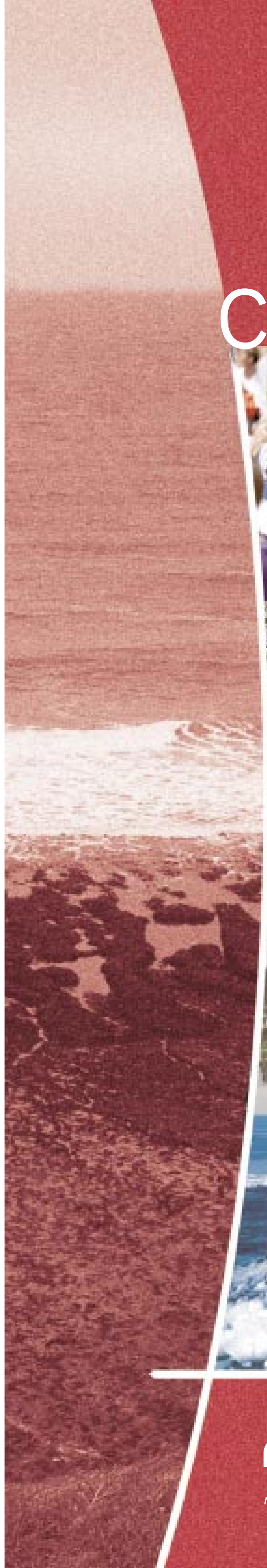

How to control the risks?

Climate Change

research for
man and environment

RIJKSINSTITUUT VOOR VOLKSGEZONDHEID EN MILIEU
NATIONAL INSTITUTE OF PUBLIC HEALTH AND THE ENVIRONMENT

Climate change research at RIVM

Foreword

Climate change has become one of the most complex and politically challenging environmental problems. Climate policy development is strongly influenced by international negotiations and firmly based on scientific information as illustrated by the important role played by the comprehensive assessments of the UN Intergovernmental Panel on Climate Change (IPCC). Implementation of climate policy affects large parts of society and the economy. It faces trends of increasing emissions and needs to have a strong long-term orientation to control the risks of climate change. This is exactly an area where RIVM's long standing integrated environmental assessment expertise can play an important role in informing and advising Government and International Institutions.

This brochure gives a brief overview of our capabilities. It covers key aspects of the climate change problem: "how is climate change going to affect us?", "how can we implement the Kyoto Protocol?" and "what can be done to limit, reduce or adapt to climate change?" It highlights our work on national emission monitoring and long-term strategies to address climate change. Much of the work makes use of our strong modeling capabilities, including IMAGE, one of the world's leading Integrated Assessment Models, and interactive decision-support models for assisting policy-making processes. In this context we have gained much experience with policy-science dialogues as a way to better tune the analyses to the needs of policy makers. And that is of course our ultimate objective: to better assist the decision- making process towards controlling the risks of climate change at the national, European and global level.

Dr. Bert Metz,
Head of the Global Environmental Assessment Division of RIVM
and co-chairman of IPCC Working Group III on Mitigation of Climate Change.

How to control the risks?

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1 How is climate change going to affect us?

Introduction

Climate is changing. The 20th century has experienced a 0.6°C increase in global mean temperature. Impacts on ecosystems have already been observed throughout the world. IPCC states that at least part of this change is caused by human activities. It expects climate change to continue. Coping with climate change requires a good understanding of its causes, its dynamics and its impacts. Policy makers need to understand the implications of particular choices. Climate change is often expressed as an increase in global mean annual temperature. However, such a simple indicator masks regional and seasonal differences and it does not specify concurrent changes in other climatic variables, such as rain intensity, frost events and storms. Temperature increase may result in a particular region being much wetter, while other regions would experience a serious drought. Local changes will have a much larger bearing on sensitive systems and sectors than just a change in global mean temperature. Therefore regional characteristics will have to be considered in impact assessments. Here, we relate different impacts to mean temperature increase, using IMAGE 2 (see box). We highlight impacts on sea-level, crop patterns and yields, and natural ecosystems. The results all stem from a series of baseline, emission reduction and concentration-stabilisation scenarios.

The IMAGE 2 scenarios provide regional detail but can be easily aggregated globally. The baseline scenarios nearly all lead to a more than doubling of the atmospheric CO_2 concentration. To address how climate change is going to affect us, impact levels are ordered along different values of mean temperature increase. By evaluating impacts for high (4.5°C), medium (2.5°C) and low (1.5°C) climate sensitivity, each individual can select a personally acceptable impact level, which complies with his or her interpretation of Article 2, the objective of the UN Framework Convention on Climate Change.

The IMAGE 2 global-change model

IMAGE (Integrated Model to Assess the Global Environment) simulates the whole causal change of climate change. Human activities characterise specific energy-use and land-use patterns, which determine the emissions of greenhouse gases and aerosols. IMAGE 2 calculates global atmospheric concentrations which alter the radiative properties of the atmosphere and cause climate change altering sea level, biogeochemical cycles, hydrology, land use and ecosystem patterns. The strength of IMAGE 2 is in its comprehensive description of the Society-Biosphere-Climate system with its many interactions at different levels. An IMAGE 2 simulation results in comprehensive scenarios. Socio-economic aspects are simulated for 17 regions. Environmental factors are simulated on a high resolution grid. IMAGE 2 incorporates a simple climate model, but through the IPCC-methodology of pattern scaling, outputs of advanced climate models (GCM) are used to generate consistent spatial patterns of temperature and precipitation change. The use of different climate models helps to evaluate the uncertainty in regional impact assessments.

Sea-level rise

One of the impacts calculated by IMAGE 2 is sea-level rise, which mainly results from the thermal expansion of surface waters and melting of glaciers and the net melting of icecaps on Greenland and Antarctica. Larger increases in temperature, as foreseen for higher CO_2 stabilisation levels, lead to higher sea-levels (Table 1). However, even if temperatures stabilise, sea-levels continue to rise for several centuries. Hence, there is a delay between global warming and the response, due to the large inertia of the oceans. The time lags also increase with increasing temperatures. It is therefore important to evaluate not only the achieved sea-level rise in 2100 but also the anticipated rises beyond 2100.

