce the economic risks related to security of energy supply. It would also reduce the import dependence and improve the trade balances of most large energy-consuming countries, an issue that is of particular relevance for many developing countries that have no choice but to rely on imported energy for fuelling economic development, even at the expense of their financial capability. In contrast, energy services, domestic renewable resources, or domestic coal with carbon capture and storage, would provide valuable alternatives and also local income and employment.

In the long term, a sustained and globally supported climate policy could have an important impact on energy prices. Energy efficiency and alternative technologies reduce demand for fossil fuels, and this in turn would lead to lower prices. In a carbon constrained world, the price of energy would obviously be a combination of an energy component and a carbon component, so the overall cost picture might be less divergent. However, this energy price structure would have some interesting features that make it more attractive, in particular:

- the high sensitivity of energy prices to supply–demand imbalances would be largely eliminated;
- different distributional effects, since "carbon euros" would be paid either domestically or spread across the world, while "petro-dollars" would mostly be diverted towards a limited number of countries;
- the carbon component of the energy price would change anti-cyclically, thereby easing economic fluctuations.

Technology innovation fosters employment

It is necessary to take a comprehensive view of the effects of climate change policies on economic growth and employment to adequately determine the net benefits. Studies on the indirect economic effects of mitigation policies show that they can create jobs.[45] This is plausible considering that energy efficiency investments increase the marginal benefits of capital and/or energy. This means that energy efficiency improvements in any country could create new jobs by using domestically produced energy-efficient technologies and services to replace imported energy. For example the number of people employed in the European wind industry has increased to over 72,000, compared with 25,000 in 1998.[46] Biomass in particular is a sector that has the potential to create new jobs.

Reducing air pollution

Recent studies indicate that the co-benefits of greenhouse gas mitigation may amount to a substantial proportion of mitigation costs.[47] These co-benefits are significant and lead to lower emissions of other pollutants, lower pollution control costs and lower environmental impacts. Moreover, whilst the full benefit of emission reductions resulting from further climate mitigation policies may be experienced only by future generations, the co-benefits will accrue to the present generation.

For example, a scenario with 15 % CO_2 reduction in the power sector compared to the baseline[48] found considerable side-impacts on the emissions of the conventional air pollutants due to lower consumption of fossil fuels, namely:

– a reduction of the SO_2 emissions value by 240kt or by 6% (equivalent to the total SO_2 emissions of Italy).

– a decline in NO_x emissions by 75kt or around 1.2 % (comparable to the total emissions of Hungary);

– a decline in primary emissions of PM2.5 by 37kt (approximately three times the total emissions of Denmark).

In total, the fuel substitutions aimed at reducing CO_2 emissions in fact cut the costs of complying with the present EU air quality legislation by €2.36 billion/year. The declines in air pollutant emissions are a mere side-impact of the (fuel substitution) measures targeted at the 15 % CO_2 reduction in the power sector. So these emission cuts do not come at additional costs. This co-benefit must be seen in relation to the costs of fuel substitution in this scenario, which are calculated by RAINS at €3.48 billion/year. Thus, net costs of the CO_2 reduction result at €1.12 billion/yr, which is only 32 % of the direct CO_2 control costs.

Lower air pollution emissions mean better air quality. A provisional assessment was conducted with the RAINS model to quantify the health impacts of less human exposure to

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[45] *The Forgotten Benefits of Climate Change Mitigation: Innovation, Technological Leapfrogging, Employment, and Sustainable Development* OECD ENV/EPOC/GSP(2003)16/FINAL.

[46] *Wind Energy, The Facts*, an analysis of Wind Energy in the EU-25, EWEA, 2004.

[47] *The Extension of the RAINS Model to Greenhouse Gases*/IIASA Interim Report IR-04-015.

[48] Same baseline as in '*European energy and transport – Trends to 2030'* outlook of DG TREN (EC, 2003) and limited reductions quantities calculated by the PRIMES model for a scenario "with climate measures" for a carbon price of 20 €/ton CO_2 in 2020.

fine particles (resulting from less primary emissions of PM2.5 and precursor emissions of secondary aerosols, i.e., SO_2 and NO_x). This analysis suggests for the CO_2 control scenario that the number of premature deaths attributable to air pollution is 3,370 fewer per year compared to the reference case.

About 50% of the costs of the Kyoto target can be offset against reduced costs of air pollution control (i.e. air pollution control cost reductions of €2.5–6.6 billion/year versus costs of climate policies of €4–12 billion per year).[49] Interestingly, the total annual air pollution control costs expected for 2010 in this study are considerably higher than the expected costs of implementing the Kyoto Protocol. As a result, even modest climate policies (in terms of costs) may have relatively large financial co-benefits in terms of avoiding the most expensive air pollution control measures.

Some greenhouse gases, such as methane, are also precursors for tropospheric (ground level) ozone. Thus reductions in methane emissions would have co-benefits in tackling the ozone problem. Recent estimates from MIT[50] show that current (2000-2005) crop damage from ozone amounts to $5-8 billion for the US, $9-10 billion for the EU and $9-16 billion for China (3 to 6% of the value of crop production in the US and the EU; and 6 to 10% in China). It is obvious that ozone, or reductions in ozone precursor substances, have an effect on the sequestration of carbon in the biosphere. From these studies, it can be concluded that a combined analysis of greenhouse gas mitigation and air pollution control leads to substantially different conclusions about the cost-effectiveness of strategies than traditional approaches that analyse these two problems in isolation.

The synergetic effects on climate change and air quality are probably the most marked for low-income but rapidly growing regions of the world, i.e. mostly in Asia. In China, for instance, public health and environmental damage are projected to grow from over 7% of GDP to 13% in 2020[51]. As climate change policies induce significant changes from baseline for sulphur and nitrogen oxide emissions, they will bring substantial co-benefits in terms of reduced regional air pollution, and improved human health. For certain countries, air quality benefits could indeed be the major driving force for taking action and participating in a future climate regime.

4.3. Competitiveness

An important element in the post-2012 strategy process is the concern that, if the EU adopts a more ambitious medium-term mitigation strategy, specific EU industrial sectors could lose competitiveness as a result of other major economic regions not participating effectively or pursing less ambitious mitigation efforts. In such a situation some CO_2-intensive production activities may consider to move outside the EU thereby undermining the global environmental effectiveness.

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[49] *Exploring the ancillary benefits of the Kyoto Protocol for air pollution in Europe* - Energy Policy; D.P. van Vuuren et al. (EEA, Copenhagen, 2004).

[50] Massachusetts Institute of Technology, John Reilly XXII Global Change Forum Venice 9-11 June 2004.

