GREENHOUSE GAS REDUCTION PATHWAYS IN THE UNFCCC PROCESS UP TO 2025

– POLICYMAKERS SUMMARY –

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– *TABLE OF CONTENTS* –

Executive summary

The need for further action

The long-term objective of the European Union climate policy is to prevent global mean temperature rising by more than 2°C over pre-industrial levels. Without policy induced constraints this target will be missed by a substantial margin. According to model-based estimates and projections, if no further action to control emissions is taken concentrations of greenhouse gas in the atmosphere may increase from 425 parts per million volume (ppmv) CO_2-equivalent today to 935 ppmv CO_2-equivalent in 2100. This could cause global temperature to rise by more than 3°C by 2100.

To explore the implications of the EU climate target, two constrained global emission profiles have been developed. They correspond to stabilising the total greenhouse gas concentration at levels of 550 and 650 ppmv in CO_2 equivalent, for the set of six greenhouse gases covered by the Kyoto Protocol. These profiles are hereafter referred to as S550e and S650e.

The range of the temperature rise associated with these two emission profiles depends on the uncertainty about the 'climate sensitivity' parameter, which is defined as the global average temperature rise resulting from doubling CO_2 concentrations. The Intergovernmental Panel on Climate Change (IPCC) estimates the range of the climate sensitivity to be from 1.5 to 4.5°C, with a median value of 2.5°C.

Using this uncertainty range, the S550e profile will result in a global mean temperature rise of less than 2°C for a low to median value of the climate sensitivity. The S650e profile only stays below this value if the climate sensitivity is at the low end of the range. This means that this profile is less likely to meet the EU target. If the climate sensitivity is high, the EU target will not be met in either profile.

The profiles clearly differ in the timing and level of the emission reductions needed. Global emissions must peak as soon as 2015-2020 under the S550e profile, and around 2030 in the S650e profile. Delaying emission reductions would imply very steep global reductions later or overshooting the targeted concentration levels, leading to a bigger rise in temperature.

The abatement effort required in the constrained profiles may be measured by the percentage change in anthropogenic greenhouse gas emissions from their 1990 level, and from the baseline projection (that is, the levels they would have reached without specific abatement actions). For greenhouse gas emissions from energy use and industrial processes this implies:

- In 2025 global emission levels can still rise about 20% above 1990 levels in the S550e profile, but this already implies reducing emissions by one third compared to the baseline projection. In the S650e profile, the reduction compared to the baseline is smaller, but still significant, at around 15%.
- In 2050 emissions have to be reduced strongly in the S550e profile, not only compared to the baseline level (65%), but also compared to 1990 levels (15%). In contrast, in S650e, greenhouse gas emissions can still be 50% above their 1990 level by 2050. However, compared to the baseline, global emissions need to be reduced by about 35%.

Options for the future architecture of international climate policies

The changes in emission trajectories that are required to meet the EU climate objective will require strong emission reductions. The Kyoto Protocol is a very first step in climate policies and does not set out a long-term emission profile. However, approaches based on binding quantified emission targets combined with mechanisms to implement these targets flexibly, such as the Kyoto Protocol, provide an effective and efficient incentive structure for implementing the reductions needed.

Proposals for other types of targets, such as technology standards or voluntary efficiency targets, have been made as well, but these give less certainty about meeting the level of reductions needed. It is clear that after 2012, the climate change commitments under the UNFCCC must be deepened and broadened. This raises the question of how to do this in a fair and acceptable way, particularly given the need for economic development in different parts of the world.

Equity principles usually refer to general concepts of distributive justice or fairness. Among the key principles explored or invoked in the international climate negotiations up to now, one can identify:

- *Egalitarian:* each human being has an equal right to use the atmosphere.
- *Sovereignty and acquired rights:* all countries have a right to use the atmosphere and current emissions constitute a 'status quo right'.
- *Responsibility / polluter pays:* the greater the contribution to the problem, the greater the share in the mitigation / economic burden.
- *Capability:* the greater the capacity to act or ability to pay, the greater the share in the mitigation / economic burden.

Another key aspect characterising climate policy architectures is whether all Parties participate immediately (after 2012) with simultaneously defined endowments related to a long-term global emission profile, or if the number of participants and the stringency of their commitments is gradually increased. The international architecture may thus develop in two different directions:

- A set of rules or targets that define how all Parties' emission quotas develop over a long period. This type of regime may be called a *'full participation*' regime.
- An incremental but rule-based approach to extending the climate regime, with a gradual expansion of the Annex I group of countries adopting binding quantified emission limitation or reduction objectives, whether absolute or dynamic. This type of regime may be called an *'increasing participation*' or – when including multiple thresholds – *'multi-stage'* regime.

This study of international commitment schemes has included a first exploratory phase, and a second more in-depth analysis of a limited number of solutions, deemed as representative of the 'full-participation' and 'multi-stage' approaches.

In the first phase, three 'full participation' regimes – described as Per Capita Convergence, Soft Landing and Global Preference Score – and three 'increasing participation' regimes – described as the Brazilian proposal, Ability To Pay, and Multi-Stage – were examined. This preliminary exercise pointed at different strengths and weaknesses of the various approaches.

Two schemes which proved to be sufficiently generic and robust were then selected for further analysis: the Per Capita Convergence, representing a 'full participation' option, and the Multi-Stage (MS), representing an 'increasing participation' option. For each scheme, different variants were evaluated under the two global emissions profiles described above, S550e and S650e.

For the Per Capita Convergence scheme, two alternative time-horizons for convergence in per capita emissions – 2050 and 2100 – have been considered, to describe two cases that impose different constraints on Annex I countries in the short to medium term: these are the Per Capita Convergence-2050 and Per Capita Convergence-2100 cases.

Three alternative cases were developed for the 'Multi-Stage' approach. All are based on the same definition of the consecutive stages for the commitments of non-Annex I countries: Stage 1 – no commitment, Stage 2 – emission limitation targets, and Stage 3 – absolute emission reduction targets. The threshold used for the transition from Stage 1 to Stage 2 is also common to all three cases and is based on a 'Capacity-Responsibility index', defined as the sum of per capita GDP and per capita emissions in each region. The three cases – Multi-Stage 1, Multi-Stage 2 and Multi-Stage 3 – differ in the way the transition from Stage 2 to Stage 3 is made: in Multi-Stage 1 the corresponding threshold is based on world average per capita emissions; in Multi-Stage 2 it is based on a second Capacity-Responsibility index, while in Multi-Stage 3 the transition is based on differentiated transition periods to stabilise emissions.

Assessment of the emission profiles and endowment schemes

The different schemes for international commitments can be analysed and assessed either from the perspective of endowments, where relevant indicators are used to compare changes in emission endowments in the different regions of the World, or from the perspective of outcomes, where the consequences of the emission constraints in terms of the costs implied by the adjustments needed in the technical and economic systems are compared.

The ratio of endowments to base year emissions does not say much about the effort required from the different Parties, as this mainly depends on the likely growth of emissions without a constraint. The 'endowment to baseline' ratio, although it depends on the no-constraint projection and thus cannot be observed directly, gives a more relevant basis to assess the international acceptability of different climate architectures.

A first general conclusion from the analysis is that the Annex I countries' endowments for the different Multi-Stage variants and the Per Capita Convergence-2050 case are broadly similar. By 2025 the assigned amounts of all Annex I regions are about 40-60% below the baseline in the S550e profile and 15-40% in the S650e profile. In 2050, reductions are about 80% to 50% in S550e and S650e respectively. Of the Multi-Stage scenarios, the Multi-Stage 3 variant implies the largest reductions in the short-term in Annex I. By contrast, the Per Capita Convergence-2100 case requires substantially smaller reductions in the Annex I countries than all the other cases.

The endowments for non-Annex I regions that result from the various scenarios are quite sensitive to particular assumptions, such as participation thresholds and the global emission profile. No general conclusion for this group can be drawn. Under the S550e profile, the Multi-Stage 3 variant tends to result in fewer reductions in the more developed non-Annex I regions, while the Multi-Stage 2 case requires the least efforts in the least developed regions. Under the S650e profile, the results of the different variants are quite similar in the short term (2025) due to the late participation of most non-Annex I regions. In the South East & East Asia regions and in particular China, the Per Capita Convergence approaches lead to large reductions under both profiles, due to relatively high per capita emissions.

The economic implications of the different schemes have been assessed using partial equilibrium and general equilibrium analyses. The former approach analyses the costs of domestic abatement and of emission trading resulting from the regional allocation of emissions according to the various endowment schemes. The latter approach also considers the macro-economic costs implied by the adjustments needed to the technical and economic systems. This approach thus also takes into account changes in sector activity levels and international trade due to emission constraints.

All calculations assume least-cost implementation, based on international emission trading. This implies that the reduction options implemented and the global costs are largely independent of the emission endowment schemes. However, the costs for the different regions will of course crucially depend on the rules adopted for the commitments of each Party.

The global mitigation costs of meeting the S550e profile are much higher than for S650e. Both profiles will, however, require major changes in world energy consumption and other greenhouse gas emitting activities. They will also induce new dynamics in using and diffusing new technologies, not only in the energy sector, but also in industry and agriculture. These changes all contribute to the costs of mitigation. As expected, the energy sectors play the most important role in the adjustment at world level. The key impacts on these sectors come from reduced overall energy consumption and substituting carbon intensive fuels by non-fossil energy sources. Apart from the energy sector, energy intensive activities contribute most to the economic adjustment.

The combination of baseline emission projections in each region, endowments as provided in the different cases and the carbon value that emerges from international trade in emission quotas, produces a value that represents a transfer of income from net buyers to net sellers of quotas. The size of this transfer represents the economic constraint imposed on the different regions, which finally determines the welfare implications of the different scenarios.

There are, however, exceptions to the correlation between quota trade and welfare changes. The most notable is the Middle East, which registers the biggest welfare losses. This is mainly due to a deterioration of the terms of trade due to lower export revenues from crude oil. Conversely, the region that benefits most in terms of welfare is the South Asia region. Because of relatively abundant endowments, it is a net exporter of quota in all cases. High positive welfare impacts are also present in the other Asian regions, while the outcomes for Africa are to some extent negatively influenced by the presence in the region of large oil producers and exporters.

The key conclusions are:

- Introducing flexibility mechanisms, such as international emission trading, not only allows the costs of abatement policies to be limited, it also makes this cost in principle independent of the endowment schemes.
- The cost of achieving the reductions (in terms of world GDP) ranges between -0.7 and -0.9 % in 2025 in the S650e profile and from -1.9 to -2.8 % in the S550e profile.
- The Multi-Stage schemes provide better welfare prospects for the developing regions in both profiles as they imply higher income transfers in 2025.

Co-benefits of climate policies: the case of regional air pollution

The mitigation scenarios have very considerable potential co-benefits. The significant changes in energy consumption and in the energy system that would result from abatement actions may have significant side effects, in particular for emissions of regional air pollutants.

Many air pollutants and greenhouse gases have common sources, their emissions interact in the atmosphere and, separately or jointly, they cause a variety of environmental effects at the local, regional and global scales. Thus, emission control strategies that simultaneously address air pollutants and greenhouse gases may improve environmental quality at all scales.

Currently, both climate change policies and air quality control are still relatively marginal issues in most low-income countries, particularly compared with issues such as poverty eradication, or food, water and energy supply. To curb the risks of fast growing emissions of both air pollutants and greenhouse gases in these countries, use could be made of synergies between sustainable development targets and climate change.

Implementing accelerated sustainable development strategies that would also include climate change mitigation could in this way become a common target for both developing and industrialised countries.

The constrained emission profiles show significant reductions compared to the baseline in global sulphur and nitrogen oxides emissions as a side effect of climate policies. The S650e profile leads to worldwide reductions from the baseline of 50% and 35% in sulphur and nitrogen oxide emissions, respectively. The S550e profile leads to even larger reductions, 70% and 50%.

These results can also be analysed region-by-region showing that co-benefits occur in all regions. However, as emissions of both sulphur and nitrogen oxides are comparatively larger in the low-income regions as a result of currently less strict air pollution control policies, the co-benefits are more important in these regions: in particular, the baseline emissions of the Asian regions become very important in 2025 and 2050 and would thus incur significant reductions.

