RIVM report 728001025/2003

Regional costs and benefits of alternative post-Kyoto climate regimes

Comparison of variants of the Multi-stage and Per Capita Convergence regimes

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This research was conducted as RIVM's contribution to a collaborative research project "Greenhouse gas reduction pathways in the UNFCCC post-Kyoto process up to 2025", commissioned by DG Environment of the European Commission. The research also profited from support by the Dutch Ministry of Environment for the International Climate Change Policy Support Project (M/728001 Ondersteuning Klimaatbeleid)

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Abstract

The study documented here explores technical, economic and environmental implications of different post-Kyoto climate regimes for differentiation of future commitments that would lead to a stabilisation of greenhouse gas concentrations (Kyoto gases) in the atmosphere at 550 and 650 ppmv CO_2-equivalents (S550e and S650e profile). The S650e profile requires less strict emission reductions but is unlikely to limit global temperature increase to 2^oC over pre-industrial levels. In contrast, the S550e profile is more likely to keep global temperatures below this limit by 2100. Constrained by these two profiles, the implications of two different regimes, the Multi-stage and Per Capita Convergence approaches, are evaluated. For the Annex I regions, reduction targets are more dependent on the stabilisation level than on the type of regime chosen. In 2025, most regimes show emissions reductions for Annex I regions of 25-50% compared to their 1990 levels. For the non-Annex I regions, the results are generally more differentiated and differ strongly per regime and in time. Under all regimes, early participation of (major) non-Annex I regions is needed. Four groups of regions with similar efforts can be identified with respect to their abatement costs as percentage of GDP, i.e.: 1) the high income regions with high per capita emissions with average costs when compared to other regions (OECD90 regions); 2) Regions with medium to high per capita emissions and medium income levels show relatively the highest costs (Middle East & Turkey, FSU and to a lesser extent, Latin America; 3) Regions with low to medium income levels and per capita emissions (South-East & East Asia) are confronted with low to average costs. 4) Regions with low per capita emissions and a low income (Africa and South Asia) show net gains from emissions trading. Implementation of these regimes leads to significant changes in the energy system and, consequently, in energy trade. For some regions, lost fuel export revenues can reflect the same order of direct abatement costs (in particular, the Middle East), while the revenues from biofuel trade can party offset these losses. The changes in the energy system can also induce significant co-benefits, such as a decrease in the sulphur and nitrogen oxide emissions. Overall, the analysis shows that in evaluating the implications of various regimes, it is not sufficient to evaluate only the allocation of the emissions compared to baseline. Abatement costs and changes in energy trade will also have to be assessed. The gains from participating in global-emissions trading and realising reduced air pollution damage and/or abatement costs can make early participation of (large) developing countries in global GHG control possible at low costs or even net gains. However, the level and form of commitment will have to be well chosen – and not be too strict - to balance economic risks and political viability.

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Acknowledgements

This report describes the research conducted by RIVM, National Institute for Public Health and the Environment, as a contribution to the EU research project ‘Greenhouse gas reduction pathways in the UNFCC post-Kyoto process up to 2025’. This project was directed by CNRS-IEPE (Institute de l’Economie et de Politique de l’Energie, France), with contributions from RIVM (Netherlands), National Technical University of Athens (Greece) and Center for Economic Studies, Katholieke Universiteit Leuven (Belgium). The report also draws on research performed for the Dutch Ministry of Environment within the Climate Change Policy Support project (M/728001 Ondersteuning Klimaatbeleid). The authors would like to thank the participants of IEPE, Patrick Criqui and Alban Kitous, for the constructive collaboration. We would like to thank our RIVM colleagues, in particular Bert Metz, André de Moor, Bert de Vries and Tom Kram for their comments and contributions and Ruth de Wijs for language-editing assistance. The authors are very grateful to IIASA (and in particular Markus Amann and Janusz Cofala) for allowing us to use the RAINS-Asia model. Finally, we would like to thank Peter Zapfel and his collegues from DG-Environment of the European Commission for supporting the research and the discussions and suggestions during the project.

Contents

Summary

The Kyoto Protocol has been an important milestone in international climate policy-making, but is only a first step in the efforts required to stabilise the greenhouse gas (GHG) concentration (UNFCCC, Article 2). This raises important questions about what future levels of commitments will be needed in the longer term and what will constitute a fair differentiation of commitments among countries. In an earlier report (den Elzen et al., 2003b), we analysed five different climate regimes in terms of their regional reduction targets (Multi-stage, Per Capita Convergence, Brazilian Proposal, Jacoby Rule and Preference Score). In this study, we will present the results of two approaches selected for an in-depth analysis:

- The *Per Capita Convergence approach* (or *Contraction and Convergence*) which defines emission permits on the basis of a convergence of per capita emissions under a contracting global GHG emission profile (Meyer, 2000), with all countries participating from 2013 onwards.
- The *Multi-stage approach,* consisting of a system to divide countries into groups with different types of commitments (stages). The approach results in a gradual increase over time in the number of countries involved and their level of commitment (Berk and den Elzen, 2001).

The regional environmental, technical and cost implications of variants of these two approaches are analysed under two different global emission profiles, leading to stabilisation of GHG concentrations at 550 and 650 ppmv CO_2-eq., respectively. For the analysis, we used a modelling framework consisting of the Integrated Assessment model, IMAGE 2.2, the world energy model, TIMER 1.0 and the climate policy assessment model, FAIR 2.0. The whole analysis is based on a multi-gas approach, with the aim of finding the most cost-efficient set of reduction options.

Baseline development and profiles for stabilising GHG concentrations.

- **Sharp GHG emission reductions are required to limit global mean temperature increase to 2°C over pre-industrial level. For a median climate sensitivity, global GHG emissions need to peak before 2020 and return to 1990 levels around 2030.**

The baseline scenario of this study, depicting possible GHG emission trends in the absence of climate policies, leads to a global mean temperature increase of more than 3°C over pre-industrial levels by 2100 with further increases thereafter.

Table 1: Overview of the two emission profiles

	Year in which:		Change in 2050		Temperature increase	
	Peak of global emissions	Emissions below 1990	Compared to baseline	Compared to 1990	2100	Equilibrium
IMAGE-S550e	2015	2030	-65%	-15%	2.0 (1.3-3.0)	2.4
IMAGE-S650e	2030	2070	-35%	+50%	2.3 (1.5-3.5)	2.9

Note: temperature increases are given for median climate sensitivity; the numbers in parentheses indicate ranges for lowest and highest climate sensitivity of the IPCC range. Numbers for equilibrium temperature (i.e. the ultimate temperature increase achieved after 1-2 centuries) are taken from comparable profiles in (IPCC, 2001b)).

Two global emission profiles, S550e and S650e, were developed for stabilising GHG concentrations at 550 and 650 ppmv CO_2 equivalent, respectively (see Table 1). Under the

S550e profile global mean temperature increase can remain below 2°C by 2100 for a low to medium value of the climate sensitivity[1]. Under the S650e profile, temperature increase in 2100 is unlikely to stay below this level, unless the climate sensitivity is at the low end of the range. At the same time, stabilising CO_2 equivalent concentrations at 550 ppmv requires substantially larger and earlier emission reductions than at 650 ppmv.