[51] *Transforming Coal for sustainability, A strategy for China*, Task force on Energy Strategies and Technologies to the China Council for International Cooperation on Environment and Development.

It should be stressed that important elements of the EU's climate strategy are to use the most cost-effective policies and to open up its ETS to project credits in an effort to develop an international carbon market.

Comprehensive analysis of the issue of competitiveness is rather difficult as it is multi-faceted and would require detailed sector-specific analysis of the country-specific regulatory environment. Analysis is further complicated by the fact that the sectors most exposed to international competition tend to be those with long-lasting capital investment, and need to distinguish temporary and permanent differences in environmental ambition and mitigation costs. Still, it is important to note that the EU enjoys a high standard of living and economic activity, but has also achieved a high level of environmental protection in recent decades.

The UK-based Carbon Trust has undertaken analysis for selected sectors of the competitiveness of UK energy-intensive industries as a result of implementation of the 2008 to 2012 Kyoto targets under the EU emissions trading scheme (EU ETS). It concluded that generally sectors need to pass on only a very small portion of the EU ETS-related increase in marginal production costs to maintain current levels of profitability as they receive allocations covering most of their direct emissions. This means that sector average costs rise by far less than their marginal cost, which generally has the biggest influence on prices. It is this difference that creates a potential for increased competitiveness and profits.

Electricity sector: In the central scenario modelled, with an allowance price of €10/tCO_2 and a large allowance cutback focused on electricity, the generating sector can maintain its profits by increasing wholesale UK industrial electricity prices by about 5%.

Steel, cement & newsprint: Even if the electricty sector passes through three times as much (the level that would theoretically maximise its profits from the EU ETS), both steel and cement have to raise final prices by only about 1.5% in order to maintain their current profitability, whilst the corresponding rise in newsprint prices is negligible (0.1%). The model predicts that both cement and newsprint would pass through more of their marginal cost increase than this, across a range of carbon prices, leading to net sector profits. Steel may be able to pass through enough costs to maintain or increase profits in our central scenario, but its low margins and international exposure will potentially prevent this at higher carbon prices.

Aluminium: With no free allowances and high international exposure, this sector may minimise its losses by increasing prices up by some 3%, but higher carbon prices may cause European firms to leave the market.

This analysis shows that the competitiveness effects of a moderate mitigation policy based on allocating allowances free of charge are limited. Recent work by the International Energy Agency[52] comes to the same conclusion.

A mitigation strategy that is more ambitious in the short to medium-term may have limited adverse competitiveness impacts in the short-run, but entails also a possibility to yield a competitive advantage in the long-term if competitors have to catch up with necessary mitigation, and the early movers can serve as suppliers of advanced technology and techniques.

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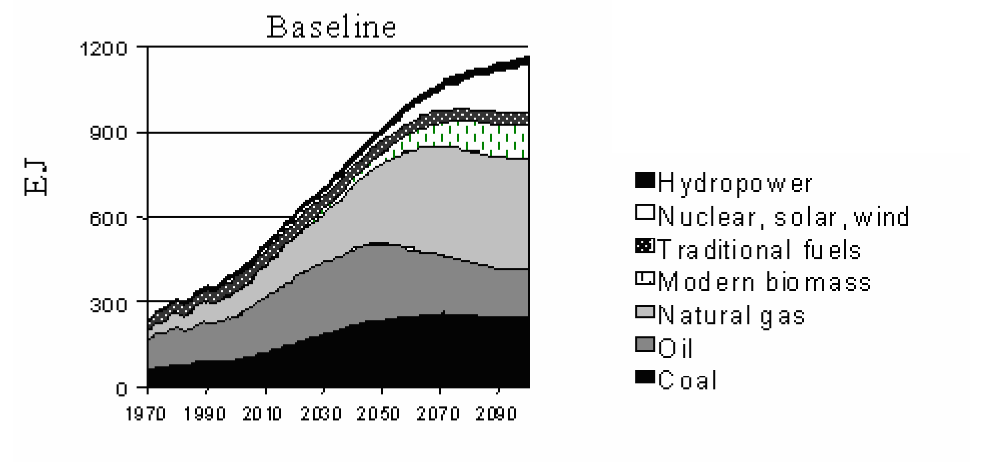
[52] Industrial Competitiveness under the European Union Emissions Trading Scheme, IEA Information Paper, Julia Renaud, December 2004.

5. CAPTURING NEW INNOVATION OPPORTUNITIES: INDUCING TECHNOLOGICAL CHANGE TOWARDS A CLIMATE-FRIENDLY GLOBAL ECONOMY

5.1. Energy supply in the baseline scenario

The baseline scenario developed in the study *"Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025"* implies a steadily increasing demand for fossil fuels in the next decades. Until 2030, gas and coal demand would grow at approximately 2.5% per year and oil at 1.7% per year. However, even in this baseline scenario, fossil fuel production is expected to peak: first oil and later also gas and coal. From 2030 onwards they are increasingly being supplemented by alternative energy sources. As indicated before, this scenario leads to an increase of greenhouse concentrations in the atmosphere that is incompatible with a stabilisation scenario.

Figure 10: Total world primary energy supply for the baseline scenario



Source: Greenhouse gas reduction pathways in the UNFCCC process up to 2025

5.2. Technology is crucial for realising a climate-compatible emission pathway

Considering the large discrepancy between the baseline scenario and emissions pathways compatible with the 2°C target, climate mitigation policies will induce a gradual transformation of energy and transport systems in the coming decades. The prevention of *dangerous anthropogenic interference with the climate system* therefore implies that the global economy is moving steadily towards a low-carbon economy. The figure above shows alternative technologies are expected to be deployed sooner or later due to gradual depletion of oil and gas reserves, or other energy supply problems. As world-wide demand for energy and transport services will continue to grow, the reduction of greenhouse gas emissions will need to be realised through technologies based on lower carbon intensity per unit of service than current technologies. Obviously technologies to tackle other greenhouse gas emissions, and management strategies to reduce land-use, land-use change and forestation emissions, are bound to be part of the overall cost-effective climate strategy.

The IEA alternative policy scenario of the 2004 World Energy Outlook scenario indicates that provided the right policy incentives are put in place, faster deployment of clean and efficient technologies is possible. This would require higher investment on the demand side, but this would be balanced out by a reduction of investment costs on the supply side.