All studies undertaken so far show that links between climate and air quality policies are important. Their direct impact seems to be significant, but they are also highly relevant for policy design. Economic studies of the co-benefits of greenhouse gas mitigation suggest that the avoided damages may compensate for a significant part of the costs of reducing emissions. The constrained emission profiles considered here may significantly increase the likelihood of reducing regional air pollution and meeting higher urban air quality standards by 2025, and in the longer term.

Conclusions

Meeting the EU objective to limit the global average temperature rise to 2 °C above pre-industrial levels requires global greenhouse gas emissions to peak within the next two decades under a medium value of the climate sensitivity. This means that early participation of developing countries in global emission control is needed, even if the Annex I countries significantly strengthen their commitments.

It is possible to design a set of consistent rules to attribute long-term emission endowments to the different world regions. The gains from participating in global emission trading and from reduced air pollution damage and/or abatement costs can make early participation of developing countries in global greenhouse gas emission control attractive, provided that the level and form of the commitment are well designed.

In evaluating the equity implications of various regimes to differentiate future commitments, the study shows that it is not sufficient to evaluate *ex-ante* the allocation of the emissions compared to baseline. It also requires *ex-post* assessment of the impacts due to emission trading and the impacts resulting from changes in energy trade and from other macro-economic adjustments. To avoid excessive burdens that would be politically unacceptable for some regions, these impacts should be taken into account in the allocation process.

Because the Multi-Stage schemes include the possibility of different types of commitments for regions with different levels of wealth and intensity of emissions, they may probably be considered as good candidates to form the basis of the long-term international climate architecture that is yet to be developed.

These post-Kyoto architectures would probably provide the right combination of information, incentive and constraint that will stimulate development of new low greenhouse gas technologies. Due to the significant co-benefits of mitigation, they would also create a powerful support for sustainable development strategies in the developing world.

The options identified have undergone some initial assessment, mainly in quantitative terms and emphasising economic aspects. As a next step, the approaches deemed promising need to be analysed in a more detailed and refined way, including issues of practical feasibility such as data needs and availability, or implementation and control conditions.

*G*REENHOUSE GAS *R*EDUCTION *P*ATHWAYS IN THE *UNFCCC* *P*ROCESS UP TO *2025*

To prevent potentially dangerous changes in the earth's climate, further international action is required, beyond the Kyoto Protocol's time-horizon. This summary describes the results of a research project in which different possible climate regimes and greenhouse gas reduction targets have been explored. The full results of this study are described in the 'Greenhouse gas Reduction Pathways' Technical Report. The study has developed along the following lines:

- Identifying the global emission targets that could stabilise atmospheric greenhouse gas concentrations and limit the rise in global mean temperature to 2°C compared to pre-industrial levels.
- Reviewing the different principles and commitment schemes that are currently discussed to derive regional emission targets for 2025 and 2050.
- Further developing two selected commitment schemes, the Per Capita Convergence approach and the Multi-Stage approach, while respecting the two global emission profiles.
- Evaluating variants of the two selected commitment schemes in more detail. This has been done by assessing the regional abatement costs using abatement costs-based approaches with emission trading and by assessing the macro-economic impacts under a general equilibrium framework.
- Identifying the main co-benefits that would result from the abatement actions, in particular air quality improvement in developing regions.

The need for further action

The EU Council indicated in 1996 that the long-term objective of the European Union climate policy is to prevent global mean temperature rising by more than 2°C over its pre-industrial level. It is clear that if current trends in world greenhouse gas emissions continue, the temperature rise will probably substantially exceed that goal. Further action – beyond the Kyoto emission limitation or reduction objectives – is therefore required.

Identifying options to meet this EU climate target and assessing their economic consequences requires both a consistent baseline projection that reflects *what may happen if no further action were taken,* and greenhouse gas emission profiles that will stabilise greenhouse gas concentrations.

In this study, two constrained emission profiles have been developed and analysed to assess the feasibility and costs of the EU climate policy target against the baseline scenario. They represent different levels of ambition for international climate policies, as they correspond to stabilising the atmospheric concentration of greenhouse gases at levels of 550 and 650 parts per million volume (ppmv) CO_2-equivalent, accounting for the six greenhouse gas covered under the Kyoto Protocol: CO_2, CH_4, N_2O, HFC, PFC and SF_6.

World greenhouse gas emissions, if unconstrained, lead to levels of concentrations that are inconsistent with the EU climate target

The dynamics of unconstrained global greenhouse gas emissions result from developments in population and economic growth in the different regions of the world, and from the non-climate related environmental constraints such as energy resources or land availability up to 2100.

The scenario pictures a world in which globalisation and technological development continue to be the driving forces of economic development. Low-income regions generally grow faster than high-income regions, so the relative gap between these two groups narrows over time. However, in the next decades, the conditions of institutional development and stability that are necessary for sustained economic growth are not fully met in all regions. These barriers to economic development are progressively removed, so that after 2025 all developing regions are assumed to have taken off in terms of economic development.

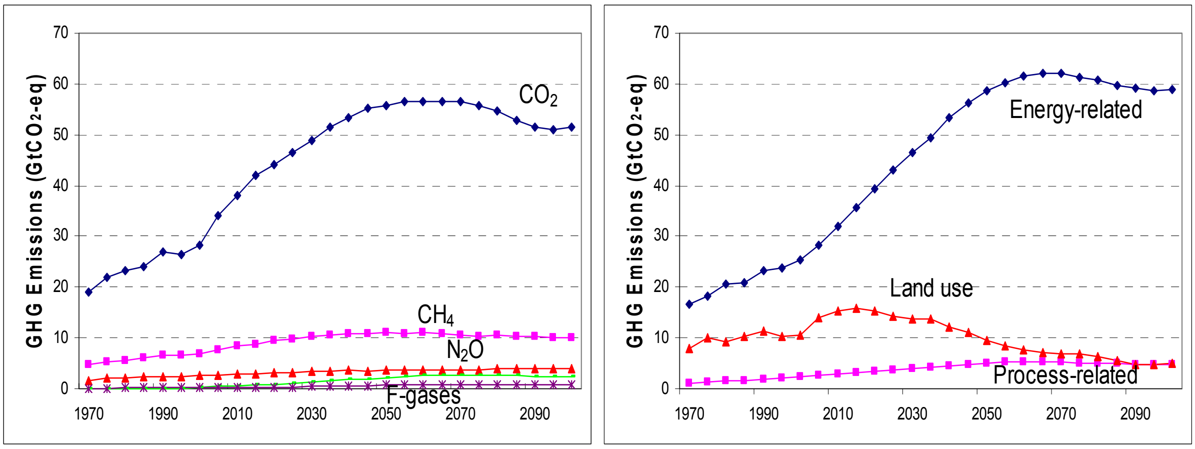
Further key elements of the projected baseline are:

- In line with the United Nations' "medium projection", world total population will increase from the current 6 billion to nearly 8 billion in 2025 and then 9 billion in 2050, before stabilising at 9.5 billion by 2100.
- World average per capita income will increase by 2-2.5% per year, from the current 4 900€/pc to 9 100 and 14 400 €/pc, in 2025 and 2050 respectively (in 1999 constant Euros).
- Total primary energy use increases by about 75% between 2000 and 2025 and by another 40% in the 2025-2050 period. Most of this growth occurs in the Kyoto Protocol's non-Annex I regions. Oil continues to be the most important energy carrier until 2040. After 2040, both natural gas and coal take over its position.

The resulting picture for CO_2 emissions is:

- Energy-related carbon dioxide emissions increase strongly from 21.6 $GtCO_2$ in 2000 to 39.5 $GtCO_2$ in 2025 and 55 $GtCO_2$ in 2050; they continue to be the dominant source of greenhouse gas emissions. This emission increase lies between that of the B2 and A1b scenarios described in the Special Report on Emission Scenarios of the Intergovernmental Panel on Climate Change.
- The share of non-Annex I countries in energy-related carbon dioxide emissions increases from 37% in 1995 to 45% in 2025 and 66% in 2050.
- After 2050, however, the stabilisation in population slows further growth of carbon dioxide emissions.

Figure 1: Greenhouse gas emission in carbon-equivalents by gas (left) and sector (right)



Source: IMAGE 2.2

Total greenhouse gas emissions (including land use related emissions and non-CO_2 greenhouse gases) increase significantly until 2060, thereafter emissions stabilise and then fall slightly (Figure 1). Within this global profile, the share of non-Annex I countries in total emissions is higher than for CO_2 only and increases rapidly, from 48% in 1995 to 71% in 2050. This is because:

- Population growth and the shift to higher grade diets lead to a significant need for additional agricultural land in the first half of the century, in spite of improving agricultural productivity.
- After 2050, further productivity gains result in an excess of agricultural land in high-income regions, which can be converted into forest land. As a result, carbon dioxide emissions from land use increase slightly between 1995 and 2040, but decrease afterwards.
- Most of the land use related emissions come from developing regions, due to population growth. As a key result, the share of non-Annex I in total anthropogenic greenhouse gas emissions is larger than that of energy-related CO_2 emissions.

- Methane and nitrous oxide emissions increase until 2060, and thereafter remain approximately constant.
- Finally, industrial emissions, including in particular the high-GWP gases and carbon dioxide process emissions from cement production and feedstocks increase only slowly over the whole century and remain relatively small compared to other sources.

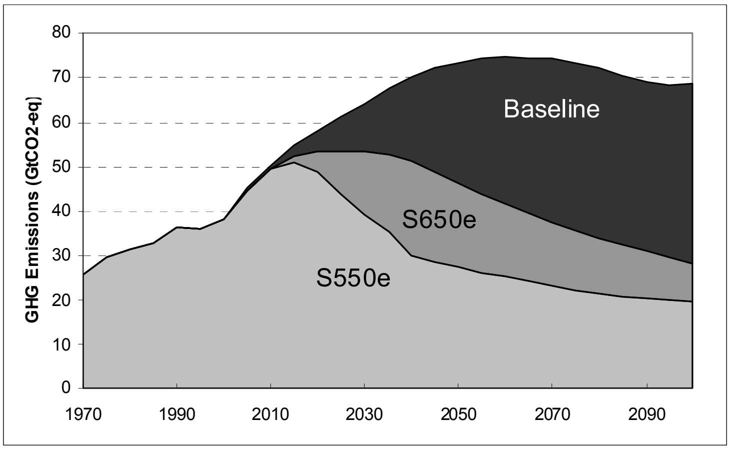
This baseline scenario results in a strong increase in greenhouse gas concentration levels. The CO_2 concentration increases from 370 today to 700 ppmv in 2100. The concentration of all greenhouse gases increases from 425 to 935 ppmv CO_2-equiv. This results in a projected temperature rise of more than 3°C in 2100, and which is still rapidly rising at that time, supposing a median climate sensitivity. Given the EU target to limit the global temperature rise to 2°C, this clearly demonstrates the need for long-term, global action to curb world greenhouse gas emissions.

Stabilising greenhouse gas concentrations at levels meeting the EU target implies substantial changes in emissions immediately after 2010

To explore the implications of the EU climate target, two constrained global emission profiles were developed. They correspond to stabilising total greenhouse gas concentrations at levels of 550 and 650 ppmv in CO_2 equivalent respectively, for the set of six greenhouse gases considered in the Kyoto Protocol, and are hereafter referred to as S550e and S650e. These levels are more or less consistent with stabilising concentrations of CO_2 only at about 450 and 550 ppmv. The multi-gas abatement analysis in this study only considers the global CO_2 equivalent profiles.

Up to 2010, the constrained emission profiles take into account the Annex I Kyoto Protocol targets and the proposed emission intensity targets for the USA. The profiles also assume that the major part of the excess emission quotas in the hands of some Annex I countries is banked for use in the following periods. Non-Annex I countries are assumed to emit according to their baseline in this initial period. After 2010, the emission profiles are designed in such a way that they meet the long-term stabilisation targets (Figure 2).