Regional emission reduction objectives resulting from different climate regimes

- **Halting global emissions growth within 2–3 decades will require early participation of developing countries in climate policies at lower income levels than Annex I countries under the Kyoto Protocol. Considerable strengthening of the reduction targets of Annex I countries is also required.**
- **The abatement efforts (allocations) for Annex I regions for S550e generally range from 25%-50% below 1990 levels in 2025 (across regions and regimes) and 70-85% in 2050. For S650e, these efforts range from 10% increase to 25% reduction in 2025 and 40-60% reduction in 2050. The 2100 Per Capita Convergence regime forms an exception, leads to lower targets for Annex I regions.**
- **Most non-Annex I regions will need to reduce their emissions by 2025 compared to baseline levels, but emissions can increase compared to 1990 under all regimes analysed. For non-Annex I regions, the results are generally more differentiated for the various commitment schemes, stabilisation targets and time horizons (2025 versus 2050) than for Annex I regions.**

The study explored three variants of the MS approach (different participation and differentiation rules) and two variants of the PCC approach (with different convergence years: 2050 and 2100) in terms of emission reduction requirements. For the Annex I regions, these were found to be much more determined by the stabilisation level than by climate regimes (in 2025, 40-60% reduction from baseline for S550e and 15-40% for S650e). Only the PCC regime based on a convergence year in 2100 forms an exception, and leads to the lowest reduction efforts for Annex I regions but the highest for non-Annex I regions. For the non-Annex I regions, results differ much more between regions and allocation regimes. For the low-income regions (Africa and South Asia), the reductions compared to the baseline levels in 2025 are limited (from less than 10% to even excess emission allowances), but increase to 20-40% in 2050. For the middle income regions (Latin America, Middle East & Turkey, and East and South-East Asia), these reductions increase from approximately 35-50% in 2025 to about 60-85% in 2050. Whether the PCC regime is more attractive to (low-income) non-Annex I countries depends strongly on the convergence year chosen. The analysis of the MS variants shows the SE & East Asia region (including China) to play a key role, as its participation relaxes the emission reductions for the other participating regions. Finally, the robustness analysis shows that future emission reductions of the different variants will depend just as much on the parameter chosen within each variant as the variant itself (the threshold levels for the MS approach and the convergence year for the PCC approach).

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[1] The climate sensitivity indicates the relationship between an increase in the GHG concentration and temperature. The range (1.5 – 4.5) indicates the current uncertainty in this relationship according to IPCC.

Abatement costs and implementation of the different climate regimes.

- **Stabilising the GHG concentrations at 550 and 650 ppmv CO_2-eq. was found to be feasible but resulting in major changes in the energy system. Restricting emissions to the S550e profile will require larger abatement costs than the S650e profile (equivalent to 1.0% versus 0.2% of world GDP in 2050)[2]. These numbers are subject to uncertainty (in particular regarding marginal abatement costs and the baseline scenario). There are large differences among the various regions. Under the S550e profile, costs range from net gains from Africa and South Asia in some regimes to costs up to 3-4% of GDP for Middle East&Turkey and 2% for CIS.**
- **Global costs of the Per Capita Convergence regimes are generally lower than the MS regimes, but this depends on a fully effective functioning of emission trading.**
- **The financial consequences of changes in fuel trade could for some regions (Middle East, North and West Africa, Oceania, possibly CIS and Latin America) be of the same order of magnitude as direct costs of implementing climate policies.**

Realising stabilisation of the GHG concentration at 550 and 650 CO_2-eq requires contributions from a large range of reduction options, including improved energy efficiency and profound changes in the energy mix. These changes, in combination with other mitigation measures, lead to larger abatement costs for the S550e profile than for the S650e profile (equivalent to 1.0% and 0.2% of GDP, respectively, in 2050), with a corresponding international permit price of €120-130 and €30-40 per ton CO_2-equivalent. Robustness analysis found for S550e, the costs to range from 1.0-1.5% for different assumptions on abatement costs. The international permit price and global abatement costs are mostly dependent on the GHG stabilisation level and the number of participants in international emission trading, while the regional effort rate is also dependent on the emission allocation rules; this can differ largely between regions (in particular, the non-Annex I regions).

For the abatement costs as per cent of GDP, four groups with similar effort rates can be identified, i.e.: 1) regions with high per capita emissions and a high income (Annex I regions excluding the FSU) who are confronted average costs when compared to other regions (0.5-1.0% of GDP in 2025); 2) regions with medium to high per capita emissions, but a medium to low income (FSU, the Middle East & Turkey, and to a lesser extent, Latin America) confronted with average to high costs (1.0-2.0% of GDP in 2025 and lower for Latin America); 3) regions with low to medium income levels and per capita emissions (South-East & East Asia) showing low to medium cost levels (0-0.3% of GDP in 2025); and 4) regions with low per capita emissions and a low-medium income (Africa and South-Asia) showing low costs or net gains from emissions trading. The financial flows involved in emission trading can be large, and depend on the regime. For the S550e, they amount to €200 billion for most regimes in 2025 and more than €500 billion in 2050. For the S650e profile, these numbers vary between €10-50 billion in 2025 and €150-300 billion in 2050.

The changes in the energy system will have a significant impact on energy trade. While some regions will gain from reduced energy imports (OECD90, Asia), others will suffer from reduced exports (Middle East, CIS, Latin America, parts of Africa). For the latter group lost oil revenues can be of similar magnitude as direct costs of climate policies. The export of biofuels might partly compensate the export losses of Latin America and CIS.

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[2] These abatement costs are equal to the sum of domestic abatement costs and the allowances traded times the international permit price (see also further in this report). These costs are compared to GDP measured in purchasing power parity to give an indication of the possible economic impacts in different regions.

- **Climate policies can have significant co-benefits, both in terms of reduced emissions of such regional air pollutants as SO_2/NO_x and in terms of avoided costs to control these gases. For developing countries, co-benefits could be an important support for sustainable development strategies.**

Implementing the S550e profile or, to a lesser extent, the S650e profile leads to lower emissions of air pollutants, thus also improving urban air quality and reducing acidification risks. For acidification in Asia, implementing the S550e profile can limit the areas exposed to high levels of acidification by an average of 50% compared to baseline.

Overall findings

- **In evaluating the fairness and political acceptability of the various regimes, it is not sufficient to only evaluate the allocation of the emissions compared to baseline. Also required is an assessment of the distribution of abatement costs, impacts from emission trading and the impacts resulting from a change in energy trade.**

Although all regimes start off from a consistent set of ‘fairness’ principles, it was found that that abatement costs, impacts of emission trading and changes in energy trade may result in a much larger burden for some regions than for others, possibly constituting a ‘disproportional or abnormal burden’(UNFCCC, Art. 3). Therefore, in evaluating the fairness and political acceptability, it is important to not only assess emission allocations but also the resulting regional cost levels. The most prominent example in our analysis is the Middle East & Turkey region, confronted with much higher costs than other regions as a consequence of not only high abatement costs but also loss of energy exports.

- **Financial gains from emission trading and co-benefits of climate policies may allow non-Annex I countries to take on quantified emission limitation commitments (if not too strict) at net gains or low costs while alleviating the costs of GHG emission policies at the world level at the same time. This, however, requires a fully effective functioning of emission trading instruments.**

Global emission trading and reduced air pollution damage can make early participation of developing countries in global GHG emission control possible at net gains or low costs, provided that the level of the commitment is well chosen (not too strict). The PCC2050 and the MS variants provide schemes that fulfil this criterion. However, the financial gains depend on a fully effective functioning of emission trading instruments, which may be hampered due to limited institutional capacity in low-income countries. As participation of low-income countries also reduces global abatement costs, there is an important interest in capacity building in this area.

- **Further research is needed on alternative future commitment regimes, implementation issues and methods to take national circumstances into account.**

In this study, selected regimes have undergone an initial assessment in terms of their costs and benefits. It would be worthwhile to analyse alternative proposals, including those which have already formed part of our earlier assessment. As a next step, the approaches deemed promising need to be subjected to a more refined analysis, including issues of practical feasibility (e.g. data needs) and institutional requirements. Finally, the large differences in regional costs indicates that national circumstance may need to be better accounted in the design of future regimes.