Table 1. IMAGE 2 computations of long-term sea-level rise for different levels of CO_2 stabilisation in the atmosphere

	350 ppm	450 ppm	550 ppm	550 ppm
	Sea-level rise relative to 1990 (cm)			Temperature increase since 1990 (ºC)
2100	24	29	33	1.7
2200	41	56	66	2.0
2300	56	74	88	2.1
2400	68	90	106	2.1
2500	78	103	122	2.2

Impacts on agriculture

Agricultural production is highly dependent on climate and will therefore be influenced by climatic change. These influences are crop and region specific. For example, sugar cane requires adequate moisture during its development, while millet needs a drought period for seed maturation. Most of these crop-specific requirements are included in IMAGE 2, which makes the model well suited to calculate changes in productivity for different crops (Table 2 and Figure 1).

__Figure 1:__ Changes in potential yield of temperate cereals on current cropland in Asia. For (A) the Hadley Centre Climate Model, version 2 (HADCMZ) and (B) The Canadian Community Climate Model (CCC-GCM). The different climate-change patterns lead to large differences in regional impacts.

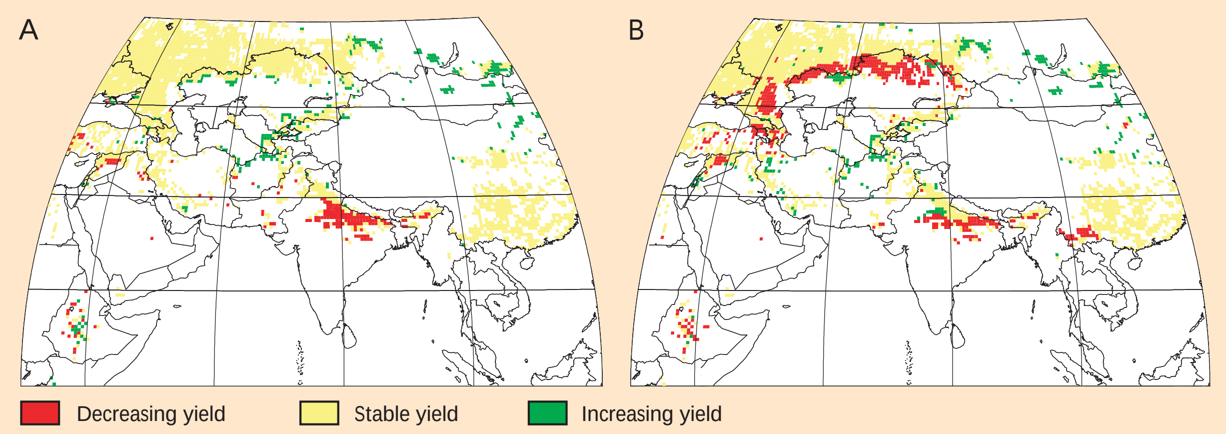


Table 2. Globally aggregated impacts on agricultural crops and ecosystems as a function of global mean annual temperature increase since 1990.

	1.5 ºC	2.5 ºC	3.5 ºC
Percentage change in potential rain-fed yield			
Decrease temperate cereals	18	22	26
Decrease maize	22	30	37
Increase temperate cereals	4	12	16
Increase maize	6	13	19
Percentage decrease in crop extent			
Temperate cereals	13	15	17
Maize	16	20	22
Percentage changes in ecosystems			
Vegetation shift in ecosystems	26	39	47
Endangered nature reserves	24	35	43

Explanation:

- Yield decrease and increase represent the percentage area with at least a 10% change in potential rain-fed yield. The reference area is the current crop area of that crop.
- Decrease in crop extent is the percentage area where the climate conditions are unsuitable for growing that crop. The reference area is the current crop area.
- Vegetation shift in ecosystems is the percentage land area that shifts from one vegetation type to another under future climate conditions.
- Endangered nature reserves are the percentage of reserves, where the original vegetation disappears. The reference is the total reserve number.

Table 2 contains a globally aggregated overview of climate change impacts on the agricultural potential rain-fed yield, as computed with IMAGE 2. Such a potential yield is the maximum achievable yield under the existing climate and soil conditions. There are positive and negative effects of climate change but the negative effects prevail. Table 2 shows the combined response of two crops as examples of different responses to increased CO_2 concentrations. Cereals react to increased CO_2 by a larger growth, while maize does not. A possible negative yield impact due to climate change can thus be partly offset for the first crop type by yield enhancement due to increasing CO_2. Table 2 also gives the decline in *crop extent* (the area where crops are grown now, but cannot grow in the future). Reduced soil moisture levels cause most of this decline. Crops shifting into currently unsuitable areas is also a possibility, but this is most likely to happen in up-slope mountainous areas and in northern territories – both per definition agriculturally marginal regions for other reasons. Therefore they will not be discussed here.

Regionally, there are large differences. The regional patterns indicate some of the uncertainty emerging from the analyses. Depending on the selected climate-model (GCM) result one can simulate yield increase (green in Figure 1) or decrease (red in Figure 1). However, when these impacts are aggregated globally for the different climate-model results in IMAGE 2, a much grimmer pattern emerges.

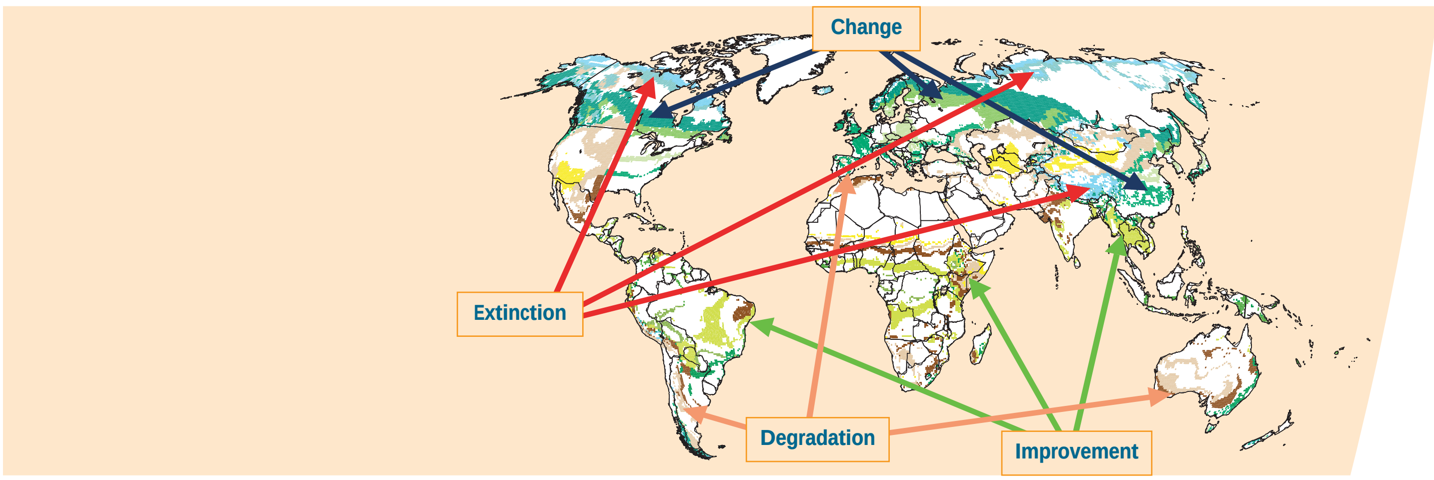
Although there is a wide range (6-14%) of simulated negative impacts for the different climate-change patterns, all show significant impacts somewhere. This addresses some aspects of uncertainty: it is difficult to project where impacts will occur, but it is virtually without doubt that in many regions impacts will emerge, even with relatively small climatic changes. While climate change will have both positive and negative impacts, the negative impacts will start to dominate when temperature increase continues.