Figure 2: Global emission profiles for stabilising greenhouse gas concentrations at 550 ppmv (left) and 650 ppmv (right), CO_2 equivalent



Source: IMAGE 2.2

In the S550e and S650e profiles depicted in Figure 2, greenhouse gas emissions continue to rise in the first decades of the simulation. However, after this initial period emissions need to be reduced. By the end of the century, the S650e profile requires a reduction of about 50% compared to baseline; the S550e profile requires a reduction of about 70%.

In the S650e case there is some flexibility in the timing of emission reductions. Flexibility is very limited in the S550e case, as this target requires reductions from 2020 onwards. When compared with the profiles published by IPCC for stabilising CO_2 concentrations, it is clear that on-going climate policies up to 2010 already delay global emission reduction efforts (Table 1). Further postponing emission reductions would imply steeper global emission reductions later in the century, or an overshooting of the targeted concentration levels.

Table 1: Conditions for stabilising CO_2 concentrations (from IPCC 2001)

WRE CO2 Stabilisation Profiles (ppmv)	Accumulated CO2 emissions 2001 to 2100 (GtC)	Year in which global emissions peak	Year in which global emissions fall below 1990 level
450	365 - 735	2005 - 2015	< 2000 - 2040
550	590 - 1135	2020 - 2030	2030 - 2100
650	735 - 1370	2030 - 2045	2055 - 2145
750	820 - 1500	2040 - 2060	2080 - 2180
1000	905 - 1620	2065 - 2090	2135 - 2270

Source: IPCC-TAR, Synthesis Report

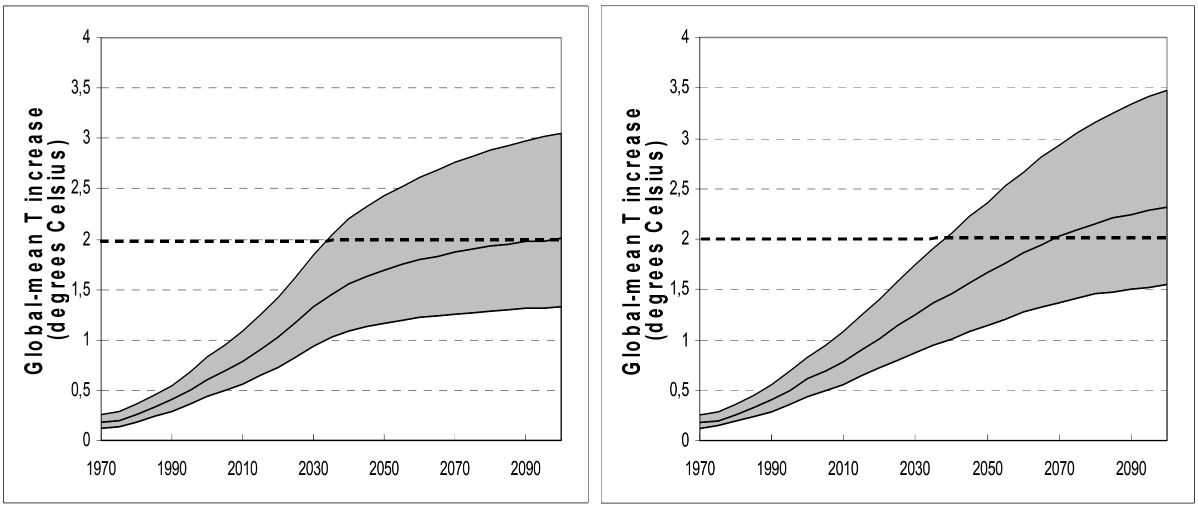
Meeting the EU climate target is only likely under stringent global emission profiles

Figure 3 depicts the range of global mean temperature rise up to 2100 resulting from the two emission profiles taking into account the uncertainty in the 'climate sensitivity', which is defined as the temperature rise resulting from doubling CO_2e concentrations. The IPCC estimates the range of the climate sensitivity between 1.5 and 4.5°C, with a median value of 2.5°C.

A climate sensitivity close to the median value is much more likely than one near the outer ends of the uncertainty range. For a median climate sensitivity the S550e profile already results in a 2°C rise by 2100, while in the S650e profile the rise is about 0.3 degrees more. In both profiles, no equilibrium has been reached by 2100, so further warming will take place afterwards. It is estimated that with a median climate sensitivity, the global temperature rise will eventually stabilise at 2.3 and 3.0°C in the S550e and S650e profiles, respectively.

From Figure 3, it can be concluded that in principle the S550e profile can meet or at least stay near the EU target for the maximum global temperature rise for a median to low climate sensitivity. The S650e profile only does so if the climate sensitivity is at the low end of the range. Therefore, this profile is less likely to meet the EU target. If the climate sensitivity is high, the EU target will not be met in either profile.

Figure 3: Global-mean temperature rise since pre-industrial levels, S550e (left) and S650e (right), assuming different climate sensitivities (1.5, 2.5 and 4.5).



Source: IMAGE 2.2

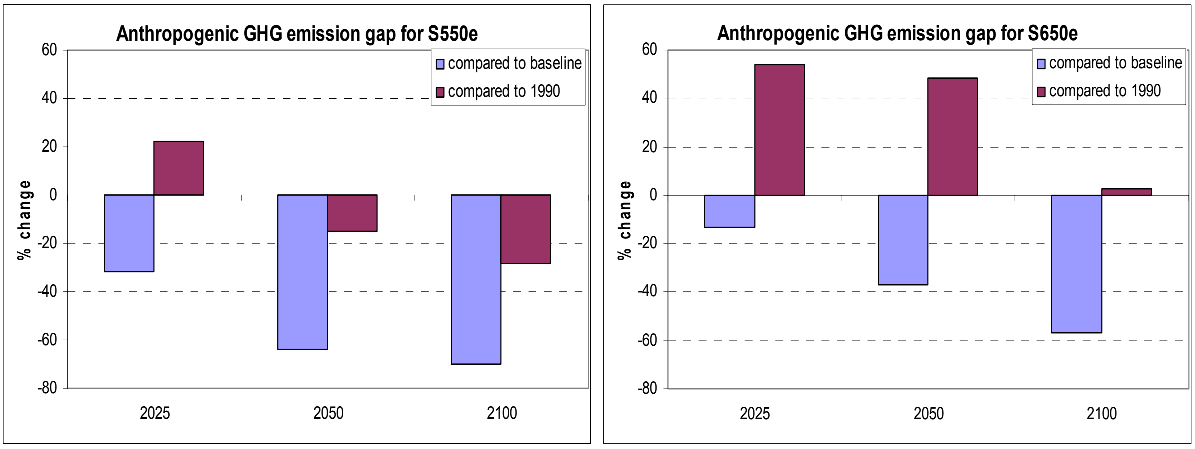
By 2025, reductions of 15 to 30 % from baseline are required

The abatement effort required in the constrained profiles may be measured by the percentage change in greenhouse gas emission levels from the 1990 level and from the baseline. Figure 4 shows the percentage change in the levels of greenhouse gas emissions from energy use and industrial processes required under the S550e and S650e profiles compared to both the baseline and 1990 levels for the years 2025, 2050 and 2100. These levels are somewhat different from the reductions indicated in Figure 2 because they do not consider the impacts of land-use change.

Figure 4 shows that:

- In 2025 global emission levels can still increase to about 20% above 1990 levels in the S550e case, but this already implies a reduction in emissions of 30% compared to the baseline. In S650e the reduction compared to the baseline is smaller, but still significant at around 15%.
- In 2050 emissions have to be reduced strongly in the S550e case, not only compared to the baseline (65%), but also compared to 1990. In contrast, in S650e, greenhouse gas emissions can still be 50% above their 1990 level by 2050. However, compared to the baseline, global emissions need to be reduced by about 35%.
- By the end of the century, both stabilisation profiles imply that global emissions would be substantially reduced, by 70% and 55% from baseline, respectively. When compared to 1990, this implies a reduction of 30% for S550e, and an emission level comparable to the 1990 level for S650e.

Figure 4: Reduction effort for global greenhouse gas emission reduction in energy and industry for S550e (left) and S650e (right).



Source: IMAGE 2.2 model

It is thus clear that stabilising CO_2 equivalent concentrations at 550 ppmv requires substantially larger and earlier global emission reductions than stabilising CO_2 equivalent concentrations at 650 ppmv. Global emissions need to be reduced well below the 1990 level before 2050 in the former case and only after 2100 in the latter case.

Options for the future architecture of international climate policies

The analysis above shows that to meet the EU climate objective during the next century, global greenhouse gas emissions must be substantially constrained. Apart from emission targets, other types of international commitments are sometimes considered in the proposals for future architectures: the concept of a Technology Protocol, for instance, focuses on the accelerated development and diffusion of new low-carbon technological options, but without identifying precise emission targets. While this type of approach may bring some advantages in terms of acceptability to the different Parties, its main drawback is probably that it does not identify the expected outcome of the policy considered and thus runs the risk of not providing enough incentives or constraints.

The Kyoto Protocol must be considered as a very first step in climate policies and does not determine a long-term emission profile. However, it has been considered in this study that the ‘Kyoto-type’ approaches, based on binding quantified emission targets and timetables combined with international flexibility mechanisms to implement of the targets, provide an effective and efficient incentive structure to reach the type of global emission profile identified above as meeting the EU’s climate objectives.

One common feature of all approaches to differentiating future commitments is that they involve issues of international fairness and acceptability. From the rich and abundant literature on these issues, very different solutions can be defined and proposed for each of the dimensions of international climate mitigation regimes.

The diversity in principles and variables for the design of international climate policies

When designing an international architecture for climate policies, a series of questions must be considered. They successively concern the definition of the problem, the principles to be invoked, the way targets are set, the timing for participation of the different Parties and the type of commitments adopted.

- *Problem definition (burden sharing or resource sharing)*

The climate change problem can be defined either as a pollution problem or as a resource sharing issue. These approaches have different implications for the design of climate regimes. In the former case, the focus will be on defining who should reduce or limit pollution and by how much; in the latter, the focus is on who has what user rights, and the global reduction in emissions corresponds to the sum of user rights.

- *Equity principles*

Equity principles refer to more general notions or concepts of distributive justice or fairness. In the literature many different categorisations of equity principles can be found and they cannot in general be easily reconciled. Among the key equity principles explored or invoked in the international climate negotiations up to now, one can identify:

- *Egalitarian:* each human being has an equal right to use the atmosphere; this translates into schemes based on per capita entitlement.
- *Sovereignty and acquired rights:* all countries have a right to use the atmosphere and current emissions constitute a ‘status quo right’; this translates into schemes based on grandfathering entitlements.
- *Responsibility / polluter pays:* the greater the contribution to the problem, the greater the share in the mitigation / economic burden.
- *Capability:* the greater the capacity to act or ability to pay, the greater the share in the mitigation / economic burden.

While the first two principles refer to a problem of allocating rights, the last two can be implemented in either an *ex ante* or an *ex post* perspective, considering the abatement target or the corresponding economic burden, respectively. Generally, the equity principles need to be distinguished both from equity criteria or indicators and from specific rules or formulas that may be used in order to compute practical commitments or targets.

- *Setting emission reduction targets (top-down or bottom-up)*

One can define the emission reduction top-down by first defining the global budget for emissions and then applying certain participation and differentiation rules to allocate the overall reduction effort needed. A bottom-up way will conversely define emission endowment or targets among Parties, without a predefined overall emission reduction effort.

- *Timing of participation (synchronous or differentiated)*

The question is whether all Parties should participate immediately – after 2012, the end of the Kyoto Protocol commitment period – based on simultaneously defined endowments (*full participation*), or if the number of participants can be gradually increased (*increasing participation*). In the latter case, choices need to be made about the types, number and levels of participation thresholds.

- *Type of commitment (baseline-dependent or not, absolute or dynamic)*

The approaches for differentiating commitments can either pre-define the allocations of emissions over time or make the allocation dependent on developments in levels of economic activity, population or emissions. The latter approach results in baseline-dependent targets. These targets can in turn be defined *ex-ante* or *ex-post*. In the latter case, instead of fixed targets, dynamic targets which make the commitments dependent on actual (future) baseline developments can be defined.