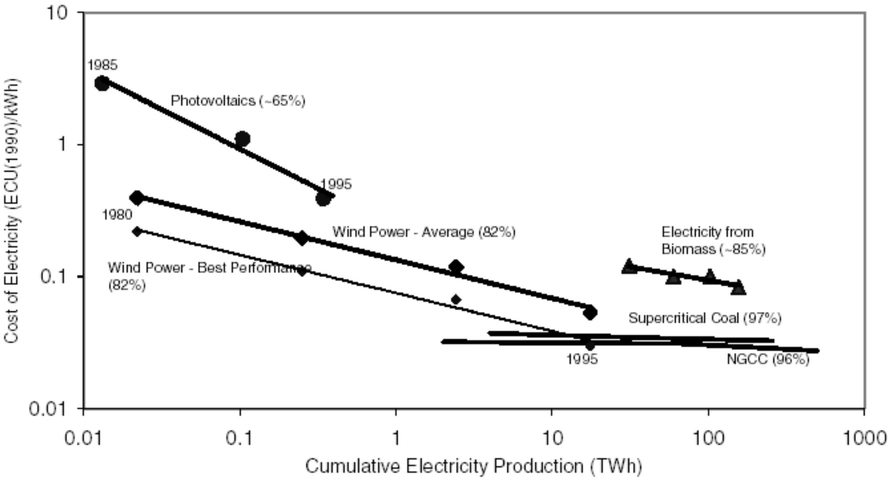
The best way of achieving a cost-effective solution is to implement two complementary policy approaches - technology push and market pull - side by side.

5.3. Market pull: Economic instruments enable market penetration

As crucial as new technologies are, they cannot provide a solution to climate change on their own. This is evidenced by various studies that indicate that even a considerable acceleration of technological progress will only achieve a limited reduction in greenhouse gas emissions. To compete effectively in the market, they will need to be economically rewarded for the climate change benefits they bring. The more prices truly reflect external costs, the more investment in climate-friendly technologies will increase. Establishing a market value for greenhouse gases, for instance through emissions trading or taxation, will provide a financial incentive promoting the widespread use of these technologies. Similarly, abolishing distorting subsidies will help to create a level-playing field among different energy sources. In 2004, the European Environment Agency estimated energy subsides in the EU-15 for solid fuels, oil and gas amounted to more than € 23.9 billion and for renewable energy to € 5.3 billion. Moreover, international transport - aviation and maritime - is almost entirely excluded from taxation. Getting prices right will have positive effects (i) by curbing demand, e.g. for fossil fuels and, for production processes and technologies that release greenhouse gases (ii) shifting consumer demand towards cleaner and more CO_2-effcient products and (iii), by stimulating the development and deployment of low- and no-emission technologies.

These market-based instruments can be complemented with smart and cost-effective policies that encourage the adoption of new technologies by promoting their early deployment. They are particularly suitable in the early stages by helping to overcome barriers to their introduction and facilitating demonstration. For some decades, many EU Member States have been successful with this approach for pulling new technologies onto the market. Experience shows that rapid deployment has helped to reduce unit costs of production of renewable energy technologies in the electricity sector in the years 1980-1995 (- 65 % for photovoltaics, - 82 % for wind power, - 85 % for electricity from biomass).

Figure 11: Learning curves - Cost reduction in electric technologies in EU 1980 to 1995[53]



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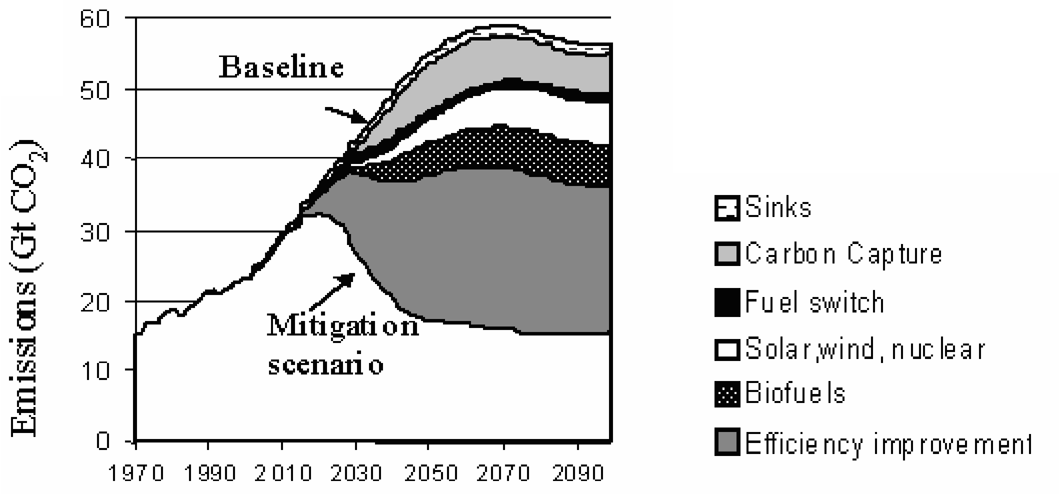
[53] Numbers in parenthesis are estimates of progress ratios. They indicate the change in cost when market size doubles. Thus, for example, if the size of photovoltaics markets doubles, the cost of PV electricity is reduced to 65% of its previous value.

Source: IEA, 2000; Experience Curves for Energy Technology Policy OECD/IEA

The penetration of new technologies is illustrated through analysis of how emissions reductions will be achieved in the 550 ppm stabilisation scenario and for a carbon value associated with this scenario. It shows the contribution of different abatement options to the overall reduction objective. Over the whole simulation period, in particular in the first two decades, most reductions come from energy efficiency improvements. By 2030, other options start to become important: using biofuels instead of fossil fuels and solar/wind or nuclear power for power generation. Thermal generation with carbon capture and sequestration also plays an important role throughout the century under this scenario. Obviously, the practical contribution of each technological option will depend on how its costs evolve in the future as a result of technological progress, how they compare to each other and on economic development in general. In addition to the CO_2 abatement technologies the capturing of CH_4 from landfills, from coal mines and gas networks, the reduction of HFC emissions from refrigeration and the abatement of (industrial) N_2O emissions have a role to play.[54] In view of this uncertainty it seems therefore wise to keep a broad range of options open.

Figure 12: Emission reduction by mitigation measure for a 550 ppm stabilisation scenario



Source: Greenhouse gas reduction pathways in the UNFCCC process up to 2025

Another cost aspect is the time-frame in which alternative technologies become competitive and penetrate the market. Costs will be lowest if alternative technologies are introduced along the normal business investment cycles. The Kok report indicates that 'failure to act now means greater, and possibly irreversible, damage or higher remedial costs in the longer term'. Business therefore needs a long-term stable framework. Future emission pathways that more or less continue business as usual and count on future breakthrough technologies are not only more risky in terms of preventing climate change, but are also likely to be more costly if significant reductions need to be achieved in a time-frame that does not respect normal business cycles. In particular, investments in the power sector, industry, transport infrastructure or buildings tend to impact on CO_2 emissions for several decades. This has significant implications for the EU and for developing countries, albeit for different reasons.