Impacts on ecosystems

Climate is the dominant factor for the large-scale patterns and functioning of ecosystems. The cold polar and mountainous regions are characterised by low productivity tundra vegetation. More to the south, winters become milder and summers warmer. Tundra changes along this gradient into needle-leafed forests and then broad-leafed forests. Further south, moisture patterns become the dominant factor. The savannah and desert belts are characterised by strong seasonal droughts and low precipitation levels throughout the entire year respectively. Around the equator, precipitation is superfluous again, allowing for tropical rainforests to develop. Like agriculture, many relations between ecosystem properties and climate can be readily modelled. The 2nd assessment report of IPCC gives many examples.

Figure 2 shows the projected shifts in ecosystems for a global average warming of 3^{o}C. More than 40% of all ecosystems world-wide will change: tundra becomes needle-leafed forest, needle-leafed forests become broad-leafed forests, etc. Regionally, many different changes occur. Sometimes, under wet climate conditions, there is a shift from desert towards grassland, or from grassland towards forests. Here tree cover and productivity increases. In many other cases productivity remains very similar, but species composition changes considerably. Or the combined effect of increased temperature and too small an increase (or even a decrease) in precipitation even leads to ecosystem degradation and desertification: productivity declines and tree cover will be reduced. In a few

Figure 2: Impacts on ecosystems at a global average temperature increase of 3ºC. The coloured areas indicate ecosystems where climate change will cause a shift.



cases, marginal ecosystems along coasts and on mountains will completely disappear, which forms a direct threat to biodiversity.

The modern landscape is not only shaped by natural ecosystems. Currently, human land-use dominates large regions. To show the vulnerability of biodiversity in human dominated landscapes, we have plotted all large (>1000 ha) nature reserves onto the shifting ecosystems. If the current ecosystem disappears from a nature reserve, its conservation objectives cannot be achieved and it will probably become redundant. Most likely, the species characterising its original ecosystem will become extinct. Above 1.5ºC temperature increase, more than a quart of all nature reserves will be threatened. Such an analysis clearly shows the links between climate problems, biodiversity and desertification.

All these changes do not happen overnight. With time, ecosystems will adjust to the new situation. This has happened in the near and distant past. However, the currently projected rate of change is several times faster than those that occurred in the past. This could result in an increase in abundance of opportunistic species (like weeds) with wide distributions and fast dispersal rates, while the rarer species decline. Further, the transition to new conditions will generally be triggered by large-scale disturbances like fire, insect attacks and storms. Such events will rapidly (i.e. years to decades) deteriorate ecosystems and simultaneously release large quantities of CO_2 to the atmosphere. The subsequent new succession of better adapted ecosystems will proceed slowly (centuries to millennia). In general, the higher the rate of change, the lower the adaptive capability of ecosystems and the higher the probability of large scale disturbances. In IMAGE 2 at least 50% of all ecosystems seem to adapt at rates of change lower than 0.05ºC to 0.1ºC per decade. Beyond that rate the adaptation percentage rapidly declines.

2 How to implement the Kyoto Protocol?

The reduction of CO_2 emissions as agreed upon in Kyoto is an important first step in the battle to combat climate change. The implementation of the agreed reductions is of course the real challenge. Several aspects will be discussed briefly.

The importance of greenhouse gas accounting

RIVM has recently published a second report in a series of analyses on greenhouse gas emission estimates to assess the quality and uncertainty of national greenhouse gas emission inventories. Measuring greenhouse gas concentrations in the atmosphere is not the only independent method to verify inventories, because measurements and atmospheric models also contain errors and uncertainties. Comparisons with (semi)-independent inventories on national, regional and global scales can provide more insight into the quality of the inventories. Specific conclusions from the study are:

- National annual inventories from *industrialised countries* as reported in National Communications are not transparent, comparable, complete and accurate enough to assess compliance of the Kyoto Protocol.
- Precise and complete information on emissions from *non-Annex-I countries* is still missing. A lack of statistics on long-term trends and a lack of country-specific emission factors make national inventories from these countries incomplete and inaccurate, especially for agriculture, forestry and land-use change. Energy statistics are reasonably accurate but can be improved.
- Developing countries *lack adequate instruments* like basic statistics and emission factors to develop their own country-specific information.
- It is necessary to agree on a *level of detail and accuracy of reporting* the national inventories of countries. Transparency in reporting can be improved by the mandatory use of standard data tables for reporting emissions, activity data and aggregated emission factors for all sectors.

For more detailed information see RIVM report nr. 773201001, RIVM, Bilthoven.

The costs of implementing the Kyoto Protocol

One important question is: how much will the Kyoto Protocol cost? If Annex-B countries (countries agreeing to take up measures according to the Kyoto Protocol) are to achieve their emission targets entirely *at home*, global costs are likely to run up to several hundreds of billions of dollars in 2010. This would mean a reduction of consumption growth by less than 1%. Marginal abatement costs are quite high for Japan and the EU and significantly lower for the USA (Figure 3).

These compliance costs can, however, be substantially reduced using the so called Kyoto mechanisms: *joint implementation* (effectuating greenhouse gas-reduction and/or -absorption projects in another Annex-B country), *Clean Development Mechanism* (effectuating GHG-reduction projects and maybe even GHG-absorption projects in a non-Annex-B country) and *emission trading* (paying a country for "using" (part of) its permits).