A short review of key approaches to the future climate architecture

Among the large number of approaches or proposals to set emission targets in an international framework that can be found in the existing literature, six schemes have initially been explored. While the origins, design and details of these schemes are presented in the Technical Report on which this summary is based, the following gives a generic description of each of them:

- *Per Capita Convergence in emission endowments*

This approach, based mainly on the egalitarian principle, has been developed into a dynamic perspective by defining emission endowments based on convergence of per capita emissions under a contracting global greenhouse gas emission profile. In such a convergence regime, all countries participate in the climate regime with emission quotas converging to equal per capita levels at a chosen date in the future.

- *Soft Landing in emission growth*

Aiming principally at reaching a global target while limiting the constraint imposed on each world region, this approach proposes progressively stabilising emissions in developing countries, with the timing of the reduction of current emission growth rates based on per capita emission and income levels. For Annex I countries, continued emission reductions are required, according to an ‘extended Kyoto’ trend.

- *Global Preference Score approach*

This scheme defines a mixed indicator for endowment that combines a grandfathering entitlement method and a per capita approach. A 'Preference Score Share' is calculated by adding the relative emission shares of each obtained using the two methods by country, weighted by the share of world population assumed to prefer the first or second approach (basically Annex I countries versus non-Annex I countries).

- *Historical Contribution to Climate Change or 'Brazilian proposal'*

During the negotiations on the Kyoto protocol, Brazil made a proposal to link the relative contribution of industrialised parties to their relative contribution to the global mean temperature rise, based on the responsibility principle.

- *Ability To Pay*

This principle was developed as a scheme to progressively integrate non-Annex I countries into a system of global emission reductions with an initial per capita GDP threshold, and subsequent levels of reduction to meet long-term climate targets basically depending on each country's per capita GDP.

- *Multi-Stage approach*

The Multi-Stage approaches divide countries into different groups, with different levels of responsibility or types of commitment (stages). The number of countries involved and their level of commitment gradually increase over time, according to pre-defined participation rules.

The review of the different approaches indicated that the international architecture may develop in two different directions:

- A set of rules or targets that define how all Parties' emission quotas develop over a long period. This type of regime may be called a *'full participation*' regime.
- An incremental but rule-based approach to extending the climate regime, gradually expanding the Annex I group of countries adopting binding quantified emission limitation or reduction objectives, whether absolute or dynamic. This type of regime may be called an *'Increasing participation*' or – when including multiple thresholds - *'multi-stage'* regime.

According to this distinction, the Per Capita Convergence, the Soft Landing and the Global Preference Score approaches belong to the former type of architecture, while the Brazilian proposal, Ability To Pay or Multi-Stage approaches belong to the latter.

The first phase of this study assessed these six endowment schemes, with variants reflecting different values of the key parameters. This preliminary exercise identified the strengths and weaknesses of each of the approaches (Table 2).

Table 2: Strengths and weaknesses of six endowment schemes

	Strengths	*Weaknesses*	*Possible remedies*
Per capita convergence in emission endowments	• Certainty about participation and effectiveness. • Simple concept • Allows for full emission trading	• Possible implementation problems for developing countries • Possible surplus emissions • Could lead to large reductions for some countries	• Include adjustment factors • Adjust convergence year • Limit the use of emission trading • Allow for regional Per Capita Convergence approaches with internal redistribution
Soft Landing in emission growth	• Certainty about participation and effectiveness • Smooth transition • Allows for full emission trading	• No direct relation to equity principles • Possible implementation problems for developing countries • No specification of reduction stage	• Introduce a participation threshold • Define a reduction stage
Global Preference Score Approach	• Certainty about participation and effectiveness • Simple concept • Allows for full emission trading • Funds for less developed countries	• Extreme results • Extra costs for Annex I / middle-income developing countries • Possible implementation problems developing countries • Non-compatible with UNFCCC	• Extend policy delay / include adjustment period • Give more weight to emissions than population in voting • Include adjustment factors
Historical contribution to Climate Change	• Originates from a developing country • Formal status under UNFCCC	• Focus on responsibility only • Extreme results • Relatively complex approach • Inflexible (in original form)	• Use other responsibility indicator (e.g. cumulative emissions from 1950 or 1990)
Ability to pay	• Results in a balanced distribution of costs.	• Based on capability only • Abstract parameters	• Simplify approach
Multi-stage approach	• Covers different equity principles • Flexible concept offering room for negotiation • Compatible with Kyoto Protocol and UNFCCC	• Many parameters • Intensity targets reduce certainty about environmental effectiveness and complicate implementation	• Limit number of stages • Dual targets concept • Ex-post trading for developing countries with intensity targets • Use other burden sharing schemes than per capita emissions

Per Capita Convergence and Multi-Stage as two generic endowment schemes

Based on the initial evaluation, two schemes that proved to be sufficiently generic and robust were selected for further in-depth analysis:

- the Per Capita Convergence for the ‘full participation’ schemes, and
- the Multi-Stage approach for the ‘increasing participation’ schemes.

Furthermore, a set of contrasted hypotheses has been associated with each of the generic solutions, to identify the impacts of changes in the key variables and associated parameters.

- *Per Capita Convergence: testing for an earlier or later convergence year*

In the Per Capita Convergence scheme, two time-horizons have been considered for the final convergence, 2050 and 2100: this provides the Per Capita Convergence-2050 and Per Capita Convergence-2100 cases. Both use the same hypotheses about the shape of the convergence profile, which is considered as linear, and the absence of a cap on population to calculate total endowments.

- *Multi-Stage: a graduated approach to emission targets*

Three alternative 'Multi-Stage' cases have been developed but each uses the same definition of the consecutive stages for the commitments of non-Annex I countries:

- Stage 1. No quantitative commitments
- Stage 2. Emission limitation targets (for example, intensity targets).
- Stage 3. Emission reduction targets, similar to those of Annex I countries.

- *Stage 1 to Stage 2: from no-constraint to emission limitation (carbon intensity) targets*

In all the Multi-Stage schemes a region's transition from Stage 1 to Stage 2, that is, entry to a constrained emission profile, depends on a Capacity-Responsibility (CR) index. This index draws from the mention in Article 3.1 of the UNFCCC of the *"common but differentiated responsibilities and respective capabilities"* that should be taken into account in defining the appropriate action of the different Parties. The Capacity-Responsibility index is defined as the sum of **per capita income** (in k99€), which relates to *capacity to act*, and of **per capita CO_2-equivalent emissions** (in tCO_2), which reflects *responsibility* for climate change.

Because it combines variables of a different nature, this composite index should in principle be normalised or weighted. It happens, however, that in this particular case a one-to-one weight produces fairly satisfactory results. At any date, the Capacity-Responsibility index can simply be computed as the sum of GDP and of total greenhouse gas emissions, divided by the population of the region or country considered, as shown in Table 3.

Table 3: The Capacity-Responsibility (CR) index, regions ranked by decreasing value in 2000

	2000			Baseline - 2025		
	Per Capita GDP (1000 €, PPP)	+ Per Capita Emissions (tCO2e)	*= CR Index**	Per Capita GDP (1000 €, PPP)	+ Per Capita Emissions (tCO2e)	= CR Index
USA	32	26	*58*	46	27	73
Canada	26	21	*47*	38	21	59
Oceania	19	17	*35*	31	17	48
Japan	25	10	*35*	38	12	50
Enlarged EU	19	10	*29*	33	12	45
CIS + Other Europe	5	10	*16*	12	16	28
Middle East	5	6	*12*	10	8	18
Latin America	7	5	*11*	11	6	17
South East Asia	4	3	*8*	10	6	16
China	4	4	*8*	11	7	18
Africa	2	2	*4*	3	3	5
India	2	2	*3*	6	4	10
Rest South Asia	2	1	*3*	3	2	5

** Index may differ from the sum due to independent rounding*

Source: POLES model

While resulting from a pragmatic approach, this indicator shows good 'screening' properties, in the sense that it allows the existing Annex I to be identified, as well as relevant country groupings for non-Annex I regions. The ranking of regions by the 2000 index is modified in 2025 for only a limited number of cases, reflecting the buoyant trends that are expected in China and India.

- *Stage 2 to Stage 3: from emission limitation to reduction targets*

The three Multi-Stage cases, Multi-Stage 1, Multi-Stage 2, and Multi-Stage 3, differ only in the transition from Stage 2 to Stage 3, that is, from dynamic to absolute targets:

- In Multi-Stage 1 entry into Stage 3 depends on a threshold that is defined as a proportion of the world average per capita emission level.
- Multi-Stage 2 uses the CR index, with a value that is about twice that used for the Stage 1 to Stage 2 threshold.
- In Multi-Stage 3 entry into Stage 3 begins after a fixed and pre-determined stabilisation period that allows the rate of growth in emissions to be progressively reduced to zero.

The levels chosen for the different thresholds and the rules applied after the entry to each Stage have to be differentiated according to the global emission profile. Under the S650e case, there is a less pressing need for non-Annex I regions to contribute to global emission control. Thus, the different parameters can be significantly relaxed compared to the much more stringent S550e case: the CR threshold values are higher, the maximum value for the de-carbonisation rate is lower and the stabilisation periods are longer, as described in Table 4.

Table 4: Assumptions for the three Multi-Stage cases and the two emission profiles

<table>
<tr><th colspan="2">S550e</th><th>MS1</th><th>MS2</th><th>MS3</th></tr>
<tr><td rowspan="2">Stage 2</td><td>Threshold</td><td colspan="3">CR = 5</td></tr>
<tr><td>Target</td><td colspan="2">dynamic targets, decarbonisation rate function of per capita GDP (*), max = -3 %/yr</td><td rowspan="2">stabilisation period, function of per capita emissions (**) (constant = 70)</td></tr>
<tr><td rowspan="2">Stage 3</td><td>Threshold</td><td>100 % of average per capita emissions</td><td>CR = 12</td></tr>
<tr><td>Target</td><td colspan="3">absolute targets, reductions proportional to per capita emissions</td></tr>
</table>

<table>
<tr><th colspan="2">S650e</th><th>MS1</th><th>MS2</th><th>MS3</th></tr>
<tr><td rowspan="2">Stage 2</td><td>Threshold</td><td colspan="3">CR = 12</td></tr>
<tr><td>Target</td><td colspan="2">dynamic targets, decarbonisation rate function of per capita GDP (*), max = -2.5 %/yr</td><td rowspan="2">stabilisation period, function of per capita emissions (**) (constant = 100)</td></tr>
<tr><td rowspan="2">Stage 3</td><td>Threshold</td><td>120 % of average per capita emissions</td><td>CR = 20</td></tr>
<tr><td>Target</td><td colspan="3">absolute targets, reductions proportional to per capita emissions</td></tr>
</table>

(*)The de-carbonisation rate, expressed in percentage reduction per year, is a linear function of per capita income (GDP/cap): a x GDP/cap, a = 0.33, with a maximum de-carbonisation rate.

(**)The length of the stabilisation period is given by the transition constant (TC) and is calculated by dividing the TC by per capita emissions (in tCO_2/cap.yr) in the reference period: e.g. if the transition constant is 70, a region with a per capita emission level of 5 will have to bring down its emission growth rate to zero in 14 years

An assessment of emission profiles and endowment schemes

The selected international commitment schemes have been assessed in two steps:

i. study of the timing and reduction targets in each commitment scheme, and

ii. economic analysis of their outcomes and corresponding costs.

For the economic analysis, two alternative methodologies have been used, an abatement cost oriented approach and a general equilibrium approach. The abatement cost approach calculates the regional costs of the different commitment schemes using technology-oriented models. Marginal abatement cost curves are used to determine a cost-optimal implementation of abatement options in the different regions, assuming international emissions trading. This approach, however, does not account for full economic adjustments and feedbacks.

The general equilibrium approach calculates the regional macro-economic impacts (in terms of GDP and welfare loss), taking into account not only the impacts of the additional costs implied by the adjustments needed to the technical and economic systems, but also the impacts resulting from the induced changes in sector demand and international trade. When used in parallel, these different assessments provide a good overview of the potential consequences of each commitment scheme.