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[54] Rao, S. and K. Riahi (2004) Op.Cit. page 28.

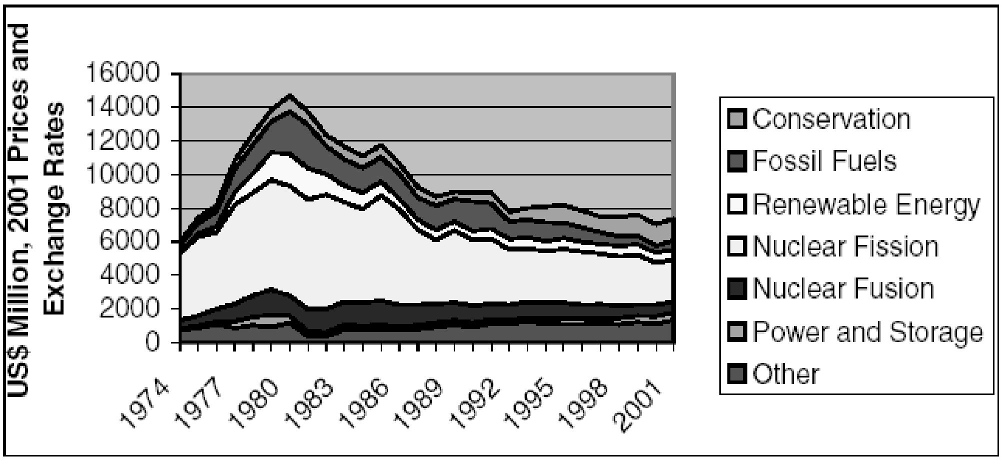
For the EU, several studies have demonstrated that a large part of the existing electricity generation capacity needs to be replaced in the next 20 years, which is a real opportunity for eco-efficient upgrading of the power sector along the normal business cycle. For developing countries that are building up their infrastructure, it is an opportunity to leapfrog immediately towards a more sustainable energy system.

5.4. Technology push: R&D and demonstration needs a boost

Data collected by the IEA on resources allocated by IEA member countries show that the challenge that energy systems are facing is not reflected in deployment of government R&D resources (Figure 13 below). Since the first and second oil shock, government R&D efforts have been steadily declining in this area. Considering the high potential and political expectations from renewables and energy efficiency and conservation, these issues in particular seem underrepresented in the total R&D portfolio.

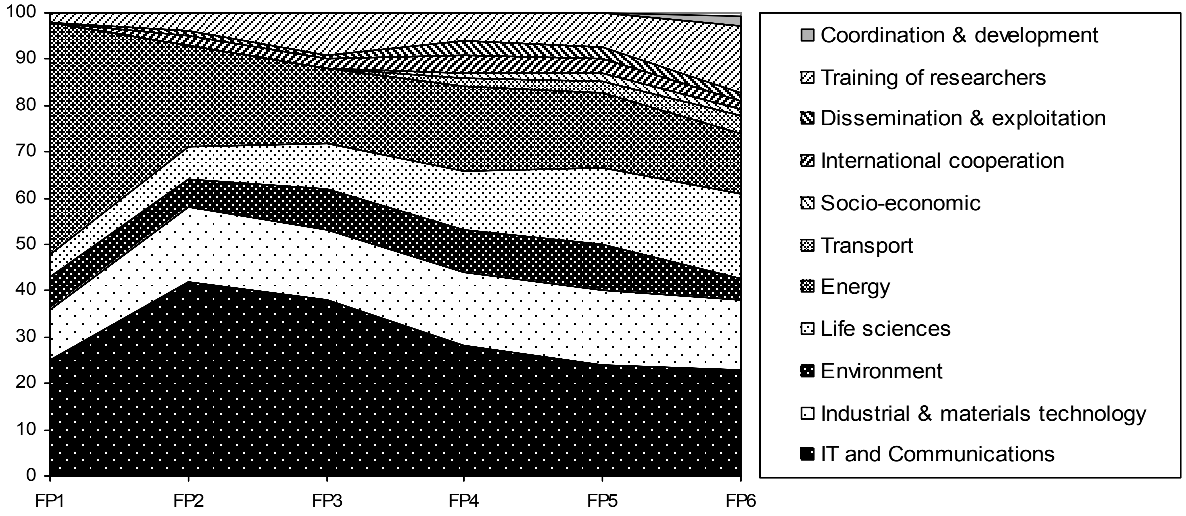
A similar conclusion can be drawn when analysing the R&D portfolio of the consecutive framework programmes (see Figure 14). While the first framework programme spent approximately 50% on energy and transport R&D, this has been reduced to less than 18% in the 6th Framework Programme. This trend needs to be reversed if the EU wants to improve its competitiveness in these two markets, which are expected to grow in the future.

Figure 13: IEA government energy R&D budgets, 1974-2001



Source: Data reported to the IEA by IEA Member countries.

Figure 14: Trends in EU RTD framework programmes



Source: European Commission (DG RTD)

International cooperation, i.e. encouraging information, cost-sharing and technology transfer can enhance the effectiveness of policies on technological innovation. Initiatives, like the International Partnership for a Hydrogen Economy and the Carbon Sequestration Leadership Forum are already being developed. The development of climate-friendly technology could be further enhanced in the context of a future climate regime and could involve various options such as international research collaboration, guaranteed markets, agreements on climate technology R&D expenditure, technology targets, technology prizes, progressive supranational standards, and improvement of conditions for trade in climate-friendly goods.

Any institutional approach would need to fit with and build upon existing work by UNFCCC (such as Article 4.5 on technology transfer) and IPCC. In addition, the private sector would need to be involved as a major partner. Technology transfer to the developing world should be a matter of primary importance, given expected development trends there. As countries in both the developing and developed world would appreciate the benefits of a technological cooperation framework, it would indeed be a strong incentive for countries to join a future climate regime.

5.5. Technological innovation - a competitive advantage in a carbon constrained world

The Kok report stresses that Europe can gain a first mover advantage by focusing on resource-efficient technologies that other countries will eventually need to adopt. No doubt, the EU has a real opportunity to create a competitive edge by positioning itself as a first mover in climate-friendly technologies. Competitive advantages will be enhanced as participation to a future climate regime is broadened and deepened over time. Those market players that succeed in developing and marketing climate-friendly technology and products will have a competitive edge.

As an example, the few countries that have taken the lead in promoting renewable energy, now have 95% of the rapidly growing wind turbine industry. Looking forward, this kind of phenomenon could also emerge in other countries and other sectors. For instance, upcoming regulations in China and California regarding CO_2 emissions of passenger cars will influence the competitive situation of manufacturers in these markets.