Samenvatting

Hoewel het Kyoto Protocol een belangrijke stap vormt in de ontwikkeling van internationaal klimaatbeleid, zijn voor stabilisatie van de broeikasgas (BKG) concentraties in de atmosfeer (UNFCCC, Artikel 2) veel verdergaande reducties nodig. Een belangrijke vraag daarbij is hoe een ‘eerlijke’ verdeling van inspanningen tussen landen eruit zou kunnen zien. In een eerder RIVM rapport (den Elzen et al., 2003b) zijn een vijftal regime benaderingen geanalyseerd in termen van verdeling van regionale reductiedoelstellingen (Multi-stage, Per Capita Convergence, Braziliaans Voorstel, Jacoby Rule en de Preferentie Score). Dit rapport beschrijft de resultaten van een uitgebreidere analyse van de technische en economische consequenties van (varianten van) twee van deze benaderingen:

- De *Per Capita Convergentie benadering* (of *Contraction and Convergence*), waarbij voor alle landen vanaf 2013 emissierechten worden gedefinieerd op basis van een convergentie van hoofdelijke emissie ruimte onder een (dalend) wereldwijd BKG plafond (Meyer, 2000).
- De *Multi-stage benadering,* waarbij landen op grond van hoofdelijk inkomen en emissies worden ingedeeld in groepen met verschillende typen van doelstellingen (stadia). Deze benadering resulteert in een geleidelijke uitbreiding van het aantal landen met met kwantitatieve doelstellingen alsmede van de stringentheid van hun doelstellingen (Berk and den Elzen, 2001).

De consequenties van beide regimes zijn geanalyseerd voor twee mondiale emissieprofielen die leiden tot stabilisatie van de BKG concentraties op respectievelijk 550 en 650 ppmv CO_2-eq. De analyse is gebaseerd op een zogenaamde multi-gas benadering, gericht op het vinden van een kosten-optimale set van reductie opties. Voor de analyse is gebruik gemaakt van een raamwerk bestaande uit het ‘Integrated Assessment’ model, IMAGE 2.2, het wereld energie model TIMER 1.0 en de klimaatbeleid scanner FAIR 2.0.

Baseline ontwikkeling en profielen voor stabilisatie van de BKG concentratie

- **Sterke BKG emissiereducties zijn nodig om de mondiale gemiddelde temperatuur stijging te beperken tot 2°C boven preïndustrieel niveau. Wanneer wordt uitgegaan van een medium klimaatgevoeligheid, moeten mondiale BKG emissies pieken vóór 2020 en rond 2030 terugkeren op 1990 niveau.**

Zonder klimaatbeleid stijgt in het referentie (baseline) scenario van deze studie de mondiale gemiddelde temperatuur tot met meer dan 3°C boven het preïndustriele niveau in 2100, nog sterk doorstijgend daarna. Als alternatief zijn twee mondiale emissie profielen, S550e and S650e, ontwikkeld die leiden tot stabilisatie van de BKG concentraties op respectievelijk 550 en 650 ppmv CO_2 equivalent in 2100 en 2150. In geval van het S550e profiel zal de gemiddelde temperatuur in 2100 met minder dan 2°C gestegen zijn voor een lage tot medium waarde van de klimaatgevoeligheid[3]. Onder het S650e profiel is het onwaarschijnlijk dat de temperatuur stijging tot dit niveau beperkt zal blijven tenzij de klimaatgevoeligheid dicht bij de onderkant van de IPCC range blijkt te liggen. Voor stabilisatie op het S550e niveau zijn echter aanzienlijke sterkere emissie reducties vereist dan voor het S650e niveau.

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[3] De klimaatgevoeligheid geeft de relatie weer tussen een stijging van de broeikasgas concentratie en de temperatuur. De range (1.5-4.5) geeft de huidige onzekerheid in deze relatie weer volgens het IPCC.

Regionale emissie reductiedoelstellingen voor verschillende klimaat regimes.

- **Het stoppen van de mondiale emissie groei binnen 2 tot 3 decades vereist een vroege bijdrage van ontwikkelingslanden aan emissie beperking, bij lagere inkomensniveaus dan de Annex I landen onder het Kyoto Protocol. Daarnaast is een aanzienlijke aanscherping van de doelstellingen voor Annex I landen nodig.**
- **De reductie doelstellingen van Annex I landen voor S550e liggen in 2025 voor de verschillende benaderingen tussen de 25%-50% onder 1990 niveau (afhankelijk van regio en regime) en 70-85% in 2050. Voor S650e variëren deze doelstellingen van een 10% toename tot een 25% reductie in 2025 en een 40-60% reductie in 2050. Het 2100 Per Capita Convergence regime vormt een uitzondering en leidt tot lagere doelstellingen voor Annex I landen.**
- **De meeste niet-Annex I regio's moeten voor alle geanalyseerde regimes in 2025 hun emissies reduceren ten opzichte van baseline, maar kunnen hun emissies nog laten groeien ten opzichte van 1990. De resultaten voor non-Annex I regios laten in de regel een diverser beeld zien voor verschillende regimes, stabilisatie doelen, regio's en tijdsperiodes (2025, 2050) dan die voor Annex I regio's.**

In de studie zijn drie varianten van de MS benadering (met verschillende participatie en verdelingsregels) en twee varianten van de PCC benadering (met verschillende convergentie jaren: 2050 en 2100) geanalyseerd. Voor de Annex I regio's blijken de reductiedoelstellingen meer afhankelijk van het stabilisatieniveau dan van de verdelingsbenadering (in 2025 variëren de reducties van baseline tussen de 40-60% reductie voor S550e en tussen de 15-40% voor S650e). Alleen het PCC regime met convergentie jaar 2100 vormt een uitzondering en leidt tot de laagste reductiedoelstellingen voor de Annex I regio's (maar de hoogste voor niet-Annex I regio's). Voor de niet-Annex I regio's hangen de resultaten meer af van de regio's en het verdelingsregime. De reductiedoelstellingen voor midden-inkomensregio's zoals Latijns Amerika, Midden Oosten (inclusief Turkije) en Zuid Oost & Oost Azië (15-40% en 10-30% reductie voor respectievelijk S550e en S650e) zijn in de regel groter dan voor de lage-inkomensregio's Afrika en Zuid Azië. Of de PCC regime aantrekkelijker is voor niet-Annex I landen hangt zeer sterk af van het convergentiejaar. De analyse van de Multi-Stage varianten toont verder aan dat de Zuid Oost & Oost Azië regio (waaronder China) een cruciale rol speelt, aangezien deelname leidt tot lagere reductiedoelstellingen voor de andere deelnemende regio's. Tenslotte toont de gevoeligheidsanalyse aan dat toekomstige emissiereducties even afhankelijk zijn van de parameter keuze binnen elke benadering als van de benadering zelf (de regels voor de MS benadering en het convergentie jaar voor de PCC benadering).

Implementatie van de verschillende regimes en de bijbehorende bestrijdingskosten

- **Stabilisatie van de BKG concentratie op 550 en 650 ppmv CO_2-equivalent is technisch en economisch mogelijk – maar implementatie vereist sterke veranderingen in het energiesysteem. Emissiebeperking voor stabilisatie onder het S550e profiel leidt tot hogere bestrijdingskosten dan onder het S650e profiel (gelijk aan 1,0%, respectievelijk 0,2% van het wereld BNP). Deze getallen zijn globaal en afhankelijk van onzekerheden ten aanzien van de kosten van reductiemaatregelen en de baseline. Er zijn ook grote verschillen tussen de regio's. Voor het S550e profiel variëren de kosten van netto winsten voor Afrika en Zuid Azië onder bepaalde regimes tot kosten tot 3-4% als percentage van BNP voor de regio's Midden Oosten & Turkije en 2% voor CIS.**

- **De mondiale kosten van het PCC regime liggen door de volledige deelname van alle regio's aan emissiehandel wat lager dan van het MS regime, maar dit is wel afhankelijk van het effectief functioneren van emissiehandel.**
- **De financiële gevolgen van veranderingen in energie handel kunnen voor bepaalde regio's net zo groot zijn als de directe kosten van klimaatbeleid (Midden Oosten, Noord en West Afrika, Oceanië, mogelijk CIS en Latijns Amerika).**

Om de BKG concentratie op 550 and 650 CO_2-eq te stabiliseren is een bijdrage van een range van opties nodig, waaronder verbetering van de energie efficiëntie, en sterke wijzigingen in de energieproductie. In combinatie met andere maatregelen, leiden deze veranderingen tot hogere kosten voor het S550e profiel dan voor het S650e profiel (gelijk aan respectievelijk 1,0% en 0,2% van het BNP in 2050). De internationale koolstofprijs en de mondiale bestrijdingskosten zijn vooral afhankelijk van het BKG stabilisatie niveau en het aantal deelnemende landen in internationale emissiehandel. De regionale kosten zijn echter daarnaast ook sterk afhankelijk van de verdeling van emissieruimte. Deze kosten kunnen sterk verschillen tussen de regio's (vooral tussen de non-Annex I regio's).