Timing and targets for the Per Capita Convergence and Multi-Stage schemes

- *Timing and targets in the S550e emission profile*

Under this stringent emission constraint, the Multi-Stage approaches result in early entry of non-Annex I regions to the emission limitation stage. Most developing regions have to comply with the corresponding dynamic targets as early as 2010 and only the West and East Africa regions enter Stage 2 after 2050.

For the transition from Stage 2 to Stage 3, Multi-Stage 2 leads to the earliest entry to Stage 3 for the middle- and high-income non-Annex I regions, whereas Multi-Stage 3 shows the latest entry. For the low-income non-Annex I regions, all three MS cases show late entry, especially in Multi-Stage 2 and Multi-Stage 3.

In 2025, the Annex I regions' total emission endowment is highest in Multi-Stage 2, whereas Multi-Stage 3 shows the lowest level: this is the direct consequence of the early and late entry into Stage 3 of middle- and high-income non-Annex I regions, respectively.

In 2050, the differences for the Annex I regions are small, as all MS cases lead to very low endowments. The same occurs for the middle- and high-income non-Annex I regions. For the low-income non-Annex I regions, Multi-Stage 3 is the regime with the lowest endowments, due to higher reductions in the emission limitation stage (Stage 2).

When comparing the Multi-Stage with the Per Capita Convergence cases, it becomes clear that the difference in convergence year has a major influence on the emission endowments of Annex I and non-Annex I regions. A later convergence year results in much smaller reductions in Annex I emission endowments, in both the short and longer term. While the results of Per Capita Convergence-2050 are comparable to the Multi-Stage cases, Per Capita Convergence-2100 results in substantially higher emission endowments and is thus by far the least constraining for Annex I regions.

- *Timing and targets in the S650e emission profile*

The S650e profile is a significantly less severe global constraint and results in very different timing of emission targets.

In the Multi-Stage cases, the middle- and high-income non-Annex I regions participate much later in the emission limitation stage than in the S550e profile, although they still have to participate before

2050. Conversely, the low-income non-Annex I regions enter Stage 2 very late, only after 2070 for South Asia and after 2100 for West- and East Africa.

For some middle-income non-Annex I regions like South- and Central America or the Middle East, Multi-Stage 1 is clearly the more stringent because these regions enter the emission reduction stage almost immediately. Multi-Stage 3 provides higher endowments for these regions as it allows a longer transition period. For the low-income non-Annex I regions, there are almost no differences in the outcomes for the three Multi-Stage cases, since these regions do not participate before 2050. For Annex I, Multi-Stage 1 gives higher endowments in both the short and long-term due to the above-mentioned earlier participation of some middle-income non-Annex I regions in the emission reduction stage.

Compared with the Multi-Stage approach, the Per Capita Convergence schemes can be analysed as follows:

- As in the S550e profile, Per Capita Convergence-2100 results in endowments for the Annex I regions that are substantially higher than in the Multi-Stage and Per Capita Convergence-2050 cases.
- Per Capita Convergence-2050 now results in endowments for the Annex I regions that are lower than in the Multi-Stage cases and it becomes the most stringent scheme for these countries (except for Europe in 2025).
- Conversely, Per Capita Convergence-2050 gives by far the highest endowments for the least developed non-Annex I regions. It even translates, in this high global emission profile, into significant amounts of excess emissions compared to the baseline.

Regional emission reduction targets under the Multi Stage and Per Capita Convergence schemes

The first stage in assessing the acceptability of international emission targets is to compare emission reduction levels for the different regions, emission profiles and time horizons. Regional endowments can be compared either to emissions for a common base year or to the corresponding baseline emissions for the time horizon that is considered.

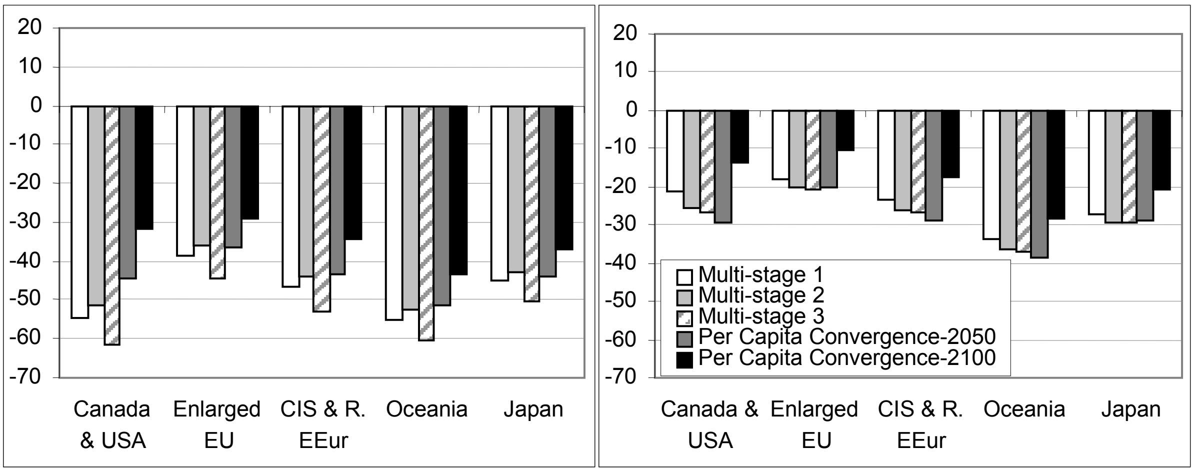
The ratio of endowments to base year emissions does not provide much information on the magnitude of effort required from the different Parties, as this effort will indeed largely depend on the baseline developments. The 'endowment to baseline' ratio has a closer relation with the actual effort needed but is not directly observable.

- *Annex I regions, 2025 horizon*

Under the low emission profile (S550e), endowments result in reductions from baseline of between 40 % for Europe and Japan and 50 % for North America and Oceania in the Multi-Stage 1, Multi-Stage 2 and Per Capita Convergence-2050 cases. Multi-Stage 3 corresponds to reductions that are about 10 percentage points greater in each region, while conversely Per Capita Convergence-2100 implies reductions that are 10 percentage points smaller.

In the higher emission profile (S650e), the endowments result in reductions from baseline that are less pronounced. They lie in a range of 20 to 30 % for all regions except Oceania (30 to 40 %), in the three Multi-Stage and in the Per Capita Convergence-2050 cases. Again Per Capita Convergence-2100 represents reductions that are about 10 percentage points smaller than the four other cases.

Figure 5: Percentage change in Annex I regions' endowments compared to baseline levels in 2025 for the Multi-Stage and Per Capita Convergence cases, for S550e (left) and S650e (right)



Source : FAIR 2.0 model

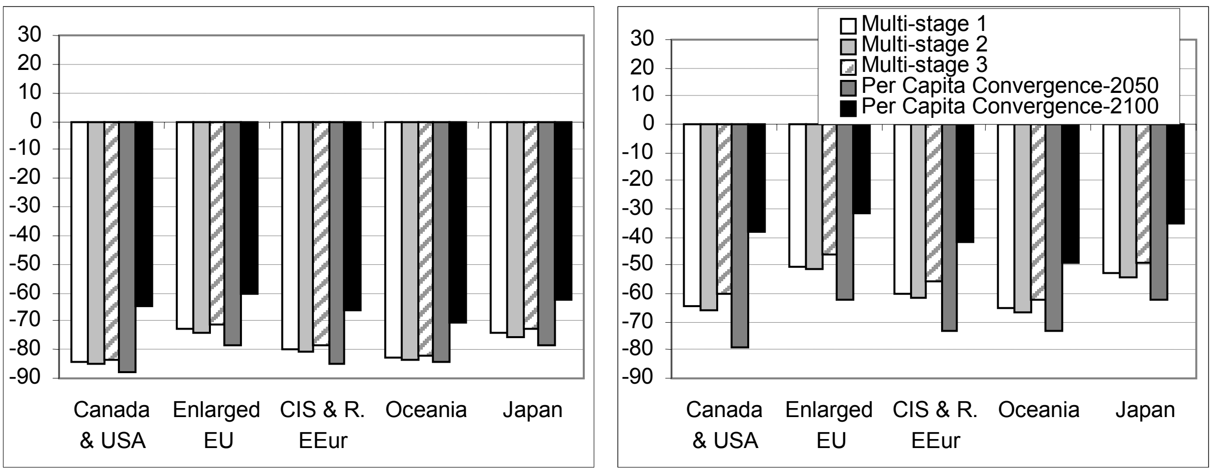
- *Annex I regions, 2050 horizon*

In the low emission profile, the three Multi-stage and the Per Capita Convergence-2050 scenarios show a substantial gap between the endowments and the baseline, as they correspond to reductions of more than 70 % in Europe and Japan and of more than 80 % in North America, Community of Independent States and Oceania. Per Capita Convergence-2100 now implies reductions in a range of 60 to 70 %.

In the higher S650e profile, more clearly still than in S550e, the three Multi-Stage cases appear as fairly equivalent intermediate solutions, with reductions in the range of 50 to 60 %. They clearly lie between Per Capita Convergence-2050, which is more constraining by more than 10 percentage points, and Per Capita Convergence-2100, which is conversely less constraining.

As a general conclusion for the Annex I endowments, it thus appears that the Multi-Stage schemes provide a set of intermediate profiles with reductions in a range of 20 to 50 % in 2025 and 50 to 80 % in 2050, depending on the global emission profile. The only exception is for the 2025 horizon and the low S550e emission profile, where the Multi-Stage cases generally appear more constraining for the Annex I regions than Per Capita Convergence-2050.

Figure 6: Percentage change in Annex I regions' endowments compared to baseline levels in 2050 for the Multi-Stage and Per Capita Convergence cases, for S550e (left) and S650e (right)



Source : FAIR 2.0 model

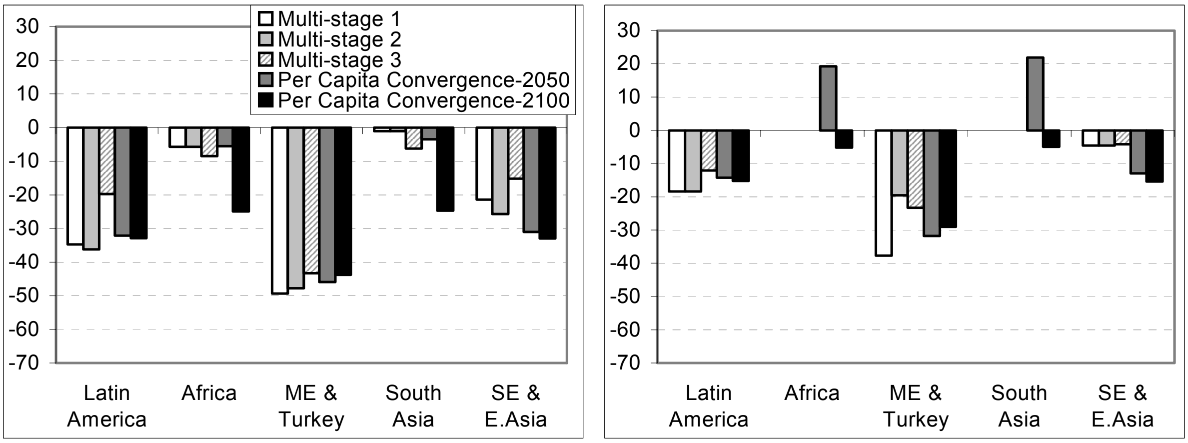
- *Non-Annex I regions, 2025 horizon*

The situations are generally more differentiated across non-Annex I regions than across Annex I regions. Africa and South Asia appear in all cases with much lower required reductions, while Latin America, the Middle East and the Southeast and East Asia regions lie in an intermediate position, between low-income non-Annex I and Annex I regions.

In 2025 under the low global emission profile (S550e), all non-Annex I regions have endowments that are lower than their baseline even in Per Capita Convergence-2050, in which their endowments may theoretically be higher and represent excess endowments. However, the reductions required are very limited for Africa and South Asia – less than 10 % – except in Per Capita Convergence-2100, where reductions rise to about 25 % compared to baseline, a level that is not much less than that of some Annex I regions. In the other non-Annex I regions reductions rise to about 30 % for Latin America and Southeast and East Asia, and to more than 40 % for the Middle East.