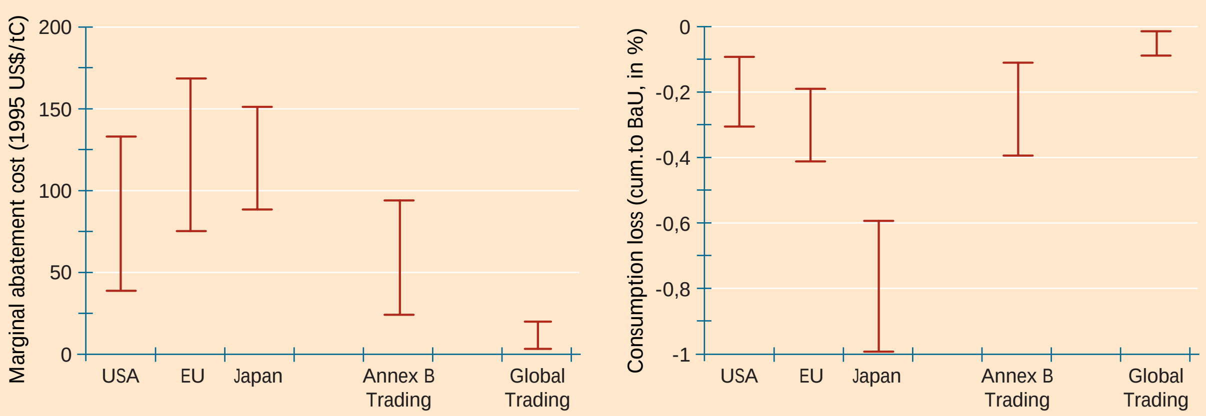
These mechanisms may lead to substantial cost savings as they allow countries to take advantage of low-cost reduction options elsewhere and abatement to be carried out where marginal costs are lowest. Figure 3 shows the effects on different countries. The range reflects the outcomes in different scenarios.

The general rule is: the more widespread this so called "where-flexibility", the lower the abatement costs. Emission trading within the Annex-B area cuts compliance costs by more than one-third. It seems that especially Japan benefits from emission trading. Increasing the where-flexibility to allow world-wide emission trading (a proxy for an ideal CDM system) leads to a further dramatic cut in carbon prices and associated costs of 80%. The unrestricted use of the Kyoto Mechanisms reduces the costs of the Kyoto Protocol substantially to a modest loss in consumption growth of only a few tenths of a percent relative to the baseline.

Carbon leakage

Using the where-flexibility through the Kyoto Mechanisms not only lowers cost, but also discourages *carbon leakage*. This phenomenon occurs as the effect of climate change policies in Annex-B countries leaks away through increasing emissions elsewhere. As energy in Annex-B countries becomes more expensive, their energy-intensive industries may relocate to non-Annex-B countries where there are no emission targets and energy is relatively cheaper (trade channel). Relatively low energy prices in these non-Annex-B countries may further cause production processes to become more energy intensive (price channel). On average, carbon leakage (the increase in emissions as a percentage of the reduction in Annex-B) may run up to about 20%. As emission trading reduces compliance costs, the distortions on energy prices are much lower. Hence carbon leakage will be more than halved.

Figure 3: The cost saving potential of emission trading (Results in 2010, based on WorldScan).



The Clean Development Mechanism (CDM), however, has a downside. CDM is particularly useful in reducing compliance costs for Annex-B countries and generating resources for non-Annex-B countries that host CDM projects. But a project-based instrument in an area with no emission targets creates several problems. It is difficult to assess whether a CDM project is really additional. Moreover, instead of reducing emmisions, CDM projects may even increase them, because energy intensive production may just shift to other places in the host country. Regional barriers in energy markets may further contribute to more energy use within the non-Annex-B region. Simulations with the economic model WorldScan suggest that CDM tends to increase carbon leakage to about 30%.

Restrictions on the Kyoto Mechanisms

A key element in the climate change discussions is the issue of restrictions on the use of the Kyoto Mechanisms. One reason for this is to reduce reliance on *hot air*, which exists if a country's emission target exceeds its projected baseline emissions, implying there would be no need for additional environmental policies. From an economic viewpoint, restricting trade is inefficient and increases global compliance costs. At the same time, it creates winners and losers, both within and outside the Annex-B area. Import restrictions would imply that importing countries will face higher costs as they have to do more domestically. Still, individual importers may actually gain from the lower permit price, because restrictions on permit imports will lead to a fall in demand and hence lower permit prices. This may be the case for the USA (Figure 4). Most OECD importers, however, are constrained and will be confronted with higher compliance costs. A similar but opposite argument holds for restrictions on permit exports. Permit prices will be higher as supply is reduced and unrestricted individual exporters may benefit. Obviously, importers will lose from the higher permit price.

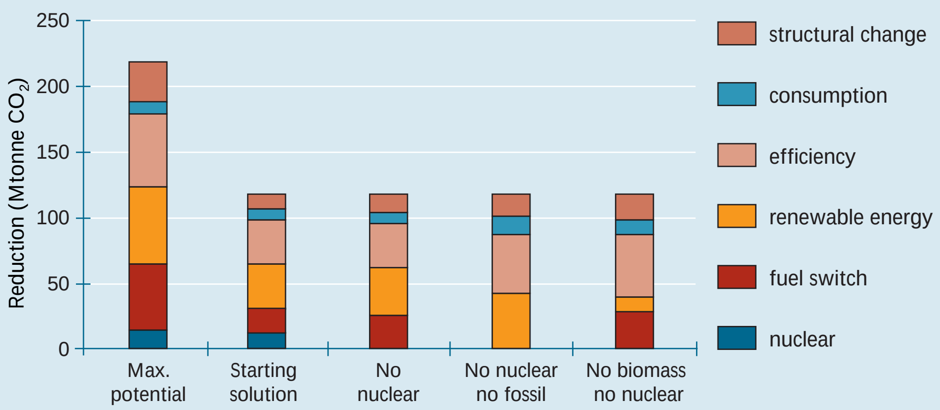
Figure 4: Possible implications of restricting the Kyoto Mechanisms (results in 2010, based on WorldScan).