In het algemeen geldt dat regio's met zowel een hoog inkomen als hoge emissies per hoofd ten opzichte van andere regio's worden geconfronteerd met een gemiddeld kostenniveau ten opzichte van hun BNP; dit betreft de OECD90 landen. Regio's met een gemiddeld inkomen, maar met relatief hoge emissies per hoofd worden geconfronteerd met relatief hoge kosten: dit betreft de CIS, het Midden Oosten & Turkije en mogelijk Latijns Amerika. Regio's met lage tot gemiddelde emissies per hoofd en laag tot gemiddeld inkomen zien relatief lage kosten (met name ZO en Oost Azië). Tenslotte hebben regio's met zeer lage emissies en inkomen in de regel geringe kosten en kunnen zij (afhankelijk van het regime) zelfs profiteren van emissiehandel: Afrika en Zuid Azië. De financiële stromen die gemoeid zijn met de handel in emissierechten hangen af van het regime, maar zijn over het algemeen zeer groot. Voor het S550e profiel liggen zij voor de meeste regimes rond de €200 miljard in 2025 en meer dan €500 miljard in 2050. Voor het S650e profiel, variëren deze getallen tussen de €10-50 miljard in 2025 en €150-300 miljard in 2050.

De veranderingen in het energiesysteem hebben ook grote consequenties voor de handel in energiedragers. Terwijl verschillende regio's zullen profiteren van beperktere import van energiedragers (OECD90 en Azië), zullen andere regio's lijden onder verminderde exportmogelijkheden (Midden Oosten, CIS, Latijns Amerika en delen van Afrika). Voor deze groep geldt dat de gemiste olieopbrengsten van een zelfde orde van grootte kunnen zijn als de directe kosten van klimaatbeleid. De export van biobrandstoffen biedt in geval van Latijns Amerika en CIS hiervoor (gedeeltelijke) compensatie.

- **Klimaatbeleid kan sterke nevenvoordelen met zich meebrengen, zowel in termen van gereduceerde emissies van stoffen als SO_2/NO_x als in termen van de vermeden kosten om de emissies van deze gassen te bestrijden. Voor ontwikkelingslanden zouden deze nevenvoordelen een belangrijke bijdrage kunnen leveren aan strategieën ten behoeve van duurzame ontwikkeling.**

Het implementeren van het S550e profiel en, in mindere mate, het S650e profiel leidt tot lagere emissies van luchtverontreinigende stoffen en, daarmee tot een verbetering van stedelijke luchtkwaliteit en vermindering van verzuringsrisico's. Voor Azië geldt dat de gebieden die worden blootgesteld aan hogere verzuringsrisico's met 50% zou kunnen afnemen als gevolg klimaatbeleid onder het S550e profiel.

Algemene bevindingen

- **Bij het evalueren van de rechtvaardigheid en te verwachten mate van politieke acceptatie van de verschillende regimes is het onvoldoende om alleen naar de initiële verdeling van emissieruimte ten opzichte van een baseline ontwikkeling te kijken. Het is ook nodig een inschatting te maken van de verdeling van de bestrijdingskosten, rekeninghoudend met de mogelijkheden voor emissiehandel, en de gevolgen voor de handel in energiedragers.**

Hoewel alle regimes starten met een consistentie set van ‘rechtvaardigheidsprincipes’, blijkt uit de analyse dat de bestrijdingskosten, de effecten van emissie handel en de gevolgen voor de handel in energiedragers kunnen leiden tot veel grotere economische gevolgen voor sommige regio’s dan voor anderen. Daarom is het in het beoordelen van de ‘rechtvaardigheid’ en ‘politieke acceptatie’ van de regimes, niet alleen belangrijk om naar de verdeling zelf te kijken, maar ook naar de regionale kostenniveaus. Het negeren hiervan kan leiden tot ‘disproportionele of abnormale lasten’ (UNFCCC. Art.3) voor bepaalde regio’s. Dit geldt met name voor de regio’s Midden Oosten & Turkije en CIS die niet worden geconfronteerd met de hoogste directe kosten van klimaatbeleid per eenheid BNP, maar ook met hoge verloren olie opbrengsten.

- **De financiële opbrengsten van emissiehandel en de nevenvoordelen van klimaatmaatregelen kunnen een reden zijn voor niet-Annex I landen om emissiebeperkingen op zich te nemen (indien deze niet te strikt zijn). Dit leidt tevens tot lagere mondiale kosten. Voorwaarde is wel een effectief functioneren van de emissiehandelsinstrumenten.**

De resultaten van onze analyse laten zien dat de opbrengsten van deelname aan mondiale emissiehandel en de baten van vermeden luchtverontreiniging redenen kunnen zijn voor ontwikkelingslanden om deel te nemen in mondiale BKG emissiebeperking. Dit geldt echter alleen wanneer de vorm en mate van de verplichtingen zo worden gekozen dat economische risico’s worden vermeden. De PCC 2050 en de Multi-stage varianten bieden beide schema’s die aan dit criterium voldoen. De financiële opbrengsten van emissiehandel hangen echter af van een volledig effectief functioneren van emissiehandel instrumenten. Dit functioneren wordt gehinderd door de beperkte institutionele capaciteiten van lage inkomenslanden. Omdat de participatie van lage-inkomenslanden ook de mondiale kosten reduceert, is er dus een groot belang bij ‘capacity building’ op dit gebied.

- **Verder onderzoek is nodig naar alternatieve allocatie regimes, methoden om nationale omstandigheden beter mee te kunnen nemen en implementatie vraagstukken.**

In deze studie is voor enkele geselecteerde regimes een inschatting gemaakt van de mondiale en regionale kosten en opbrengsten. Het is aan te bevelen dit ook te doen voor alternatieve voorstellen, waaronder die welke reeds onderdeel waren van onze eerdere verkenning. Als een volgende stap zouden de veelbelovende voorstellen nader kunnen worden bestudeerd, met name wat betreft verschillende implementatie aspecten (zoals data beschikbaarheid, institutionele vereisten, en dergelijke). Tenslotte leiden de geconstateerde verschillen in regionale kosten niveaus tot de aanbeveling nader te bestuderen hoe nationale omstandigheden beter meegenomen kunnen worden in verdelingsvoorstellen.

1 Introduction

1.1 Background

The UN Framework Convention on Climate Change calls for a stabilisation of greenhouse gas (GHG) concentrations in the atmosphere at levels that prevent dangerous anthropogenic interference with the climate system (UNFCCC Article 2) (UNFCCC, 1992). At the moment, there are still too many uncertainties across the causal chain of climate change from activities to impacts to unambiguously determine ‘safe’ concentration levels below which this condition can be considered fulfilled. In fact, determining these ‘safe’ levels is not only a scientific question but is also related to perceptions, values and political negotiations. IPCC’s Third Assessment report indicates that, in any case, such stabilisation will require substantial reductions of global GHG emissions of more than 60% of the 1990 level (IPCC, 2001b). In 1996 the EU Council adopted as its long-term climate objective, a global-mean temperature change that would not exceed 2 degrees Celsius compared with pre-industrial level, requiring a global emission reduction of at least a similar order of magnitude. It is clear that such global emission reductions will require substantial effort in future GHG emission control by all countries, going far beyond the type of reductions that have been set in the Kyoto Protocol (KP). The KP is an important milestone in international climate policy-making, as it constitutes the first international treaty with legally binding quantified commitments to limit greenhouse gas emissions for a group of industrialised countries (Annex I). In the context of the efforts required to finally stabilise GHG concentration, however, it is only a first step. This raises the important question about what future levels of commitments would be needed in the commitment period after the KP (in particular, between 2015 and 2025) and what would constitute a fair differentiation of commitments among countries.