In the higher S650e emission profile, the situation changes quite substantially as Africa and South Asia are no longer constrained in the Multi-Stage cases and as significant excess emissions appear in the Per Capita Convergence cases. Reductions are limited to 10-20 % for Latin America and 5-15 % for Southeast and East Asia.

Figure 7: Percentage change in non-Annex I regions' endowments compared to baseline levels for the Multi-Stage and Per Capita Convergence cases, for S550e (left) and S650e (right)



Source : FAIR 2.0 model

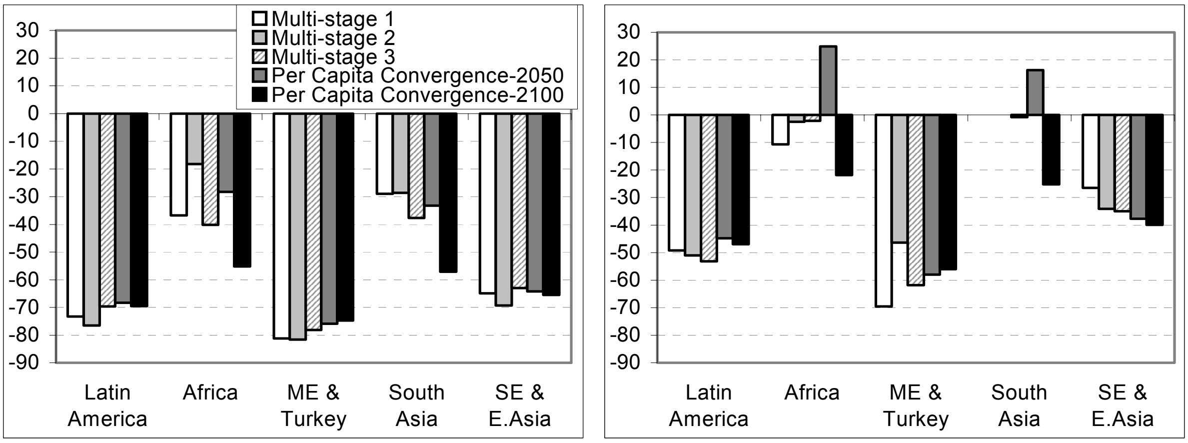
- *Non-Annex I regions, 2050 horizon*

In the longer term under the S550e profile, the endowments of the middle- and high-income non-Annex I regions turn out to be very similar to those of Annex I regions, as they all participate in the absolute emission reduction system. The reductions required are very similar across the five endowment schemes, with about 60 % reduction level for Southeast and East Asia, 70 % for Latin America, 80 % for the Middle East. Reductions remain more limited for Africa and South Asia (around 30 %), except in Per Capita Convergence-2100, where they reach 60 %.

In the higher S650e emission profile, Africa and South Asia again benefit from excess emission endowments in Per Capita Convergence-2050 and have very low required reductions in the Multi-Stage cases. In the other non-Annex I regions the reductions remain globally lower than for Annex I, with 40 %, 50 % and 60 %, respectively for Southeast and East Asia, Latin America and the Middle East.

In the same way as the Multi-Stage cases have been described above as producing a set of intermediate cases between the two early and late Per Capita Convergence cases, examining the endowments for non-Annex I regions identifies Multi-Stage 2 as the most balanced Multi-Stage approach. In particular, Multi-Stage 2 allows the relatively high emission reductions implied by Multi-Stage 1 or Multi-Stage 3 to be avoided in at least three cases: for Africa in 2050 under the S550e profile, and for the Middle East in 2025 and 2050 in the S650e case.

Figure 8: Percentage change in non-Annex I regions' endowments compared to baseline levels in 2050 for the Multi-Stage and Per Capita Convergence cases, for S550e (left) and S650e (right)



Source : FAIR 2.0 model

Assessment of the outcomes of the commitment schemes in the sectoral abatement cost approach

Meeting either the S550e or the S650e profile will require major changes in world energy consumption and in other greenhouse gas emitting activities. It will also induce new dynamics in using and diffusing technologies, not only in the energy sector but also in industry and agriculture. These changes all contribute to the costs of mitigation. In all calculations (both the abatement costs approach and the general equilibrium approach), it is assumed that international emission trading schemes will allow least-cost options to be implemented in all regions. This implies that the overall global costs are largely – although not fully, as will be shown – independent of regional targets.

The sectoral models of the energy sector and of other greenhouse gas emitting activities allow us to assess the costs of adjusting energy consumption and the technology mix to a situation of constrained emissions. When emission trading is considered, as in this study, the total cost for a given region combines the cost of domestic reductions with the purchase or sale of emission quotas. While the overall world cost mostly translates the degree of stringency of the global target, the regional cost also crucially depends on the regional endowment scheme, which determines the emission quota trading structure and the associated financial flows, which are presented below in Table 5.

Table 5: Direction of net trade in emission quotas and associated financial flows, S550e and S650e

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

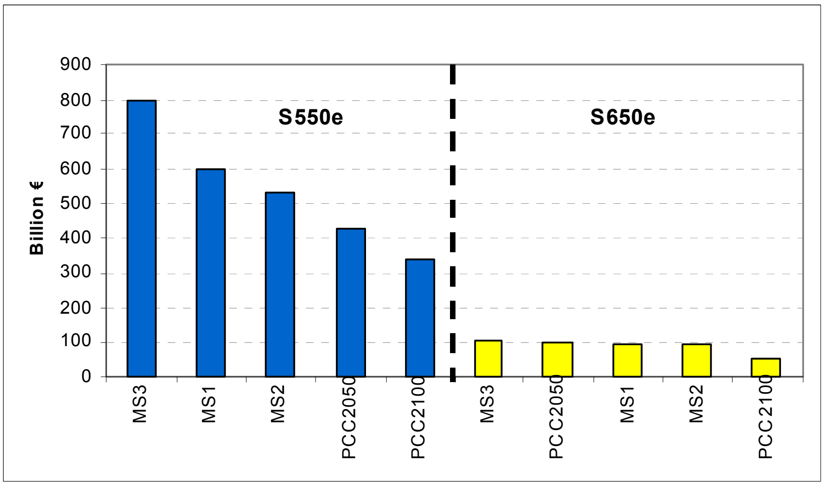
Source: POLES model

In all cases, most industrialised regions – Europe, Japan, Canada and Oceania - are net importers of emission quotas. The USA, however, turns into a major quota exporting region in the Per Capita Convergence-2100 case, for both the S550e and S650e profiles. Symmetrically, Africa, India and, to a lesser extent, the Rest of South Asia are in all cases major exporters of emission quotas, except in the Per Capita Convergence-2100 case, where their role as exporters is almost negligible.

This confirms the peculiarity of the Per Capita Convergence-2100 case, whereas the Per Capita Convergence-2050 and the three Multi-Stage cases are more similar. To some extent, China is an exception to this general statement as its role as a potential exporter ranges from a very limited one in both Per Capita Convergence cases under the S650e profile, to a largely predominant one in Multi-Stage 3 under the S550e constraint.

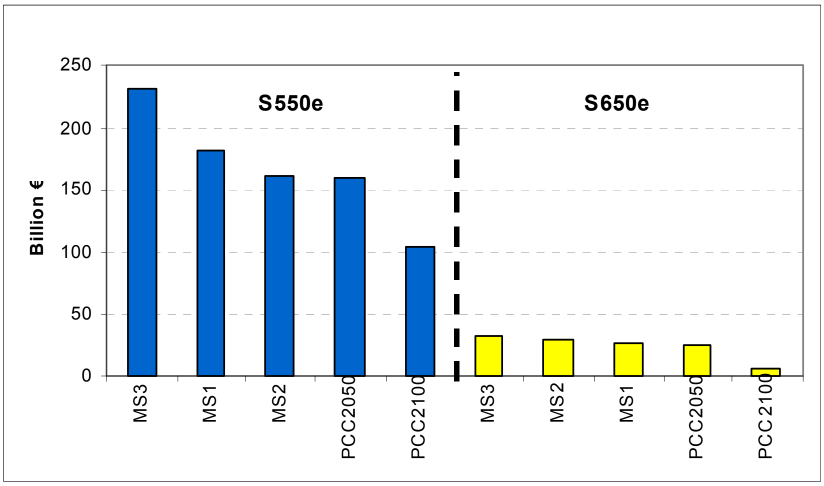
Figure 9 highlights the changes in the total volume of financial flows associated with the trading of emission quotas in the different cases. It shows in particular that the volume of trade is several times higher in S550e than in S650e. It also indicates that the Per Capita Convergence-2100 scheme – because it is the least stringent for industrialised countries – is the one that involves the lowest level of financial flows in both emission profiles, while Multi-Stage 3 involves the highest one. The same conclusions holds true for the financial flows originating from the Enlarged EU, which are described in Figure 10. These flows represent between one fourth and one third of total flows, according to the case considered.

Figure 9: Global financial flows from emission trading, 2025



Source: POLES model

Figure 10: Enlarged EU financial flows from emission trading, 2025



Source: POLES model

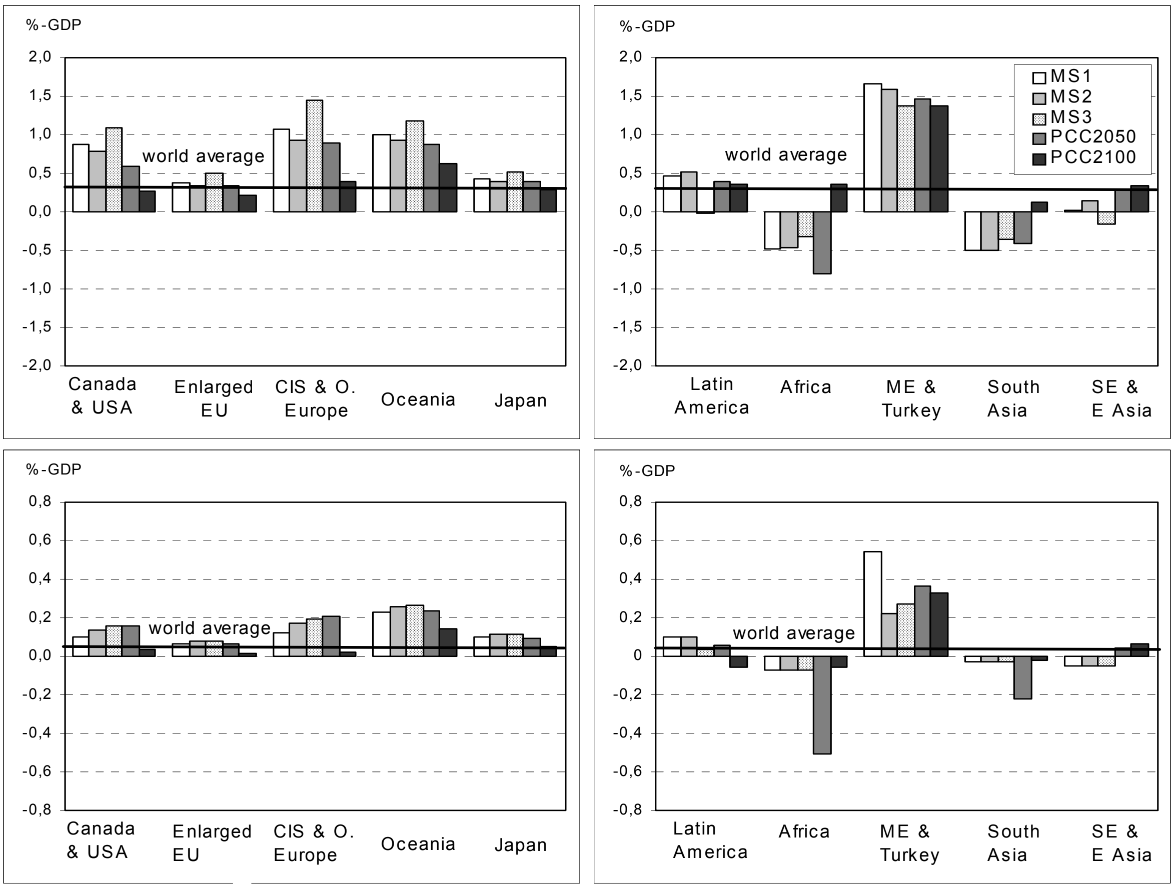
The total cost for a given region is thus dependent on trading structures and financial flows that vary considerably according to the global target and endowment scheme. The ratio of this total cost to the GDP of each region provides a good indicator of the effort that is directly imposed by the endowment scheme. When assessed with a sectoral model, the 'effort rate', however, does not account for the full adjustment of the many components of the economy, which can only be described in a general equilibrium perspective, as seen below.