Dutch perspectives on reducing greenhouse gas emissions

At the national level, as in The Netherlands, required emission reductions need to be triggered by actual measures. It is expected that in 2030 The Netherlands needs to reduce its CO_2 emissions by about 50% or 120 Mtonne compared to baseline. RIVM together with ECN has estimated the maximum potential and costs for six different perspectives for reducing CO_2 emissions as indicated in figure 5. These are based on limiting conditions, such as technology improvement, cost learning curves, availability of factors e.g. biomass and societal acceptance. The different perspectives are:

1 *Changes in the economic structure*
2 *Adaptation of behaviour/consumption patterns*
3 *Energy efficiency improvement*
4 *More use of renewable energy*
5 *Clean fossil energy sources*
6 *Nuclear energy*

Figure 5: Perspectives for reducing CO_2 emissions in the Netherlands in 2030



Based on the maximum potential of these perspectives, different packages can be constructed. The CO_2 target can be reached using 75% of each perspective (starting solution). Not using nuclear, biomass or clean-fossil energy requires a maximum utilisation of the remaining perspectives. However, this will demand a dramatic transition in the energy and mobility sectors. On average, cost-effectiveness of most perspectives are 45 to 140 Euro per tonne CO_2 avoided. Total costs of the CO_2 solutions are 0.3% to 1.5% of GDP in 2030.

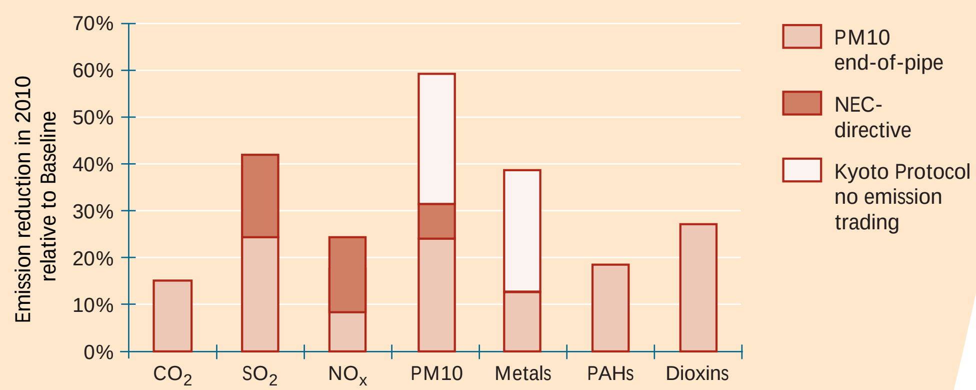
3 Synergies of climate change policy

Climate change policies produce substantial positive synergetic effects on other environmental issues. Research for the EU-15 clearly shows the benefits of an integrated approach in meeting the Kyoto Protocol commitments. Reducing CO_2 emissions by 15% compared to baseline levels in 2010 results in reductions beyond 15% for several other emissions (Figure 6).

Policy efforts to reduce CO_2 emissions contribute one third to cutting NO_x emissions and even more than half of SO_2 emissions. The synergetic effects for particulate matter (PM10) and heavy metals are relatively less but still significant. Positive synergies further occur in reducing the formation of secondary aerosols and tropospheric ozone. Without implementing the Kyoto Protocol, additional investments of at least $6 billion a year would be needed to ensure meeting the EU acidification targets.

Obviously, synergetic effects only occur if countries take domestic action. In case of emission trading, countries will not reap the full benefits of domestic environmental policies. If 50% of the European emission reduction is achieved through emission trading with other Annex-B countries (mainly from the Ukraine and Russia), the synergies will obviously be smaller, but still the reductions in SO_2 and NO_x are at 50-60% of the full synergies shown in figure 6. The explanation of the stronger effect on SO_2 is that cheap and effective policy measures, fuel switching in particular, will be taken first. These are measures that produce particular strong synergetic effects on both climate change and acidification. In general policies should be aimed at more than one pollutant at the same time to encourage measures producing the largest synergies. For example a combination of CO_2 and NO_x emission trading would encourage measures that reduce both pollutants, since companies could 'sell' the same investment twice. Generally, there will be a trade-off between cost savings from emission trading and synergies from domestic action. Interestingly, the benefits are larger than the costs, also when emmision trading would be allowed. Looking at climate change separately, benefits *only* exceed the costs if synergies are taken into account.

Figure 6: Synergies of climate change policies, assuming no emission trading and all EU-countries meet their Kyoto reduction targets. PAHs = Polycyclic Aromatic Hydrocarbons. Metals = heavy metals (lead, copper, cadmium and zinc). NEC directive: National Emissions Ceiling, an internal EU agreement. Source: RIVM et al., 2000.



4 What are effective long-term strategies to stabilise greenhouse gas concentrations?

A key policy issue is to identify long-term strategies to prevent dangerous anthropogenic interference with the climate system. One of the available tools for this purpose is the regionalised energy model TIMER. Using this model RIVM has explored various policy options to reduce CO_2 emissions for stabilising CO_2 concentrations:

- improving the end-use efficiency, that is, the amount of energy required to provide a certain energy services ("energy conservation");
- reducing energy system conversion losses, notably in the generation of electricity and the upgrading of fossil fuels;
- fuel substitution, primarily the switch from coal to crude oil products and natural gas with a lower carbon content, and to biomass-derived fuels with a close-to-zero net carbon content;
- exploitation of non-carbon energy sources, notably hydropower, nuclear fission, and wind- and solar-based electric power;
- CO_2 scrubbing, removal and storage.

Our results indicate that reducing CO_2 emissions to a stabilisation level of 450 ppm by 2100 would seem technically and economically feasible without major disruptions, starting from baseline developments in the IPCC A1B and B1 scenarios. The basic precondition is a steady increase in secondary fuel prices and a concerted effort to work towards non-carbon options. This is likely to generate sufficient cost reductions from learning-by-doing to enable a smooth transition towards a more energy-efficient, low-carbon future.

The A1B and B1 baseline scenarios

The A1B scenario depicts a world experiencing rapid economic expansion, spurred on by globalisation and rapid high-tech innovations. In this scenario CO_2 emissions peak at 21 GtC a year around 2045 (over three times the 1995-level) and then decline. The B1 scenario assumes the nature of economic activities to be less material- and energy-intensive (e.g. through more service-oriented activities as health and child care, education and information and legal services). Moreover, consumers and governments have an outspoken orientation towards sustainability and equity. The TIMER model indicates that in such cases CO_2 emissions could be much lower (about 12 GtC a year around 2040). The B1 scenario requires enormous vision, cooperation and commitment by governments and leading organisations in society. The scenario particularly emphasises the potential benefits from other environmental and socio-economic policies for climate change mitigation. However, we need to realise that for stabilising greenhouse gas emissions more effort will be required.