It should be noted that the issue of timing and level of the emission control (needed by both developed and developing countries) cannot be analysed independently of the issue at which level climate policies intend to stabilise the GHG concentration. In the case of stabilisation levels below a doubling of pre-industrial GHG concentrations (approximately 650 ppmv CO_2-equivalent concentration), it will be crucial that developing countries (non-Annex I Parties) already commit themselves to restricting their emissions in the next few decades (den Elzen et al., 2003b). The share of non-Annex I countries in global greenhouse gas emissions was about 30% in 1990, but is projected to exceed that of the industrialised countries in the coming decades (IMAGE-team, 2001; Nakicenovic et al., 2000). Considering the complexity of the issue, there is a need for an early start of analytical work that can support an evaluation of policy options.

1.2 Analysing the implications of climate regime options

Both prior to the negotiations on the KP and afterwards there have been many proposals for differentiating mitigation commitments among countries, both from academic circles as well as from Parties to the UNFCCC (see for an overview e.g. (Banuri et al., 1996; Berk et al., 2002; Depledge, 2000; Reiner and Jacoby, 1997; Ringius et al., 1998)). Amongst the most comprehensive quantitative analysis of multiple regime proposals at a global scale are studies by (Blanchard et al., 2001; den Elzen, 2002; Jacoby et al., 1997; Jacoby et al., 1999; Rose et al., 1998) (Babiker and Eckhaus, 2002; Höhne et al., 2003). In addition, there have been some more qualitative assessments including (Baumert et al., 2002; Evans, 2002; Müller, 2003; OECD/IEA, 2002). However, the number of comparative studies systematically evaluating the implications of various post-Kyoto regime options for a wider range of implications on a global scale is limited. Most studies have limitations regarding either the options reviewed, the level of elaboration (rather stylised/academic approaches), the level of analysis (Annex I only; limited regional detail), the link to (long-term) environmental implications (mostly absent, certainly in more economic oriented studies), the time horizon (only short-term / KP horizon) or quantification of technical or economic implications (often absent) or a lack of consistent quantification). In addition, almost all studies focus on CO_2-only instead of taking all (Kyoto) GHGs into account.

Earlier, we have made both a quantitative and qualitative assessment of five different Post-Kyoto climate policy regimes: Multi-stage, Per Capita Convergence, Brazilian Proposal, Jacoby Rule and Preference Score (den Elzen et al., 2003b). This study explored the implications of the regimes in terms of the allocation of emission reductions efforts under two different stabilisation targets for the atmospheric carbon dioxide concentration. In addition, we performed a multi-criteria evaluation to identify strenghts and weaknesses of the various approaches on the basis of emission allocations only. On the basis of these results, two approaches were selected for a more in-depth analysis of their technical and economic implications: Multi-stage and Per Capita Convergence. Both the earlier study – and the current study form a contribution to the first phase of the EU project ‘Greenhouse gas reduction pathways in the UNFCCC post-Kyoto process upto 2025’ (GRP) (Criqui et al., 2003)[4].

1.3 Purpose of the report

This report describes a systematic analysis of the environmental, technical and economic implications of different variants of.the Per Capita Convergence (PCC) and Multi-stage (MS) regime approaches. (see short description below). The Multi-stage approach was chosen as a typical example of an approach in which the number of regions with binding emission targets are gradually increasing. The Per Capita Convergence approach was chosen as a typical example of an approach in which all regions will participate from 2013 onwards.

- The Per Capita Convergence approach, developed and promoted by the Global Commons Institute (Meyer, 2000), defines emission permits on the basis of convergence of per capita emissions under a contracting global GHG emission profile. In such a convergence regime, all countries participate in the climate regime with emission allowances converging to become the same as per capita levels over time.
- The Multi-stage approach consists of a system to divide countries into groups with different levels of responsibility or types of commitments (stages). Over time, the approach results in a gradual increase in the number of countries and their level of commitment according to participation and differentiation rules, based on such criteria as per capita income or per capita emission (Gupta, 1998) and (Berk and den Elzen, 2001). For the purpose of the reported here, three new variants of the Multi-stage approach were developed.

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[4] The project was carried out by a partnership of European Institutes, i.e. CNRS-IEPE (Institut de l’Economie et de Politique de l’Energie, now integrated in the Departement Energie et Politiques de l ‘Environment (EPE) (department of Energy and Environment) of the University of Grenoble, France), RIVM (National Institute for Public Health and the Environment, the Netherlands), ICCS-NTUA (Greece) and CES-KUL (Belgium) for the European Commission.

We have explored the consequences of these proposals in combination with two different levels of ambition in stabilising the level of GHGs in the atmosphere: 1) stabilisation at 550 ppmv CO_2-equivalent concentration and 2) stabilisation at 650 ppmv CO_2-equivalent concentration. In this way, we can not only provide insights into the technical and economic consequences of different regimes, but also into the degree to which the results comply with an objective to limit the increase in global mean temperature to a maximum of 2°C compared to pre-industrial levels. The implications explored include overall climate effects (realising the uncertainty in the climate system), regional reduction targets, costs of implementation and emission trading, the required changes in the energy system and the impacts and the possibilities for co-benefits in terms of reducing regional air pollution (nitrogen and sulphur emissions). More than one variant per approach were analysed. Convergence years of 2050 and 2100 were used for the Per Capita Convergence approach, while three different variants of participation rules were explored for the Multi-stage approach.

1.4 General overview of the report

A modelling framework, consisting of the Integrated Assessment model, IMAGE 2.2, the world energy model, TIMER 1.0 and the climate policy scanner, FAIR 2.0 has been developed for the purpose of assessing the broad range of different impacts as discussed above. In addition, the RAINS-Asia model has been used to assess the possible co-benefits for acidification in Asia in more detail. The whole analysis was carried out using a so-called a multi-gas approach, i.e. taking into account all six greenhouse gasses considered in the Kyoto Protocol. The methodological aspects are discussed in more detail in Chapter 2.

The research was set-up along a systematic framework of analysis, consisting of five different steps (see also Figure 1.1):

1. *Development of a baseline scenario:* first, an analysis is done of the possible development of emissions in the absence of climate polices (Chapter 3).
2. *Development of global emission profiles:* next, two alternative greenhouse gas emission profiles that stabilise GHG concentration at 550 and 650 ppmv CO_2-eq, respectively, were developed. Comparing the baseline to these emission profiles allows us to identify the global emission reduction effort (Chapter 3).
3. *Development of climate regimes and evaluation of emission allowances:* after this, the consequences of the two different climate regimes are explored in terms of the emission reduction allowances per region (Chapter 4).
4. *Technical and cost evaluation of the regimes*: the allowances form the basis of an analysis into the implementation of the regimes, identifying the level of emission trading, abatements costs and the type of abatement action. Particular attention is paid to the consequences for the energy system (Chapter 5).
5. *Assessment of implications for climate change and regional air pollution:* finally, an assessment was made of the climate consequences (benefits) and co-benefits of the different regimes (Chapter 6).

The main conclusions are summarised in Chapter 7.