5.6. A wide portfolio of options

Various studies (IPPC TAR, Princeton stabilisation wedges) have shown that the technological options that are in operation or at the pilot stage today can indeed meet the world's future energy needs and at the same time follow a climate compatible emissions pathway. These technologies are available, but they are not the mainstream technologies that are fuelling today's economy. On the other hand, no single technological option can be considered a silver bullet that can solve the climate change problem on its own, nor is it possible to define what technologies will be most successful and what exact mix of these various technologies would work in the most cost-effective way. For that reason it would also be unwise for policy-makers to try to "pick winners".

A wide portfolio of more climate-friendly technologies is available, but not fully exploited. All of these technologies either improve energy efficiency and energy conservation (energy conversion technologies, end-use technologies in the domestic, industrial, services sector and transport), or reduce the carbon content of primary energy sources (renewables, carbon capture and storage, nuclear) or both. In addition, the reduction of methane, N_2O and HFC emissions can make a significant contribution, mainly in the agricultural, industrial and energy sector. A reduction of deforestation in developing countries is also an important factor.

They vary greatly in terms of technological maturity, nature of innovation (incremental improvement or 'radical'), current and projected cost, impact on energy and transport infrastructures, and societal impact. The combination of hydrogen and fuel cells can be considered a "radical" technological innovation with cross-cutting implications for the energy system, and the potential to achieve both of the above-mentioned possibilities, i.e. to combine decarbonisation of the energy carrier with increased efficiency. However, these potential gains need to be analysed from a life-cycle perspective.

5.6.1. Energy efficiency and energy conservation

Technologically, considerable efficiency gains can be achieved through energy conversion and end-use technologies in all sectors, i.e. the domestic, industrial and services sector, and in the transport sector.

Globally, it is estimated that 50% of future emissions could be eliminated through efficiency gains. Technologies in the field of energy efficiency have the advantage that their cost-effectiveness is enhanced by fuel cost savings. This also results in additional benefits related to security of energy supply, reduction of import dependence, improvement of balance of payments and reduced exposure to volatile fossil fuel prices. In addition, although many of the technologies are commercially available, they are still niche markets. There are also market barriers that prevent their more rapid use in the end-use sector, such as lack of awareness and information, and the nature of the market in which they operate (e.g. split incentives).

In terms of energy conversion, alternative technologies increase the thermal efficiencies of the conversion process or make use of the waste heat. Examples of appropriate technologies in the end-use sector are abundantly available in building design (e.g. low or zero emission buildings, energy managements systems), domestic equipment (e.g. stand-by losses, more efficient boilers, efficient light bulbs), industrial equipment (e.g. electric motor systems), and the various transport modes.

The possibilities for further improvement of these technologies are by no means exhausted. For instance, notwithstanding the improvements in the fuel economy of passenger cars in the past 30 years, further progress in conventional internal combustion engines and new technologies, such as (mild) hybrids and fuel cells, could lead to substantial fuel savings.

5.6.2. Renewables

The resource base of renewable energy (covering wind, hydro, solar, biomass, tidal, wave, and geothermal energy) is very large for each of the resources, and exceeds by far world energy demand. Most of the technologies using a renewable resource base are technologically viable and many are technically well proven. Some, such as hydro, wind, and some forms of biomass, have reached or are reaching the stage of competitiveness with conventional energy sources. For these technologies commercial and market barriers are the main obstacles. For others the cost is high relative to conventional energy sources, but still offers significant potential for technological improvement and cost reduction through R&D, investment and operating experience. Extensive scientific literature on learning curves indicates that cost-effectiveness will improve over time with sufficient penetration. A major effort will be required by industry and the research community over the next 25 years to turn more renewable resources into mainstream technology.

5.6.3. Hydrogen & fuel cells

Many see hydrogen, with fuel cells as a major energy conversion technology, as an important energy carrier for the future. The EU has established the European Partnership on the Hydrogen Economy to pool resources and expertise to develop a comprehensive strategy. In addition the EU has joined the International Partnership on the Hydrogen Economy.

From a climate perspective, the key question is the production of hydrogen. Not being a primary energy source in its own right, molecular hydrogen needs to be produced from fossil hydrocarbons, biomass, or electricity and water. The electricity can be produced from various sources, including fossil fuels (with or without CO_2 sequestration), renewables or nuclear. The various pathways have obviously a very wide range of life-cycle greenhouse gas emissions, and various other environmental impacts.

5.6.4. CO_2 capture and storage

Carbon capture and storage technologies should allow fossil fuels to be used in a carbon-free way. This would allow considerable CO_2 savings and ‘buy time’ if alternative solutions prove to be less effective, or more costly. It could prolong the life time of fossil-fuel-based technologies and smooth the transition to low-carbon technology. Although there is considerable uncertainty concerning the potential of a number of storage media, the world-wide available storage capacity is certainly very substantial. It provides a new option for those countries, such as China, US, Poland, South Africa, and Australia that view domestic coal as providing strategic energy security or as an important local industrial activity. It would also widen the low-carbon options for producing hydrogen through pre-combustion processes of fossil fuels.

The technology is already in use for other purposes, such as enhanced oil recovery. It is therefore in principle available and demonstrated on or applied at commercial scale. Average cost estimates range from only a few €/tonne CO_2 for ‘early opportunity’ applications (e.g. involving enhanced oil recovery, pure CO_2 streams) to €50 to €60 for the bulk of the potential. Cost estimates vary widely depending mainly on transport distance, the purity of the gas stream (e.g. pre- or post-combustion), and the location and nature of the storage medium.

To be an effective way of limiting CO_2 emissions, it has to be demonstrated that CO_2 can be safely stored underground and contained and monitored for long periods of time. These aspects are a central theme of a number of European research projects. Considering there is no legal framework for the application of this technology, there is an urgent need to address the necessary national and international rules governing CO_2 capture and storage.

5.6.5. Nuclear

From an isolated climate change perspective, the case for nuclear appears to be straightforward: nuclear power is CO_2-free and it already provides a significant share of the world’s energy. In the EU, it displaces approximately 300 million tonnes of CO_2 (corresponding to 7% of EU CO_2 emissions as forecasted for 2010) that would otherwise arise from thermal power plants. Its future application is however subject to considerable debate concerning the security, safety, and waste aspects of the entire nuclear fuel chain, from mining to decommissioning and final storage. In the EU, some countries have embarked on nuclear phase-out programmes, while others are keeping the nuclear option open. Finland has decided to invest in a new plant. In relation to developing countries, questions regarding safety and the possible proliferation of nuclear weapons are even more pressing.