Timing of mitigation

One important issue for greenhouse gas reduction strategies is the timing of mitigation action. This has been debated over the last years, as some of the macro-economic models indicate that delay could be attractive from an economic point of view. The technology-oriented TIMER model, however, indicates the opposite: early action is, from a cost and climate point of view, more attractive than delayed response as it captures the full benefits of induced technological development. In addition, the inertia of societal and technical systems (e.g. the lifetime of large power plants and innovation cycles) also means that policies have to be started within the first decade of this century. However, if society prefers to use a high discount rate in the belief that productivity will keep rising quickly, then the monetarised disadvantage will be small. Simulations suggest that at discount rates above 3% a year, the difference in monetary terms between early action and delayed response may be vanishing in view of the many other uncertainties.

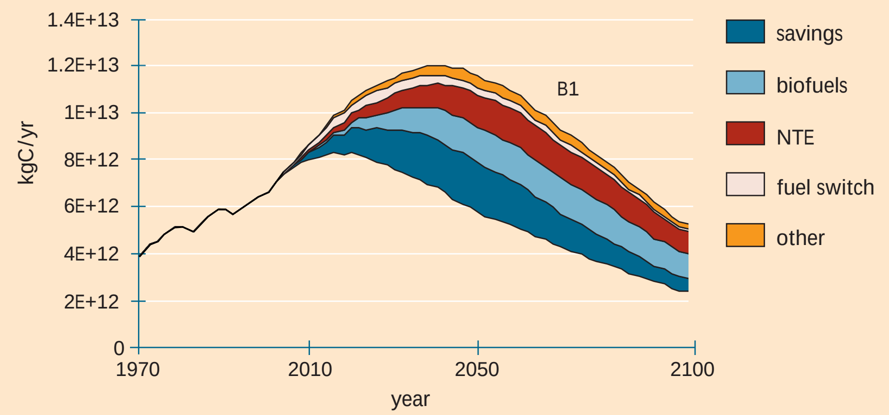
In the first and second quarters of the century most of the reduction will come from energy efficiency and fuel-switching options, while the introduction of a carbon-free supply option will later account for the bulk of required reductions. The most difficult period for long-term mitigation scenarios is the 2010-2040 period, when '"the curve" towards a lower carbon emission system will have to be initiated.

Sinks as an option for climate change policy

The Kyoto Protocol has introduced the option to achieve parts of their emission targets by taking into account carbon removals (*sinks*) by planting *Kyoto forests* as well as other land-use activities. Can these *sinks* really assist countries in fulfilling their commitments? Or do they conflict with other important policy concerns like food security and biodiversity? Our results with the IMAGE 2-model show that sinks can be an effective policy option, even without jeopardising food security. Much of this answer, however, depends on the definitions which areas are allowed to be used. Potentially, about 1-8 Mkm^2 of *Kyoto forests* can be planted up to 2100. The lower end of the range includes only *Kyoto forests* on abandoned agricultural land. These forests are initially mainly planted in Annex-B countries, but beyond 2050 land also becomes available in many non-Annex-B countries. The net contribution for reducing CO_2 concentration remains, however, limited to less than 20% of the required effort to reach a 450 ppm-CO_2 stabilisation

Figure 7: CO_2 mitigation categories – from B1 baseline scenario to a scenario that stabilises CO_2 concentration at 450 ppm.

Note: NTE = Non-thermal electricity (nuclear, solar, wind)



target, even for low baseline scenarios. Real emission reductions are needed. Significantly more land up to 8 Mkm² becomes available if *Kyoto forests* are allowed to be planted in areas currently covered by natural ecosystems, as early as 2000. More than 90% of such *Kyoto forests* would be planted outside the Annex-B area, if ARD-activities are accepted under the Clean Development Mechanism. Obviously, the potential contribution to reduce CO_2 is significantly larger. However, there may be negative consequences for biodiversity and local social structures.

The net effect further increases if products from the *Kyoto forests* are also used for the demand of either timber or biofuels. Up to 2100, the extra gain varies between 4 and 15% of the CO_2 reduction needed . In particular, using timber from *Kyoto forests* to meet the global wood demand is effective, as fewer natural forests are harvested and related carbon pools preserved.

5 What is the role of international cooperation?

To limit climate change, all countries will eventually have to participate in global greenhouse gas emissions control. Future growth of greenhouse gas emissions will take place primarily in developing countries; their share is likely to outgrow that of the developed world within a few decades. It will take longer, however, before their contribution to concentration levels or temperature increase will be equal. Their per capita emissions level will remain much lower for an even longer period of time. An important question therefore is how to foster international cooperation for realising a fair contribution by developed and developing countries to global emissions control.

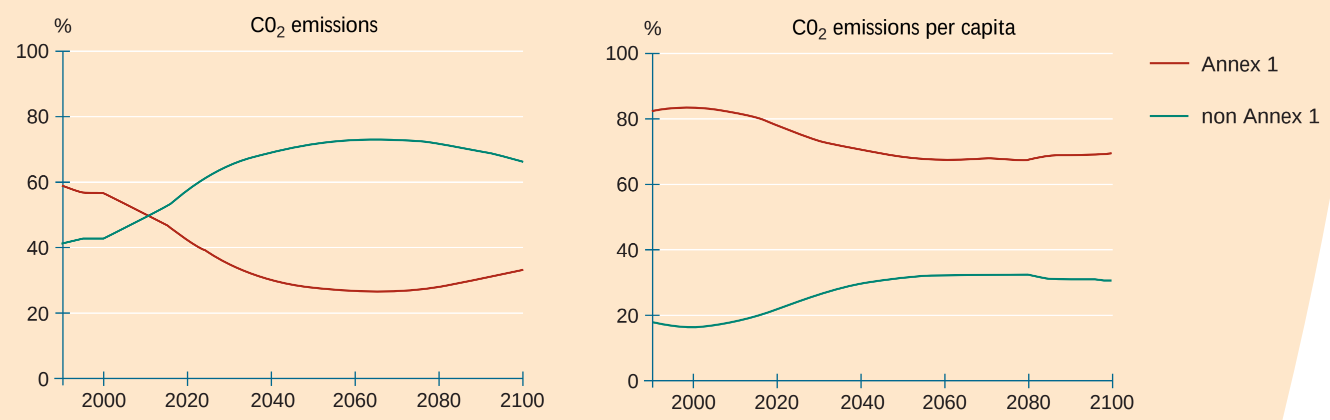
Article 3 of the Climate Convention states three major elements for defining a fair differentiation of future commitments: responsibility, capability and equity.[1]

[1] "… parties should protect the climate system for the benefit of present and future generations, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities…"

Responsibility: the Brazilian proposal

A country's responsibility for human-induced climate change is closely related to the "polluter-pays principle": the greater one's contribution to the problem, the greater one's share of the burden. It can be expressed by different indicators (see for instance the indicators in figure 8). Using an indicator later in the cause-effect chain, like the contribution to the realised temperature increase instead of emissions, is favourable to developing countries. However, the inclusion of all greenhouse gases and land-use emissions can have opposite effects. Indicators accounting for historical emissions and/or based on per capita approach are also favourable to developing countries.
During the negotiation on the Kyoto Protocol Brazil proposed to distribute Annex-I commitments on the basis of a country's relative share in realised global temperature increase, thus taking into account historical emissions. If this approach were to be applied at a global level (e.g. after 2012), all countries, including developing countries, would have to start contributing to global reduction, regardless of their level of economic development. This would contradict the principles of capability and equity. Thus, there is a need for a threshold for participation in global emission control.