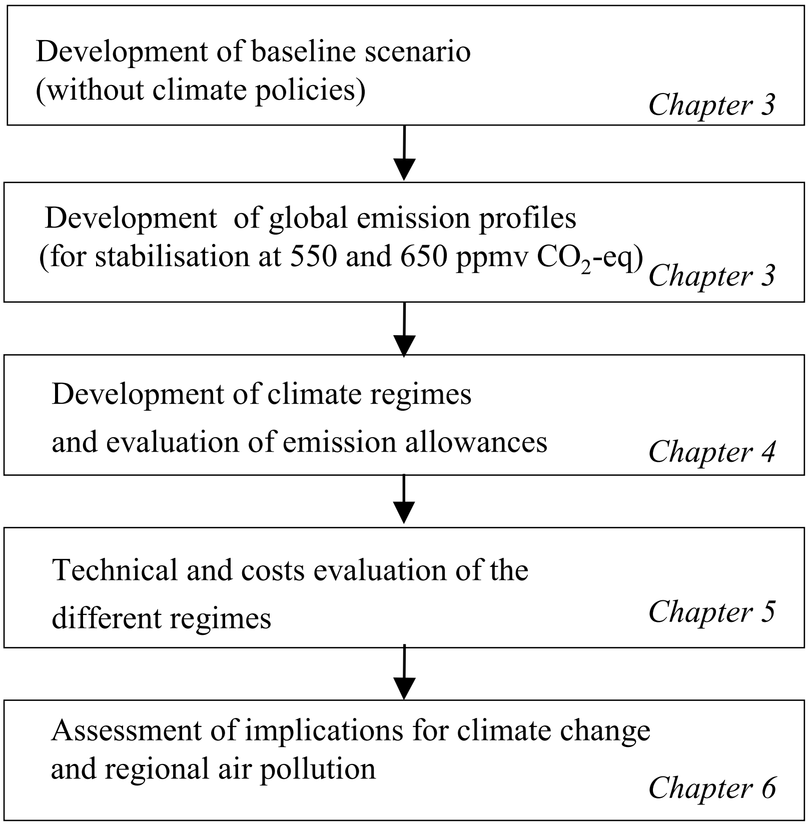

Figure 1.1: Systematic framework for the analysis performed.

2 Methodology

2.1 Introduction

We have analysed technical, economic and environmental consequences of variants of the Per Capita Convergence (PCC) and Multi-Stage (MS) approach for differentiation of future commitments (further referred as climate regimes). Both approaches will be discussed in more detail in Chapter 3. These regimes, applied under two different emission profiles, lead to a stabilisation of the greenhouse gas concentration at 550 and 650 ppmv CO_2-equivalent, respectively. For our evaluation, we used a set of linked and related models, i.e. the IMAGE 2.2 model (IMAGE-team, 2001), the FAIR 2.0 model (den Elzen and Lucas, 2003) and the TIMER 1.0 model (de Vries et al., 2002). In addition, the RAINS-ASIA model (Amann et al., 2000) was used to assess the potential co-benefits of the climate policies on regional air pollution in Asia. The methodology is described in more detail in section 2.2, while a short description of the four main models is available in Box 2.1. A more elaborate description can be found in Annex 1. In section 2.3 we will discuss some of strengths and weaknesses of the current approach.

2.2 Overall steps within the analysis

As indicated in the introduction, our analysis was structured around five main steps (Figure 1.1). Figure 2.1 indicates schematically how these steps are related to the different models used in the analysis. The different steps are described in the next sections. Details on assumptions are provided in the individual chapters recording the results.

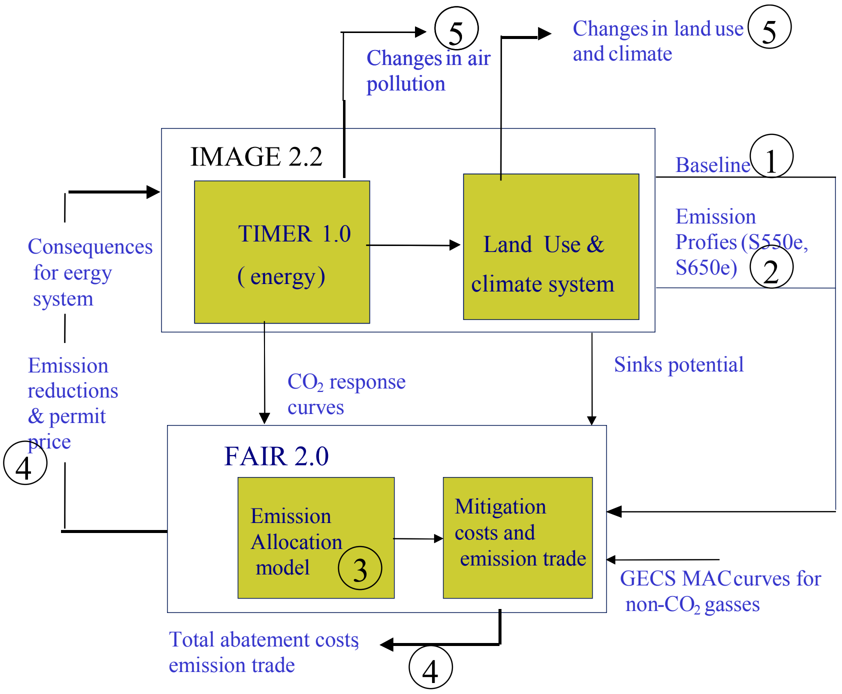

Figure 2.1: Overview of the linked model systems used for this analysis. Circled numbers refer to the steps in the analysis steps (see Figure 1.1 and sections 2.2.1 to 2.2.5).

In general terms, the IMAGE and TIMER models were used first to determine potential greenhouse gas emissions and the climate impacts in the absence of climate policies (baseline) (step 1). Next, the IMAGE model was used to develop emission profiles that would lead to a stabilisation of greenhouse gases at 550 and 650 ppmv CO_2-equivalent (step 2). Both TIMER and IMAGE also provide information on the potential costs of reducing emissions from different sources. The FAIR model was then used to evaluate the regional emission allowances resulting from the different climate regimes and emission profiles (step 3). FAIR was also used to determine the international permit price, the domestic and external abatements and cost levels on the basis of marginal abatement costs (step 4). At the same time, the TIMER model was employed to determine the impacts and costs of emission reductions within the energy system. Finally, the climate impacts and co-benefits of different regimes (step 5) were assessed.

2.2.1 Development of a baseline scenario without climate policies

The TIMER and IMAGE models were used to develop the baseline scenario assuming no climate policies. This scenario, developed on the basis of elements of the POLES baseline scenario and the IMAGE SRES A1b and B2 scenarios, is further referred as the Common Poles IMAGE baseline (CPI). The baseline assumes a continued process of globalisation, medium technology development and a strong dependence of fossil fuels. The results of this analysis are described in Chapter 3.

2.2.2 Development of global emission profiles for stabilising GHG concentration levels

Next, on the basis of the baseline, the IMAGE model was used to develop different emission profiles for six (groups of) greenhouse gases (CO_2, CH_4, N_2O, SF_6, HFC and PFCs) to lead to a stabilisation of the greenhouse gas concentration in the atmosphere. Two alternative levels were explored, i.e. stabilising greenhouse gases at 550 CO_2-equivalent and 650 CO_2-equivalent[5], respectively. Up to 2012, the global emissions of both profiles are based on the assumption that most Annex I countries will implement their respective Kyoto targets (including use of flexible instruments) while the USA will implement the objectives of the Bush Climate Action Plan (see (van Vuuren et al., 2002)). All other regions will follow the baseline. After 2012, global emissions will start to diverge from the baseline – to reach the maximum allowable emissions in order to meet the concentration targets. The profiles are all expressed in CO_2-equivalent emissions using 100 year GWPs (IPCC, 2001b)[6]. The results of the development of the baseline and the overall emission profiles are described in Chapter 3.

2.2.3 Development of climate regimes and evaluation of emission allowances

The FAIR model uses the baseline scenario (greenhouse gas emissions, population and income) and the emission profiles to distribute the global emission reduction objective over the different regions according to the different climate regimes, i.e. the PCC and the MS variants. The results of each of these climate regimes and their variants were assessed in terms of emission reduction objectives by region and are further described in Chapter 4.