Irrespective of the broader sustainability issues, the economics of new nuclear energy in the EU’s liberalised electricity markets might not be positive. Nuclear reactors have some particular disadvantages in a dynamic liberalized market: they take too long to build, have a long pay-back time, are not flexible and do not fit with a growing trend towards decentralized electricity generation. But research into new nuclear designs might change the competitive situation of nuclear energy.

6. SEEKING A GLOBAL SOLUTION FOR A GLOBAL PROBLEM: THE PARTICIPATION CHALLENGE

Climate change is a global problem that requires a global solution. Article 3 of the UNFCCC sets out the core principles to guide multilateral negotiations in finding that solution, e.g. in Article 3(1), which reads:

“Parties should protect the climate system for the benefit of the present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.”

This principle of “common but differentiated responsibilities”, enhanced with the notion of equity and the need to take into account the capabilities of Parties, has provided important guidance in the development of the climate change regime, including the Kyoto Protocol.[55] This principle, combined with the urgency of the climate challenge, has also served as a key foundation for the EU's actions on climate change in the past and must, together with the other principles set out in the UNFCCC continue to play a central role in the development of the multilateral climate change regime post-2012.

Chapter 2 described the climate challenge the world faces. Although scientific uncertainties make it difficult to determine the exact size of that challenge, there is sufficient certainty to translate this challenge into the policy objective of a maximum global temperature increase of 2^{o}C. This objective, although surrounded by some uncertainties, can be translated into actual levels of global greenhouse gas emissions that will allow us to achieve this objective. The level of participation required of each country or region to help achieve this objective, the common responsibility, depends on the contribution from the other emitters, i.e. how this common responsibility is differentiated. The more one emitter limits or reduces its emissions, the less is required from others, and vice-versa. Reduced contributions from one major emitter without larger contributions from others will, on the other hand, result in a failure to deliver the reductions needed to achieve a target.

A number of possible medium and longer term emission reduction strategies, including targets, were analysed in Chapter 4.2 above.

Both the UNFCCC and the Kyoto Protocol differentiate responsibility between developed and developing countries by requiring developed countries to limit their emissions, without imposing such obligations on developing countries. The UNFCCC required the developed countries listed in its Annex I to stabilise their CO_2 emissions at 1990 levels by the year 2000. The Kyoto Protocol sets out quantified emissions limitation and reduction objectives for developed countries in its Annex B, with a view to reducing their overall emissions of the six greenhouse gases covered under the Protocol by at least 5% below 1990 levels in the commitment period 2008-2012. The commitments undertaken by developed countries under the multilateral regime to address climate change post-2012 should build on their commitments under the UNFCCC and the Kyoto Protocol. And it is important to ensure the meaningful participation in the post-2012 regime of countries that have not committed themselves to the targets set out for them in the Kyoto Protocol. The international community should also consider expanding the list of developed countries as currently set out in Annex I of the UNFCCC and Annex B of the Kyoto Protocol to include a number of newly industrialised countries.

As a group, the developed countries must take on commitments that, on aggregate, will make a major contribution to addressing the climate challenge. The level and type of these commitments must reflect the differentiated responsibilities for developed countries, based on equity and their capability to address the source of the climate challenge. The post-2012 regime should require further absolute emission reductions from each of these developed countries, defined as a percentage of a base year. This would be a logical continuation of the approach chosen thus far and confirm the leadership taken by these countries in addressing the climate challenge. It would set a clear target for each of those countries to achieve, and

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[55] The Berlin Mandate, setting out the terms of reference of the process that led to the adoption of the Kyoto Protocol, explicitly listed this principle to guide the process and decided that the result of this process will "not introduce any new commitments for Parties not included in Annex I, but reaffirm existing commitments in Article 4.1 and continue to advance the implementation of these commitments in order to achieve sustainable development…." (Decision 2/CP.1, FCCC/CP/1995/7/Add.1).

would help clarify the effort required to get there. It also provides certainty of the environmental effectiveness of the target, assuming full compliance. Most importantly, it would allow continuation at multilateral level of key elements of what has been achieved through Kyoto, in particular international emissions trading and the project-based mechanisms.

As shown above, the projected increases of greenhouse gas emissions in developing countries, exceeding those of developed countries over the medium term means that to be environmentally effective any future regime will also require the participation of these countries. It is important that 'participation' is not limited to the type of commitments sought from developed countries. Developing country participation in a future regime must be seen in a broader context, which should not only include a wider set of participation types, but also a framework of incentives to allow and encourage developing countries to participate in the post-2012 regime. The central criterion in designing the participation types and the larger framework of incentives should be that these would allow developing countries to participate in a manner that is consistent with and promotes a path towards sustainable development and poverty reduction in line with national priorities.

Of the current group of countries not covered by limitation or reduction commitments under the UNFCCC and the Kyoto Protocol, also commonly referred to as non-Annex I Parties, the large majority are developing countries. The group of developing countries participating in the UNFCCC and Kyoto Protocol frameworks is large and encompasses countries with widely diverging characteristics. Some developing countries have a higher Gross Domestic Product per capita, or emissions per capita than some of the EU Member States, and even score higher on the Human Development Index. Other developing countries score at the lowest end of the spectrum of these indicators, in particular those belonging to the group of Least Developed Countries. A number of developing countries, such as the Small Island Developing States, have also been singled out because of specific geographical features that make them particularly vulnerable to the impacts of climate change. Some developing countries do not score high on these indicators, but because of their size, their growing population and their rapidly evolving economies, particularly with growing segments of comparably affluent consumers, they will contribute a large and growing part of the global emissions. To ensure that the participation of developing countries in the post-2012 multilateral regime is in accordance with the path towards sustainable development of each of these countries, the post-2012 regime will need to provide for types of participation that can accommodate the differences between developing countries, while still reaching the 2°C objective.

The 'staged approach' is a promising way to provide for differentiated participation by developing countries. A'staged approach' sets out a number of participation types; the type of participation applicable to an individual country is determined by a set of objective criteria. This approach also provides for graduation between approaches once a country reaches one or more thresholds defined by the regime.

When developing a 'staged approach' a number of design issues must be resolved. A first relates to the number of stages and the types of participation required under each such stage. Box 1 below sets out a list with examples of types of participation that could be considered at each stage. The precise type of participation for each stage of the staged approach would need to be designed to fit the characteristics of the group of developing countries falling into that category.

Box 1: examples of types of participation in a 'staged approach'

Absolute targets

These Kyoto-like targets (absolute limitation or reduction in emissions compared to emissions in a base-year) could apply to countries that score high in the set of indicators used.

Intensity targets

Intensity targets require a limitation or reduction of emissions in relation for instance to GDP and could apply to countries undergoing strong economic growth that are not yet ready for absolute targets.