The abatement cost analysis shows that the global mitigation costs of meeting the S550e profile are much higher than the cost of meeting the S650e profile. In the S550e profile the global effort rate after 2010 increases to 0.3% by 2025 and over 1% by 2050 (not shown). In contrast, in the S650e profile the global effort rate by 2025 is only 0.05% and increases gradually to just 0.2% by the middle of the century.

The regional effort rates are similar across the emission profiles and commitment schemes, and comparable to the 'reductions compared to baseline' ratio examined above. However, there are some differences that result from differences in GDP, cost or gains from emission trading, and of course from the differences in regions' marginal abatement costs.

While most commitment schemes result in comparable effort rates, Multi-Stage 3 and Per Capita Convergence-2100 differ the most. Due to a less stringent intermediate period for the middle-income non-Annex I regions, Multi-Stage 3 gives them more emission endowments. This significantly lowers the costs or even creates gains for these regions. Per Capita Convergence-2100 gives more emission quotas to the Annex I regions and much fewer excess endowments to the non-Annex I regions. This results in fewer emission quotas to be bought by Annex I regions, while some even turn from buyers to sellers.

Figure 11: Regional effort rates for the Multi-Stage and Per Capita Convergence cases for the S550e (top) and S650e (bottom) profiles by 2025



Source: TIMER 1.0 /FAIR 2.0 model

In general, regions with high per capita emissions and high income (the OECD regions as of 1990) are confronted with average effort rates. Regions with medium to high per capita emissions, but medium to low income (the Community of Independent States, Latin America and the Middle East) show quite high effort rates. Regions with low per capita emissions and low-income (Africa and South Asia) often show net gains from emissions trading. The exception is Per Capita Convergence-2100 in the S550e profile, which creates considerable costs for these regions. Finally, Southeast and East Asia, which contain middle-income regions (Southeast Asia) and relatively high emission regions (East Asia) display a particular profile, importing quotas in the two Per Capita Convergence cases and exporting in all but one Multi-Stage case.

Assessment of the outcomes of the commitment schemes in the general equilibrium approach

In general equilibrium economic assessments, the emission reduction constraint generates a shadow value (quota price), which increases the costs of greenhouse gas emitting activities. Then the internalisation of this additional cost into the cost structures and choices of the economic agents is governed by their ‘optimising behaviour’ (firms maximise profit, etc.). The resulting equilibrium prices and quantities, incorporating both the primary and secondary effects of the policy intervention, lead to an endogenous least-cost allocation of the abatement effort.

- *The carbon value resulting from the emission profiles*

As the emission profiles are not differentiated until 2010, both S550e and S650e produce a low carbon value in 2010. Then the wider opportunities to seek cost effective abatement options induced by the enlargement of the climate regime to developing countries reduce the growth of the quota price at least until 2015. Beyond 2020, the gradual implementation of the cheaper abatement options together with the overall tightening of the emission constraint result in shrinking supply and increasing demand for quotas, leading to a further rise in the quota price.

In 2025 the carbon value is significantly higher and reaches 11 €99/tCO_2e in the S650e profile and up to 60 €99/tCO_2e in S550e. While the carbon values are very similar in all endowment schemes in the S650e profile, a differentiation in the carbon values appears by that time in the S550e profile. This basically reflects the different repercussions of initial emission right allocations on overall activity levels, through the constraints imposed on individual regions or shifts in the world economy induced by redistributive effects. In this context, the more stringent the reductions a scenario implies, the more noticeable is the impact of the initial quota allocation.

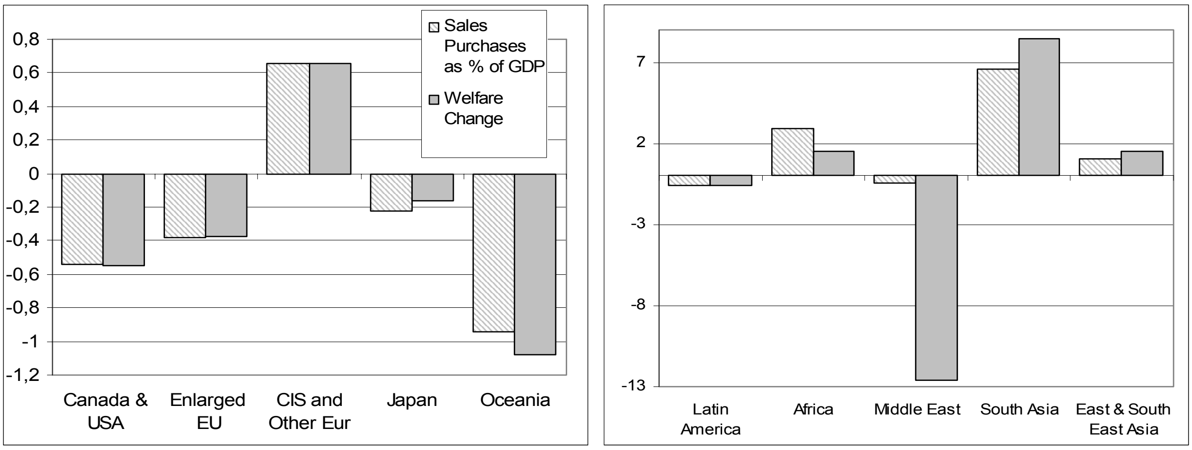
- *Macroeconomic implications at the regional level.*

The index used to evaluate the consequences of different allocations of emission rights is welfare. This index was preferred because it allows the beneficial impacts that an increase in imports entails to the consumer (household) to be taken into account. In particular the income produced by selling quotas allows a country not only to increase investment and productive capacity but also to increase imports of goods and services. This increase in imports, while not entailing higher GDP, represents a clear advantage for consumers, who benefit equally from imported and domestically produced goods.

The level of abatement, as simulated in the different scenarios, provides a clear indication of the potential for cost effective emission reductions in each region. In broad terms, major energy exporters have a large potential to reduce CO_2 as low domestic fossil fuel prices favour energy intensity in their baseline energy consumption patterns. They also have a high potential to reduce non-energy related greenhouse gas mostly because of highly cost effective options for reducing methane emissions associated with primary hydrocarbon production. Conversely, in developed regions energy-related CO_2 emissions can only be reduced at a relatively high cost, since the weight of higher fuel prices through taxation already in place has already exhausted most of the easier options.

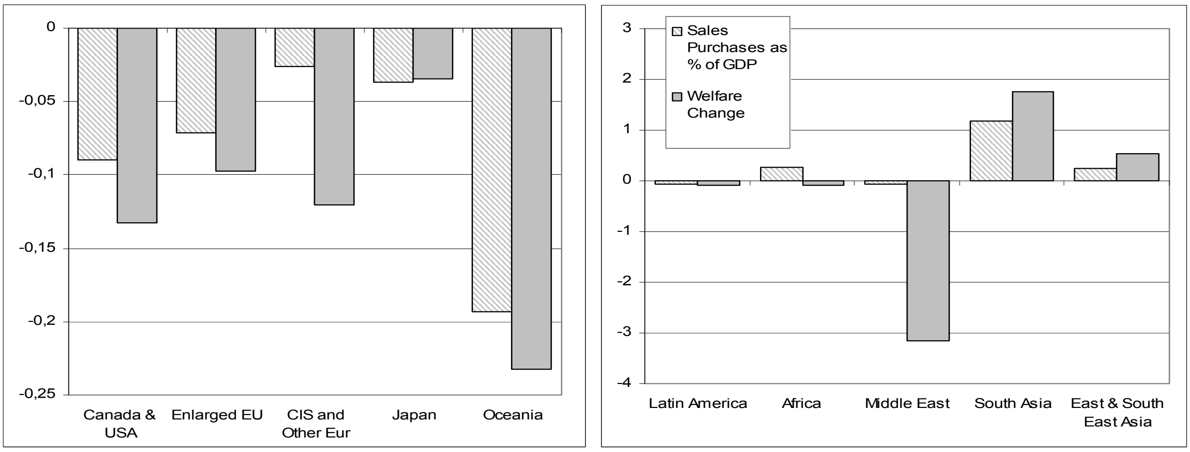
The close correlation between welfare gains/losses with the income inflows/outflows arising from quota trade is illustrated in Figure 12 and Figure 13. These plot the transfers implied by quota trade and the welfare gains/losses at the new equilibrium. Most countries/regions show similar values of the two variables, suggesting broad proportionality of the two impacts.

Figure 12: Changes in Sales (+) or Purchases (-) of Quotas as % of GDP and in Welfare, 2025, Multi-Stage 2, S550e



Source: GEM-E3 model

Figure 13: Changes in Sales/Purchases of Quotas as % of GDP and in Welfare, 2025, Multi-Stage 2, S650e



Source: GEM-E3 model

There are, however, exceptions to the correlation between quota trade and welfare changes. The most notable concerns the Middle East, which registers the biggest losses in terms of welfare. The same holds for the Community of Independent States region in the S650e profile. This is mainly due to a deterioration of the terms of trade as the price of crude oil as the main export of the region falls.

Conversely, the region that benefits most in terms of welfare is the South Asia region. Because of relatively abundant endowments and a large potential to reduce emissions relatively inexpensively, it is a net exporter of quotas in all cases. High positive welfare impacts are also present in the other Asian regions, while the results for Africa are to some extent negatively affected by the presence in the region of large oil producers and exporters.

In most cases, the abatement costs approach and the general equilibrium approach result in similar relative cost estimates for the different regions. The two key conclusions, among many others from the general equilibrium analysis of the different endowment schemes, are:

- The costs of achieving the reductions (in terms of world GDP) range between - 0.7 and - 0.9% in 2025 in S650e and from - 1.9 to - 2.8% in S550e.
- The Multi-Stage scenarios in both profiles provide better welfare prospects to the developing regions as they imply higher income transfers.

Co-benefits of climate policies: the example of regional air pollution

The significant changes in energy consumption and in the energy system that would result from the abatement actions may have significant co-benefits in terms of emissions of regional air pollutants.

Co-benefits between climate policies and regional air pollution

There is an increasing awareness, in both the science and policy communities, of the importance of addressing the linkages between traditional air pollutants and greenhouse gas emissions. Many air pollutants and greenhouse gases have common sources, their emissions interact in the atmosphere and, separately or jointly, they cause a variety of environmental effects at the local, regional and global scales. Thus, emission control strategies that simultaneously address air pollutants and greenhouse gases may improve environmental quality at all scales.

Current studies indicate that in the high-income countries currently considering climate policies, the potential co-benefits could be substantial both in environmental and economic terms. Climate change policies and air quality control are still relatively marginal issues in most low-income countries, particularly when compared to issues such as poverty eradication, or food, water and energy supply. In the effort to curb the current and future risks of fast growing emissions of both air pollutants and greenhouse gases such countries could benefit from the synergies between sustainable development targets and climate change.

Implementing accelerated sustainable development strategies that would also account for climate change mitigation could in this way become a common target for both developing and industrialised countries.