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[5] The CO_2-equivalent concentration is a measure of the radiative forcing of all Kyoto greenhouse gases in the atmosphere. The concept is explained in detail in Chapter 3.

[6] It should be noted that in the development of the profiles (rather arbitrary) assumptions were made on the reduction targets for the different GHG gases. Further on in the analysis, however, the profiles are used only in terms of total CO_2-equivalent emissions: the actual share of reductions for the different gases are in Chapter 5 determined on the basis of their reduction costs.

2.2.4 Technical and cost evaluation of the different regimes

In step 4, the emission reduction objectives were implemented in terms of actual emission reductions in the different regions, assuming a least-cost approach and including the use of flexible mechanisms (emissions trading and CDM projects) in the context of each regime. The abatement costs and emissions trading model, FAIR 2.0, were used to determine the internal market equilibrium permit price (permit price), the reductions in traded emissions and the total regional abatement costs. This is done using Marginal Abatement Costs (MAC) curves for the different regions, gases and sources. A MAC curve reflects the costs of abating the last ton of CO_2-equivalents, thereby describing the potential and costs of the different abatement options considered. The calculated permit price is used as a carbon tax in the TIMER energy model to determine the implementation of the emission reductions in the energy system. Several partial steps can be recognised within step 4. For example, information for each important source of GHG on the emissions reduction potential and its costs, available within IMAGE and TIMER, is provided to FAIR. This includes information on CO_2 emission reduction in the energy/industry system, information on the sinks potential and the activity levels, and assumed technology improvement for non-CO_2 emissions. Next, the abatement costs and level of emission trading within FAIR were determined given the different MAC curves and the conditions of trading market. Finally, the permit price was sent on to the TIMER model. The results are described in detail in Chapter 5.

2.2.5 Assessment of implications for climate change and regional air pollution

The final emission for each stabilisation level (after determining the changes in emission levels in the energy/industry system and taking into account the abatement action for land-use related sources) was finally evaluated in terms of its climate consequences in IMAGE. These climate consequences may be somewhat different from those of the original profiles due to different reduction actions for the different gases and the fact that changes in the energy system also change emissions of other gases such as sulphur dioxide (a cooling agent) and nitrogen oxides[7].

Finally, the potential co-benefits in terms of reduced regional air pollution as result of changes in the energy system were evaluated for the two different profiles. First, we evaluated the changes in emissions of sulphur dioxide and nitrogen oxide for the different global regions using the results of the TIMER model. Next, we downscaled the results of the three Asian TIMER regions to the level of different countries in order to evaluate in more detail the consequences for sulphur emissions in Asian countries using the RAINS-Asia model (Amann et al., 2000; IIASA, 2000). In this analysis, particular attention was paid to changes in the exceedance of the critical loads for acidification. The results of this analysis are described in Chapter 6.

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[7] These extra emission reductions are not taken into account in the abatement costs and emissions trading model of FAIR.

Box 2.1. Short description of the main models used

FAIR 2.0
The FAIR 2.0 model is a decision-support tool designed to quantitatively explore a range of alternative climate regimes for differentiation of future commitments in international climate policy and link these to targets for climate protection. The model consists of three integrated sub-models: a simple climate model, an emission allocation model and a abatement costs and emissions trading model. The climate model calculates greenhouse gas concentrations and climate change parameters for the different emission scenarios. The emission allocation model calculates the regional emission allowances on the basis of different climate regimes, stabilisation profiles and baseline scenarios. Finally, the abatement costs and emissions trading model determines the international permit price, the tradable emission permits and the total abatement costs in any emissions trading market, assuming a cost-optimal solution based on marginal abatement cost curves.

TIMER 1.0
TIMER is a system dynamics energy model. The model simulates the consumption and production of energy in 17 world regions, and the related energy and industrial emissions. Implementation of CO2 mitigation is generally modelled in TIMER on the basis of a carbon tax. The introduction of such a tax generates several responses within the model, including price-induced investments in energy efficiency, price-induced fossil fuel substitution, changes in the trade patterns of (fossil) fuels, and price-induced acceleration of investments in non-fossil options such as wind/solar energy, nuclear energy and biofuels.

IMAGE 2.2
The IMAGE 2.2 modelling framework consists of a set of linked and integrated models, which collectively describe important elements in the cause–response chain of global environmental change. The main objectives of the model are to contribute to scientific understanding, in particular, of the linkages between the various subsystems and their uncertainties; further, the model should support decision-making by quantifying the relative importance of major processes and interaction in the cause-response chain. The framework and its sub-models have been described in detail in several publications (Alcamo et al., 1998; IMAGE-team, 2001). Important elements of IMAGE include its description of emissions of greenhouse gases and regional air pollutants, and outlines on climate change and land-use change. Socio-economic processes are usually modelled at the level of 17 world regions, while climate, land-use and several environmental parameters are modelled at a 0.5 by 0.5 degree resolution.

RAINS-Asia 7.52
RAINS-Asia provides a consistent framework for the analysis of emission reduction strategies for sulphur dioxide emissions in large parts of Asia. On the basis of calculated emissions, the model is able to estimate acidification risks. In RAINS, a non-linear optimisation is used to identify the cost-minimal combination of measures, taking into account regional differences in emission control costs and atmospheric dispersion characteristics (Amann et al., 1999; IIASA, 2000).

2.3 Strengths and weaknesses of the current approach

We used a set of linked models as described in section 2.1 in our analysis. The approach taken has several strengths and weaknesses. The main strengths:

- Taken collectively, the models used provide a full, and detailed, description of the sources of GHG emissions and the different options for abatement. The system also has a high level of integration between energy/industrial emissions and emissions from land use in relation to environmental changes.
- The approach used considers all six Kyoto GHGs, allowing for full flexibility in abatement of these gases (so-called multi-gas approach) and in other options such as sinks.
- The description of costs of climate policies using an approach based on marginal abatement costs is transparent and flexible, allowing for a description of emission trading, including possible limitations in the use of flexible instruments (e.g. transaction costs and accessibility of reduction options).
- All of the sub-models used have been fully documented and employed in scientific and policy applications (e.g. IPCC’s Third Assessment Report).
- Integration of the IMAGE model allows us to indicate the direct climate consequences of regimes, while taking account of the uncertainties on climate sensitivity.

The main weaknesses of our approach are:

- The models have a system-dynamic orientation, in which economic changes have not been fully integrated. The costs calculated only represent the direct-cost effects based on MAC curves but not the various linkages and rebound effects via the economy or impacts of carbon leakage; i.e. there is no direct link with macro-economic indicators such as GDP losses or other measures of income of utility loss.
- The fact that the models are linked, and not integrated, also posses certain limitations. One of them is that we need to use an approach based on Global Warming Potentials (see Chapter 3 for a full discussion) to evaluate the cost-effectiveness of reduction options. At the same time, however, this is completely consistent with the way climate policies are currently formulated (e.g. Kyoto Protocol, climate policies of the USA); at the moment, no alternatives for actual climate policies seem to be available.

3 Global emission constraints and baseline emission scenario assumptions

3.1 Introduction

In 1996 the EU Council adopted as its long-term (EU) climate policy objective the aim to prevent a global mean temperature increase beyond 2 degrees Celsius over its pre-industrial level. To explore the global effort required to meet this objective, we have developed two alternative greenhouse gas emission profiles that would result in a stabilisation of the concentration of greenhouse gases at respective levels of 550 and 650 ppmv carbon dioxide equivalents (Eickhout et al., 2003)See also Box 3.1 for an explanation of the concepts of CO_2-equivalent concentrations and CO_2-equivalent emissions.

This chapter will provide a description of the main assumptions used for constructing these greenhouse gas stabilisation profiles and the baseline used in this study. It will also evaluate the emission reduction burden resulting from the baseline and the emission profiles.