Figure 8: Indicators for the contribution of Annex 1 and non Annex 1 countries.



The FAIR model (Framework to Assess International Regimes for differentiation of commitments) is an interactive model to quantitatively explore a wide range of climate policy options for international differentiation of future commitments in relation to targets for global climate protection. The model includes three approaches for evaluating international commitment regimes:

- *Increasing participation:* the number of parties involved and their level of commitment gradually increase according to participation and differentiation rules, such as per capita income, per capita emissions, or contribution to global warming.
- *Convergence:* all parties participate in the burden-sharing regime with emission rights converging to equal per capita levels over time.
- *Triptych:* different burden-sharing rules are applied for different sectors (e.g. convergence of per capita emissions in the domestic sector, efficiency and de-carbonisation targets for the industry sector and the power generation sector).

The first two options are top-down methodologies from global emission ceilings to regional emission budgets. The triptych approach is bottom-up in character, although it can be combined with specific emission targets. To construct and evaluate global emission profiles, the FAIR model also offers the following option:

- *Scenario construction:* to scan and evaluate the climate impacts of a self constructed or pre-defined global emissions profiles.

For more information on the FAIR-model, see Den Elzen et al. (2000).
Or visit our website http://www.rivm.nl/fair/ and download the free FAIR software

Combining responsibility with capability and equity

To respect the need and the right to development, participation to a global climate change regime needs to be based on a threshold. But what type of threshold should this be and at what level would it be fair to demand commitments of developing countries? A possible threshold is per capita income. Required threshold levels will depend on the stringency of global climate targets. Long-term climate targets, like stabilising global CO_2 concentrations well below a doubling of pre-industrial levels (e.g. 450-550 ppm) near the end of the century, requires early participation by developing contries like China and India. Per capita income thresholds (e.g. based on middle income developing countries) that are too high, will make such climate goals unfeasible, even with baseline scenarios assuming a relative closing of the income gap between industrialised and developing countries.

Differentiating commitments: a multi-stage approach

A multi-stage approach combines early participation of developing countries with differentiation of the level of participation to allow for economic development. This approach can be illustrated with the FAIR-model for the following simple case:

- until 2012 Annex-B countries fulfill their targets under the Kyoto Protocol;
- after 2012 all non-Annex-B countries adopt de-carbonisation targets (reducing the carbon intensity of their economic development, not limiting economic development itself);
- non-Annex-B countries become full members when per capita emissions equal world average;
- Annex-B countries share the burden of limiting global emissions below the ceiling for stabilising CO_2 concentration at 450 ppm, in proportion to per capita CO_2 emission levels.

The use of a participation threshold based on world average per capita emissions rewards both emission reductions by the industrialised countries as well as efforts by developing countries to control their emissions growth. In this case Latin America would participate in the climate regime from the second commitment period onwards, while China, India and Africa would be allowed to increase their emissions until 2025, 2030 and 2040 respectively. At the same time, the emission space for the EU, Japan and in particular the USA would diminish sharply (Figure 9).

Combining equity and capability: the convergence approach

An alternative towards developing countries participation is the *convergence approach*. It starts from the idea that the atmosphere is a global common to which each human is, in principle, equally entitled. Differentiation of future commitments should thus be based on an equitable allocation of emission rights. In order to allow developed countries to adapt, there is a transition period in which per capita emission rights converge to equal levels.
Under a global emission profile for stabilising CO_2 concentrations at 450 ppm,

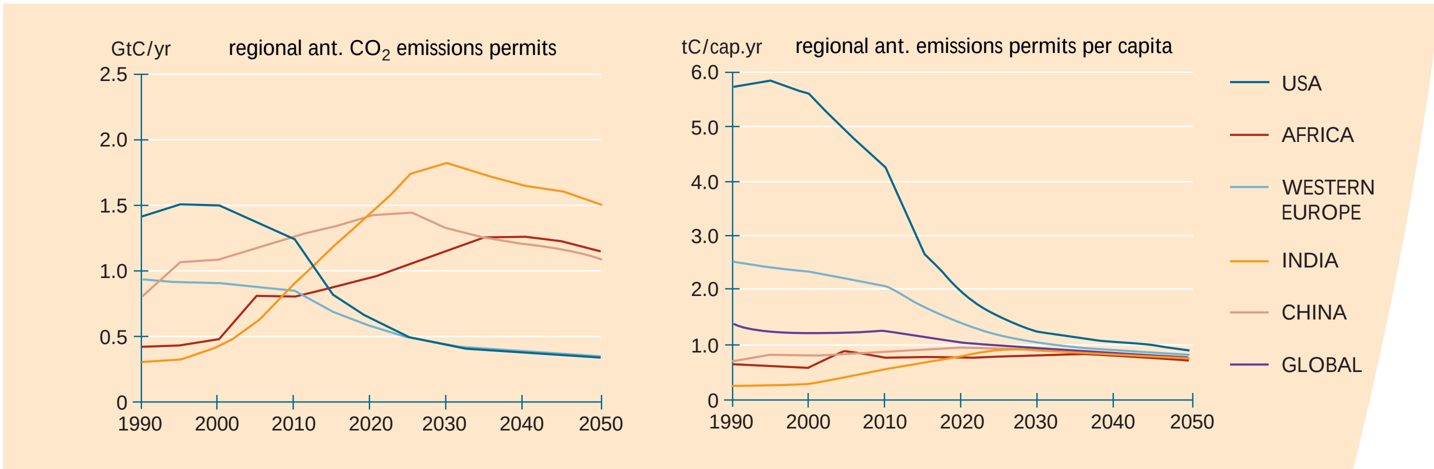


Figure 9: *Regional absolute and per capita emission space under a multi-stage regime with a CO_2 emission profile for stabilising CO_2 concentrations at 450 ppm with de-carbonisation targets for non-Annex-B countries after 2012, world average CO_2 emissions as participation threshold and burden sharing based on per capita CO_2 emissions*

convergence in per capita emission rights implies a strong reduction in allowable emissions for Annex-B regions after the Kyoto period, in particular for North-America and Oceania. At the same time, there is only limited scope for non-Annex-B regions to increase their per capita emissions and in fact, in case of Latin America, emissions are already decreasing. In some developing regions, like India and Africa, emission rights may exceed baseline levels (Figure 10). Over the long term, after full convergence in emission rights, the gap between baseline emission projections and emission rights is usually larger for developing than developed countries.