The linkages between climate change and regional air pollution

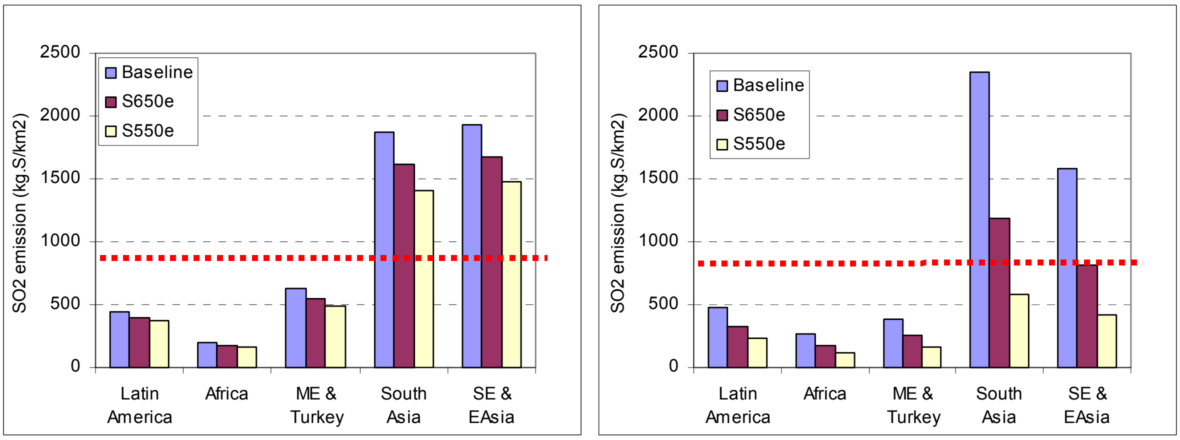
Several linkages exist between climate change and regional air pollution. First, some of the gases influencing climate change also affect regional air pollution, for instance methane, sulphur and nitrogen oxides. Second, the emissions causing both problems originate to a large extent from the same activity, fossil fuel combustion. Third, technologies to abate one pollutant may also affect emissions of other pollutants, either beneficially or adversely (for example, using catalytic converters increases emissions of N_2O, a greenhouse gas). Fourth, environmental effects may influence each other: climate change, for instance, changes weather patterns and thus the transport of pollutants and the ‘buffering capacity’ of soils. It should, however, be kept in mind that linkages work in two directions: while synergies are common, there can also be trade-offs to be managed.

- *Changes in emissions of sulphur and nitrogen oxide*

Changes from the baseline in global sulphur and nitrogen oxide emissions because of climate policies are significant in both the S550e and S650e profiles. The S650e profile leads to worldwide reductions from the baseline of 50% and 35% in sulphur and nitrogen oxide emissions respectively. The S550e profile leads to even larger reductions, 70% and 50%.

Co-benefits occur in all regions. However, as air pollution control policies are generally less strict in low-income regions, co-benefits tend to be more important in these regions. Figure 14 shows the ratio between regional sulphur emissions and the size of each region, which can be interpreted as a coarse indicator of acidification risks.

Figure 14: Sulphur oxide emissions(kg.S/km^2) under the baseline, S550e and S650e in 2025 (left) and 2050 (right)



NB: The dotted horizontal line indicates the level above which there is an increased likelihood of exceeding ecosystem critical loads).

Source: IMAGE/TIMER 1.0

Under the baseline, a substantial number of ecosystems will be confronted with serious acidification risks, in particular in Asia. In 2025, the climate policy scenarios could improve the indicator that is considered here by 10% (S650e) to 20% (S550e). The differences between the baseline scenario and the climate policy scenario become more obvious by 2050, as climate policy tightens. By that time, the S550e profile represents a reduction in the risk indicator of more than 70%, significantly decreasing the likelihood of exceeding ecosystem critical loads.

NO_x emissions are also important for acidification and eutrophication risks. In 2025, NO_x emissions are likely to exceed critical loads both in the baseline and in the constrained profiles in South and East Asia as well as in Europe. By 2050 NOx emissions are still high under the baseline assumption, but they are somewhat improving in the S650e scenario and improve considerably under the S550e scenario.

- *Potential benefits for human health*

The largest benefits of climate policies for human health can be expected from reduced concentrations of ozone and particulates. As climate policies in general lower fossil fuel use, they also reduce related emissions of particulates. Reduced exposure to these particulates can significantly extend life expectancy. Health benefits can also be gained by reducing urban concentrations of NO_2 and SO_2.

The baseline indicates that in 2025 and 2050 serious health risks in cities still exist, despite the fact that the situation slowly improves as the result of tighter air pollution standards due to rising income in most regions of the world. The climate change policies scenarios significantly improve the picture, reducing the likelihood of exceeding NO_2 standards by 2025, with further improvements towards 2050.

While a fully integrated assessment of the linkages between air pollution and climate change has not been performed yet, all studies undertaken so far show the importance of these links. Their direct impact is significant, but they are also highly relevant for policy design. The economic evaluation of the co-benefits of greenhouse gas mitigation suggests that the avoided damages may alleviate the costs of the emission reductions. In the low-income and densely populated regions it can even compensate for a significant part of the reduction costs.

Conclusions

To prevent potentially dangerous changes in the earth's climate – both at the global and local level – further international action to mitigate greenhouse gas emissions is required, beyond the Kyoto Protocol's time-horizon and geographical scope. While it is relatively easy to identify global emission profiles that correspond to the EU objective of limiting global climate change, designing a climate policy architecture that would be acceptable to all Parties to the UNFCCC is a daunting task. It will require a continuous effort in climate studies, economic analyses, discussions to develop a common understanding, and international negotiations to build a comprehensive scheme.

- *Global emission profiles for meeting the EU climate target*

Continuation of the baseline trend in greenhouse gas emissions is projected to result in a global temperature rise of over 3°C by 2100, for the median value of the 'climate sensitivity'. To assess the level of global greenhouse gas emission control needed to meet the EU target, two different global emission profiles have been evaluated. The first stabilises the concentration of greenhouse gases at 550 ppmv CO_2e (S550e), the second at 650 ppmv CO_2e (S650e).

The S550e profile can meet or at least stay near the maximum global temperature rise of the EU target for a median to low climate sensitivity. The S650e profile only does so if the climate sensitivity is at the low end of the range. Therefore, this profile is less likely to meet the EU target. If the climate sensitivity is high, the EU target will not be met in either profile.

At the same time, emission reductions under the S650e profile are considerably less stringent than under the S550e profile. The S550e profile requires global greenhouse gases to be reduced by 30% in 2025 compared to baseline, while the S650e profile requires a reduction of only 15%.

- *Building international commitment schemes*

The preceding results show that meeting the EU objective implies that global greenhouse gas emissions must peak within a few decades under a median value of the climate sensitivity. This will require a strong and co-ordinated international effort, as stabilising emissions in such a time frame implies substantial changes in the levels of many economic activities, as well as in the corresponding technologies.

It also means that early participation of developing countries is required, even if the Annex 1 countries significantly strengthen their commitments. The challenge is therefore to develop an international commitment regime that is both sufficiently effective in controlling emissions and sufficiently fair to be acceptable to various parties around the world.

Approaches based on binding quantified emission targets combined with mechanisms to achieve these targets flexibly, such as the Kyoto Mechanisms, can provide a sufficiently effective and efficient incentive structure for achieving such quick changes in global greenhouse gas emission trends.

The key difficulty in designing long-term comprehensive post-Kyoto architectures is of course related to the acceptability of the corresponding emission targets to the different Parties. While a large number of proposals are at hand, many refer to very different – if not contradictory – principles of international fairness. Until now, none has emerged as an uncontroversial point of convergence for the different Parties.

This study has first reviewed six approaches, each one representing an original, consistent and practical solution for designing long term emission endowments in the different world regions. This preliminary exercise identified strengths and weaknesses of each of the approaches.

Two generic approaches were selected for further in-depth assessment: the Per Capita Convergence approach, because it clearly refers to a concept of universal equality of rights but also provides some flexibility in the time-path of regional endowments, and the Multi-Stage scheme, because it opens the way to a graduated approach for defining emission targets and thus allows the specific situations and constraints applying to each region of the world to be taken into account.

- *Results of the assessment of the Per Capita Convergence and Multi-Stage approaches*

Each of the generic Per Capita Convergence and Multi-Stage approaches has been assessed with a limited set of variants, to illustrate the consequences of choosing different values for the key parameters that fully define the regional endowments. The key outcomes are:

- In 2025, all Multi-Stage and Per Capita Convergence approaches result, for Annex I countries, in reductions in endowments of at least 40-50% compared to the 1990 levels in the S550e profile, and 10-20% in the S650e case. In 2050, the reductions are at least 75% and 50%, for S550e and S650e respectively. For the enlarged EU, the reductions compared to 1990 levels are: for S550e 30-40% in 2025 and 70-80% in 2050, for S650e 10-15% in 2025, and 40-60% in 2050.
- Per Capita Convergence in 2100 induces the lowest constraints for the Annex I countries, whether for the low or high emission profile and for the medium or long term. The endowment profiles of the non-Annex I regions are much more differentiated, with comparatively stringent constraints imposed on the regions with the lowest income (Africa and South Asia). Furthermore, the general equilibrium study shows that this scenario, which results in the lowest financial transfers to the developing regions, also corresponds to the highest cost in terms of world GDP. It is thus doubtful that such a late convergence system may constitute a common goal, unless it is substantially adjusted to take account of these factors.
- The results of the early Per Capita Convergence scheme (2050) are more comparable to those of the Multi-Stage approaches examined below. However, the distinctive feature of this case is that it results in considerable excess emission quotas when the emission profile is relatively high, as in the S650e case. This artificially increases the amount of quota traded, which may result in relatively high welfare losses in Annex I regions.
- The Multi-Stage cases, which differ in the conditions of the transition from emission limitation to absolute emission reduction targets, globally represent intermediate cases between the early and late Per Capita Convergence cases. Only under the more stringent stabilisation profile do delays in the participation of non-Annex I regions induce higher constraints in Annex I regions than under the Per Capita Convergence cases. The MS variants have their strengths and weaknesses. These depend on the design of the variants, but also on the different parameter settings chosen.
- The responsibility oriented scheme (MS1), which is based on a world average per capita emission threshold, can result in relatively large emission reductions for some developing regions and may entail burdens that are hardly acceptable. On the other hand, it rewards Annex I action, provides an incentive for non-Annex I countries to keep below this threshold and makes the regime more robust for future adjustment of climate targets. The double Capacity-Responsibility index approach (MS2) presents more evenly distributed endowment profiles across the non-Annex I regions, because it involves early participation for most of them, but its fixed thresholds introduce some policy inflexibility. The MS3 variant provides for smooth transition pathways to the emission-reduction stage, but this makes the approach even less flexible and results in large Annex I emission reductions.
- In evaluating the equity implications of various regimes to differentiate commitments it is not sufficient to evaluate *ex-ante* the allocation of the emissions compared to baseline, as part of an allocation-based approach. The evaluation also requires an assessment of the impacts of emission trading, of the changes in energy trade and of other macro-economic feedbacks.
- The gains from participating in international emission trading and from reduced air pollution damage and/or abatement costs can make early participation of developing countries in global greenhouse gas emission control attractive, provided that the level and form of the commitment are well designed. The redistributive impacts of most of the schemes are significant, in particular when non-Annex I endowments are near to or even higher than the baseline emissions, as in the Per Capita convergence 2050 case under the S650e profile.
- The occurrence and level of excess emissions depends on the stringency of the profile, baseline emissions and the convergence year chosen. In S550e excess emissions only appear for the least developed regions, notably West and East Africa; in S650e they also appear in other regions, such as South Asia.

Overall, the study shows that it is possible to design a set of consistent rules to attribute long-term emission endowments to the different world regions. Because the Multi-Stage schemes include the possibility of commitments of a different nature for regions with different levels of wealth and intensity of emissions, they may probably be considered as good candidates for building the long term international climate architecture that is yet to be developed.

The architectures based on binding emission targets as explored in this report probably provide the right combination of information, incentive and constraint that will stimulate the development of new low-greenhouse gas technologies. Due to the significance of the co-benefits of mitigation, they would also create a powerful support for sustainable development strategies in the developing world.

The options identified have undergone some initial assessment, mainly in quantitative terms and with an emphasis on economic aspects. As a next step, the approaches deemed promising need to be analysed in a more detailed and refined way, including issues of practical feasibility such as data needs and availability, or implementation and control conditions.