Sectoral targets

Sectoral targets apply to specific sectors in an economy, such as the energy sector, or other specific industry sectors. The type of targets can differ according to the characteristics of a sector and could include the other targets listed in this box.

Human development goals with low emissions/sustainable development policies and measures

This type of participation is designed primarily to help developing countries meet their sustainable development objectives, while yiedling important climate mitigation co-benefits.

Renewable energy or energy efficiency targets

Renewable energy targets would require a specific level of, or increase in, the generation and use of renewable energy. Energy efficiency targets would require improved energy efficiency.

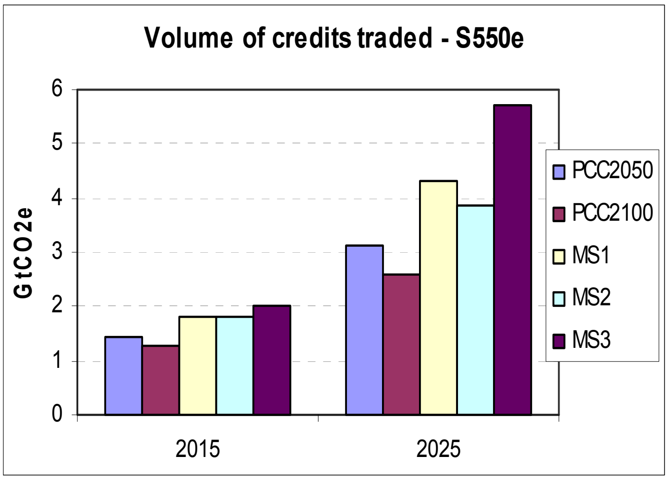
A second issue is the participation or graduation thresholds for each stage. Article 3(1) of the UNFCCC would suggest that the concepts of 'responsibility' and 'capability' should feature among these thresholds. Other concepts that could help define the thresholds include the potential to reduce emissions, and the more general concept of 'equity'. A set of indicators could provide more concrete guidance on the application of these concepts to set participation or graduation thresholds. Indicators that could be used include GDP per capita, greenhouse gas emissions per capita, greenhouse gas emissions per unit of GDP, the Human Development Index, historic emissions, emissions growth rates, or a combination of several of these indicators. While each of these criteria have their advantages and disadvantages, their application shows the large differences between developing countries and the value of such indicators in helping to provide a yardstick to determine participation and graduation in the stages of the 'staged approach'.

In the study *"Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025"* three variants for a staged approach have been developed and assessed. The first stage entails no emissions target, the second an intensity target (emissions per unit of GDP) and the third a Kyoto-type target of an absolute nature. The study used the sum of per capita GDP plus per capita total annual greenhouse gas emissions of a country to define a Capacity-Responsibility index. This was then used to classify countries in each of the three stages. This application of the staged approach should, however, be seen only as an illustration of the possibilities that this approach can provide to differentiate between developing countries.

A third important issue that needs further exploration when designing a ‘staged approach’ is the incentives for participation at each stage. Participation of developing countries in the post-2012 regime should be seen in the broader framework of incentives that will not only allow but also encourage developing countries to participate in a manner that is consistent with and promotes a path towards their sustainable development. The post-2012 regime, therefore, should not only focus on mitigation of greenhouse gas emissions but provide a broader framework in which key issues such as adaptation and the development and transfer of technology are given a central place. Additional issues include capacity-building.

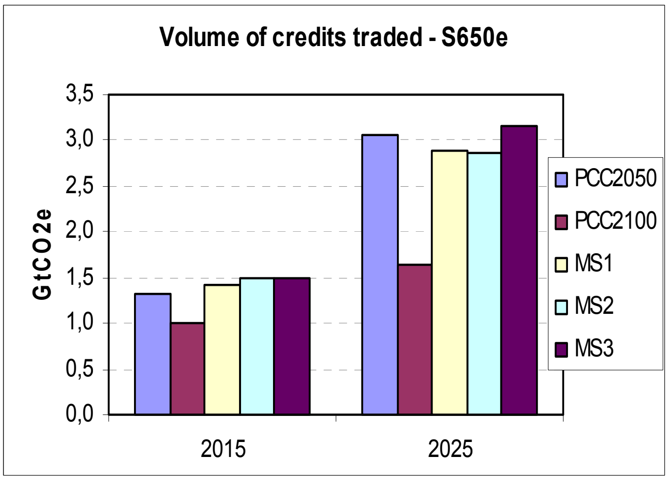
Annex - Additional figures and tables

Figure A: Volume of traded credits in 2015 and 2025 (pathway compatible with a 550 ppm concentration level)



Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025

Figure B: Volume of traded credits in 2015 and 2025 (pathway compatible with a 650 ppm concentration level)



Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025

Table A: Direction of net trade[56] in emissions credits and associated financial flows, 550 ppm pathway and 650 ppm pathway

Financial Flows (2025) **billion €**	**S550e**					**S650e**				
	PCC2050	PCC2100	MS1	MS2	MS3	PCC2050	PCC2100	MS1	MS2	MS3
Enlarged EU*	159	105	181	162	231	25	7	27	30	33
USA	5	-162	160	116	275	22	-23	16	25	35
Canada	20	12	26	23	33	6	4	6	7	7
CIS + Other Europe	33	-30	43	25	90	10	-8	6	6	6
Oceania	6	-1	10	8	17	3	1	3	4	4
Japan	42	27	48	43	64	8	4	9	9	10
Latin America	64	75	84	92	18	4	7	12	12	1
Africa	-123	1	-132	-132	-124	-39	-5	-15	-15	-15
ME & Turkey	47	45	48	60	41	11	10	15	2	8
India	-111	-8	-198	-198	-123	-30	-1	-28	-28	-27
Rest South Asia	-95	-35	-36	-36	-35	-28	-11	-4	-4	-4
China	-100	-107	-216	-140	-518	-3	-4	-38	-38	-49
Rest SE & E Asia	53	78	-19	-22	29	11	19	-9	-8	-10
Total financial flow	429	343	600	529	800	100	52	94	94	105

Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025

Table B: Effort rate, i.e. cost in % of 2025 GDP (pathway compatible with a 550 ppm concentration level)

2025 effort rates	PCC2050	PCC2100	MS1	MS2	MS3
Enlarged EU*	1,28%	0,89%	1,44%	1,30%	1,81%
USA	1,22%	0,18%	2,28%	1,99%	3,04%
Canada	2,47%	1,88%	2,82%	2,63%	3,35%
CIS + Other Europe	3,12%	1,41%	3,40%	2,90%	4,69%
Oceania	1,72%	1,10%	2,07%	1,86%	2,65%
Japan	1,31%	0,99%	1,43%	1,31%	1,78%
Latin America	1,37%	1,54%	1,60%	1,73%	0,72%
Africa	-2,00%	1,58%	-2,31%	-2,31%	-2,12%
ME & Turkey	2,61%	2,58%	2,60%	2,99%	2,38%
India	-0,31%	0,89%	-1,34%	-1,34%	-0,49%
Rest South Asia	-4,68%	-1,23%	-1,36%	-1,36%	-1,36%
China	0,83%	0,80%	0,11%	0,57%	-1,79%
Rest SE & E Asia	1,61%	1,99%	0,66%	0,61%	1,27%

Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025

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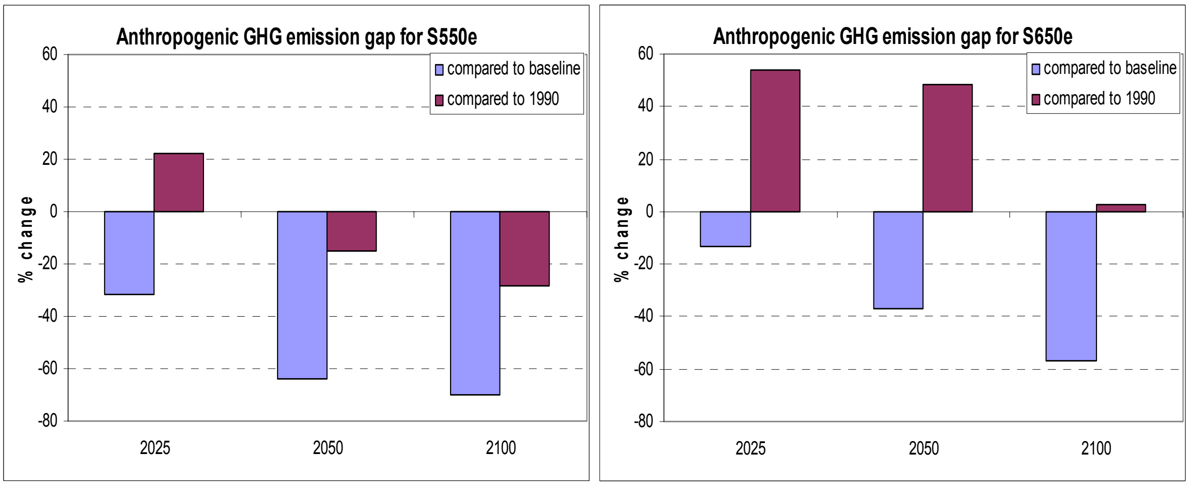
[56] Positive values are outflows of the region for the purchase of credits, while negative values are inflows for the sale of credits.

Table C: Effort rate, i.e. cost in % of 2025 GDP (pathway compatible with a 650 ppm concentration level)

2025 effort rates	PCC2050	PCC2100	MS1	MS2	MS3
Enlarged EU*	0,22%	0,11%	0,23%	0,25%	0,27%
USA	0,30%	0,00%	0,26%	0,32%	0,38%
Canada	0,58%	0,41%	0,56%	0,59%	0,62%
CIS + Other Europe	0,56%	0,07%	0,45%	0,44%	0,57%
Oceania	0,41%	0,23%	0,40%	0,43%	0,46%
Japan	0,21%	0,11%	0,22%	0,23%	0,25%
Latin America	0,09%	0,14%	0,20%	0,20%	0,06%
Africa	-1,01%	0,02%	-0,30%	-0,30%	-0,30%
ME & Turkey	0,46%	0,45%	0,58%	0,21%	0,38%
India	-0,25%	0,10%	-0,22%	-0,22%	-0,22%
Rest South Asia	-1,56%	-0,57%	-0,16%	-0,16%	-0,16%
China	0,17%	0,16%	-0,05%	-0,05%	-0,13%
Rest SE & E Asia	0,25%	0,36%	0,00%	0,00%	-0,02%

Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025

Figure C: Global greenhouse gas emissions reduction efforts for stabilisation at 550 ppm (left panel) and 650 ppm (right panel) CO_2 equivalent concentration levels



Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025

Table D: 550 ppm pathway, timing of participation of developing regions in the second and third stage

Regions	Central America	South America	North Africa	West Africa	East Africa	South Africa	Middle East	South Asia	East Asia	South-East Asia
Entry to Stage 2	2012	----	2012	2055	2065	2012	----	2015	2012	2010
Entry to Stage 3										
Multi-Stage 1	2035	2012	2040	2060	2075	2030	2012	2045	2020	2035
Multi-Stage 2	2015	2012	2050	2100	2100	2060	2012	2050	2015	2030
Multi-Stage 3	2025	2025	2030	2085	2095	2030	2020	2045	2025	2030

Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025

Note 1: for each region, white-boxes indicate the earliest entry case, dark-grey the latest, and light-grey in between

Note 2: South America and Middle-East directly enter in Stage 3

Table E: 650 ppm pathway, timing of participation of developing regions in the second and third stage

Regions	Central America	South America	North Africa	West Africa	East Africa	South Africa	Middle East	South Asia	East Asia	South-East Asia
Entry to Stage 2	2015	2012	2040	----	----	2040	2012	2050	2015	2025
Entry to Stage 3										
Multi-Stage 1	----	----	2090	----	----	2045	2012	----	2045	----
Multi-Stage 2	2055	2045	2075	----	----	----	2045	2080	2040	2050
Multi-Stage 3	2035	2030	2065	----	----	2060	2025	2075	2035	2050

Source: Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025

Note: for each region, white-boxes indicate the earliest entry case, dark-grey the latest, and light-grey in between

Table F: Electricity supply technologies in the POLES model

Conventional electricity supply technologies	New and renewable electricity supply technologies
1. Conventional, large-size hydroelectricity	1. Small hydro power plants (<10 MWe)
2. Conventional light-water nuclear reactor	2. Wind power plants for network electricity production according to wind resources
3. New nuclear design	3. Solar power plants (thermal technologies for network electricity production)
4. Pressurised fluidised-bed reactors	4. Decentralised building integrated PV systems with network connection
5. Integrated coal gasification with combined cycle	5. PV systems for decentralised rural electrification in DCs
6. Supercritical coal	6. Low temperature Solar systems in residential sector
7. Lignite-powered conventional thermal	7. Biofuels, conventional technologies (woodfuels, elec. from wastes, biofuels)
8. Coal-powered conventional thermal	8. Biomass gasification for electricity production in GT
9. Oil-powered conventional thermal	9. Proton exchange membrane fuel cells, stationary
10. Gas-powered conventional thermal	10. Solid oxide fuel cells, in cogeneration
11. Oil-powered gas turbine in combined cycle	
12. Gas-powered gas turbine in combined cycle	