Emission rights, real emissions and economic impacts

The adoption of the Kyoto Mechanisms has drastically changed the setting for discussing the economic impacts and efficiency of various regimes for differentiation of future commitments. Due to these mechanisms real emissions no longer need to be the same as allowed emissions or emission rights. In principle, their introduction has offered the possibility of attaining a high level of economic efficiency regardless of the differentiation arrangement.

A convergence regime offers the best opportunities to maximise the cost-reducing options as all parties can fully participate in global emission trading. Developing countries may receive more rights than their actual emissions, but this will not affect the effectiveness nor the efficiency of the regime, only the distribution of costs. Second, there will be no carbon leakage to countries without emission targets. Possible problems with a convergence approach may be that countries that benefit from emission trading under the Kyoto Protocol, like Russia, may lose their markets once developing countries join the global regime. The most difficult problem will be the political acceptance of the per capita emission allowance concept, in particular by countries with high per capita emissions.

In a multi-stage approach, countries adopting de-carbonisation targets may also join emission trading as far as their improvements exceed their targets. However,

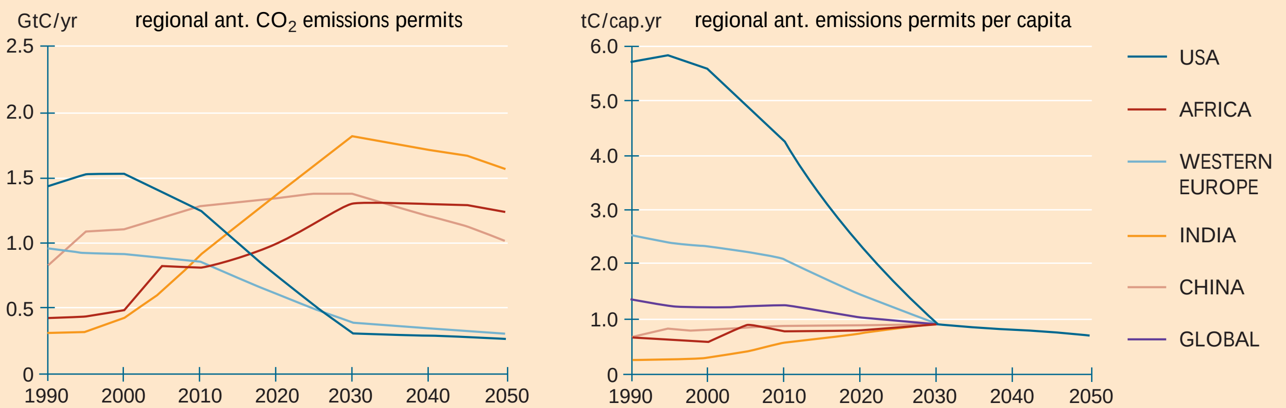


Figure 10: *Regional absolute and per capita emission space with a linear convergence of CO_2 emission rights between 2012 and 2030 under an emission profile for stabilising CO_2 concentrations at 450 ppm.*

over time, this could result in complex accounting and target setting for each subsequent commitment period, because real values will have to be corrected for emission reductions sold to other parties. Clearly, a multi-stage regime using activity-based approaches offers more flexibility in accounting for national circumstances than the convergence approach. The Kyoto Mechanisms have, however, considerably reduced the need for this flexibility. Least developed countries may be given more emission rights than their actual emissions, allowing them to pursue sustainable development.

From the perspective of the least developed countries, the convergence approach is more attractive than other approaches and also to the situation under the Kyoto Protocol. They will hardly profit from the CDM, because they have limited reduction options to offer. Under a multi-stage regime, developing countries taking on quantified commitments will have to pay for their own efforts and can only sell what they do in excess of their commitments. This raises the question if this approach is sufficiently attractive compared to attracting investments under the CDM. A convergence regime in which the least developed countries may be given more emission rights than their actual emissions, allowing them to pursue sustainable development, might therefore be attractive.

To conclude: the adequacy of a future regime for differentiation of commitments is related to the strictness of the climate targets. In the case of strict climate targets, a convergence approach would seem to offer good opportunities for securing a timely participation of developing countries and an effective and efficient regime for controlling global greenhouse gas emissions.

Further reading

On costs and the Kyoto Mechanisms:
* Bollen, J.C, A. Gielen, H. Timmer (1999), '*Clubs, ceilings and CDM: macro-economics of Compliance with the Kyoto Protocol*', in The Costs of the Kyoto Protocol: a multi-model evaluation, Special Issue of the Energy Journal, pp. 177-206, International Association for Energy Economics.

On FAIR and building partnerships:
* Elzen, M.G.J. den, M. Berk, S. Both, A. Faber and R. Oostenrijk (2000), '*FAIR 1.0: An interactive model to explore options for differentiation of future commitments in international climate policy making*', report nr. 728001013, RIVM National Institute of Public Health and the Environment, Bilthoven, The Netherlands.

On synergies:
* RIVM, EFTEC, NTUA, IIASA (in prep), '*European Environmental Priorities: an Integrated Economic and Environmental Assessment*', report nr. 481505010, RIVM National Institute of Public Health and the Environment, Bilthoven, The Netherlands.

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On mitigation scenarios
* Van Vuuren, D.P. and H.J.M. de Vries (2000), '*Mitigation scenarios in a world oriented at sustainable development: the role of technology, efficiency and timing*', report nr. 490200 001, RIVM National Institute of Public Health and the Environment, Bilthoven, The Netherlands.

On IMAGE
* Alcamo, J., R. Leemans and E. Kreileman (1998), '*Global change scenarios of the 21st century. Results from the IMAGE 2.1 model*', Pergamon & Elseviers Science, London.

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