The profiles in this chapter cover all six greenhouse gases covered in the Kyoto Protocol (CO_2, CH_4, N_2O, HFCs, SF_6, PFCs) in a so-called multi-gas approach. Most earlier work on mitigation scenarios and climate regimes, including our previous report on this issue (den Elzen et al., 2003b), focussed on CO_2 only. Although CO_2 is by far the main GHG in terms of its contribution to climate change, a full multi-gas approach can result in significantly different insights, mainly on the timing of emission reductions. These different insights result from gas-specific abatement costs and atmospheric lifetimes.

3.2 The baseline scenario

In order to identify options to meet the EU climate target and to assess their economic consequences, it is necessary to rely on a consistent baseline projection that reflects *what may happen if no further climate action were taken.* RIVM and IEPE, therefore took on the task of developing a new baseline, called the Common POLES-IMAGE (CPI) baseline, to explore the implications of different options for differentiating future commitments using both models. This baseline describes the development in the main driving forces (population and economic growth) and environmental pressures (energy, industrial and land-use emissions) for 1995-2100. The baseline is constructed by combining elements of the POLES reference scenario (Criqui and Kouvaritakis, 2000) and the IMAGE 2.2 A1b and B2 scenarios (IMAGE-team, 2001).

The baseline scenario describes a world in which globalisation and technology development continue to be an important factor for economic growth, although not as strong as assumed in the IPCC A1b scenario ((IMAGE-team, 2001; Nakicenovic et al., 2000)), for example. Economic growth can therefore be described as medium (per capita yearly growth rate of 2 to 3%) in almost all regions. As growth is greater in low-income regions than in high-income regions, the relative gap between the regions will be reduced. However, for economic growth to occur, regions will need to have a sufficient level of institutional development and stability. In the scenario it is assumed that in the first 2-3 decades, these conditions will not be met in Sub-Saharan Africa; as a result this region will clearly lag behind in terms of income growth.

However, the current barriers to economic development are gradually reduced in this same period– and from 2025/2035 onwards the region ‘takes off’ in terms of its development, similar to what we have seen for Asian countries in the past. The results of the most important driving forces by region are indicated in Table 3.1[8]. The assumptions for population are based on the UN medium projections up to 2030, as implemented in the POLES reference scenario. For the period of 2030-2100, the UN long-term medium projection as implemented for the IMAGE B2 scenario (IMAGE-team, 2001) was used. In this population scenario the global population stabilises at a level of 9.5 billion by 2100.

Table 3.1: Main driving forces of the CPI baseline by regions

	Population (in mill.)			Per Capita Income (in PPP €1995 per year)[9]			Per Capita Income (growth rates)	
	1995	2025	2050	1995	2025	2050	1995-2025	2025-2050
Canada & USA	296	362	391	25604	42520	55757	1.7%	1.1%
Enlarged EU	505	499	450	17128	34534	50107	2.4%	1.5%
CIS	293	298	273	1747	5323	14750	3.8%	4.2%
Oceania	28	40	46	15469	30054	43397	2.2%	1.5%
Japan	125	121	111	41052	65270	90424	1.6%	1.3%
Latin America	476	690	800	3591	6779	12144	2.1%	2.4%
Africa	719	1346	1831	613	873	1761	1.2%	2.8%
ME & Turkey	219	378	483	3282	6371	12577	2.2%	2.8%
South Asia	1245	1865	2160	356	1560	4060	5.0%	3.9%
SE & E Asia	1798	2293	2439	1392	7404	16930	5.7%	3.4%
World	5706	7891	8984	4931	9052	14413	2.0%	1.9%

Source: IMAGE 2.2

With the projected increase in population and income, primary energy use will also continue to grow in almost all regions. World-wide, primary energy use increases by about 75% in 1995-2025 and by another 40% in the2025-2050 period, almost all of this growth occurs in non-Annex I regions. Oil continues to be the most important energy carrier until 2040. After 2040 both natural gas and coal take over this position with particularly gas becoming the dominant energy carrier.

As a result, energy-related carbon dioxide emissions increase sharply in contrast to the the slowdown in emission increase increase at the end of the last century due. This slowdown was, in particular, due to to the sharp reductions in emissions in the Former Soviet Union and Eastern Europe following their economic decline. Another factor is the reduction in the CO_2 emissions in China in the second half of the nineties. However, the increase in energy use described above cause carbon dioxide emissions to increase from 21.6 $GtCO_2$ in 1995 to 39.5 $GtCO_2$ in 2025, and 54.7 $GtCO_2$ in 2050 (see Table 2.2 and Figure 2.1) and continue to be the major source of GHG emissions. After 2050, stabilising population levels also slow down further growth in carbon dioxide emissions. The share of non-Annex I countries in energy-related carbon dioxide emissions increases from 37% in 1995 to 45% in 2025 and to 66% in 2050.

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[8] For comparability of the modelling results, all results are presented for an aggregate of 10 world regions. The composition of these regions is given in Appendix I.

[9] GDP levels of different countries are normally compared on the basis of conversion to a common currency (mostly US$) using Market Exchange Rates (MER). However, this is known to underestimate the real income levels of low-income countries. Therefore, an alternative conversion has been developed on the basis of purchasing power parity (PPP). In this article, we have usually used PPP-based GDP estimates, but where required, MER-based estimates for comparison are used.

Using the land-use projections of IMAGE 2.2 (IMAGE-team, 2001)),we can assess total GHG emissions too (including land-use related emissions and non-CO_2 greenhouse gas emissions). In general, population growth and shifts to more luxurious diets lead to an additional need for agricultural land in the first half of century, despite improvements in agricultural production. Later, further productivity gains result in a surplus of agricultural land, in particular, land in high-income regions that can be converted into forest areas. 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 originate in developing regions, in particular, due to population growth that leads to a higher agricultural demand and, hence, deforestation. Consequently, the share from non-Annex I countries in total anthropogenic greenhouse gas emissions is larger than that of energy-related CO_2 emissions, increasing from 48% in 1995 to 65% in 2025, and 71% in 2050. Methane and nitrous oxide emissions increase up to 2060, after which they remain more-or-less constant. Finally, industrial emissions, including particularly the high GWP gases and process-related carbon dioxide emissions from cement production and feedstocks, increase slowly over the whole century – but remain relatively small compared to other sources.

Table 3.2: Main model results of the CPI baseline by region

	Primary energy use (in PJ per year)			CO_2 emissions (in $GtCO_2$ per year)			GHG emissions (in $GtCO_2$-eq per year) *		
	1995	2025	2050	1995	2025	2050	1995	2025	2050
Canada & USA	91848	121405	128373	6.10	8.09	8.40	7.55	9.50	9.58
Enlarged EU	66070	83380	86702	4.36	5.10	5.32	5.38	6.00	6.05
FSU	37276	51960	57174	2.32	3.24	3.59	3.20	4.50	4.71
Oceania	4754	7955	9675	0.33	0.54	0.64	0.53	0.79	0.87
Japan	18866	22851	22480	1.26	1.48	1.41	1.37	1.58	1.51
Latin America	21763	49891	88932	1.18	2.89	5.11	2.33	4.54	7.00
Africa	19940	43168	79215	0.79	2.32	4.52	1.60	4.17	7.32
ME & Turkey	15065	41306	67132	1.06	2.85	4.36	1.35	3.69	5.73
South Asia	25175	62628	116495	0.97	3.79	7.46	2.11	5.54	9.44
SE & E Asia	71984	168736	251999	4.62	11.36	16.03	6.64	14.42	19.28
World	372742	653278	908176	22.99	41.65	56.83	32.06	54.74	71.48

*: The GHG included here are the six Kyoto gases: CO_2, CH_4 $_2O$, SF6, PFCs and HFCs. However, the F-gases are excluded from the regional figures as only global estimates are made. Thus the regional subtotals do not add up to the world total.

Source: IMAGE 2.2

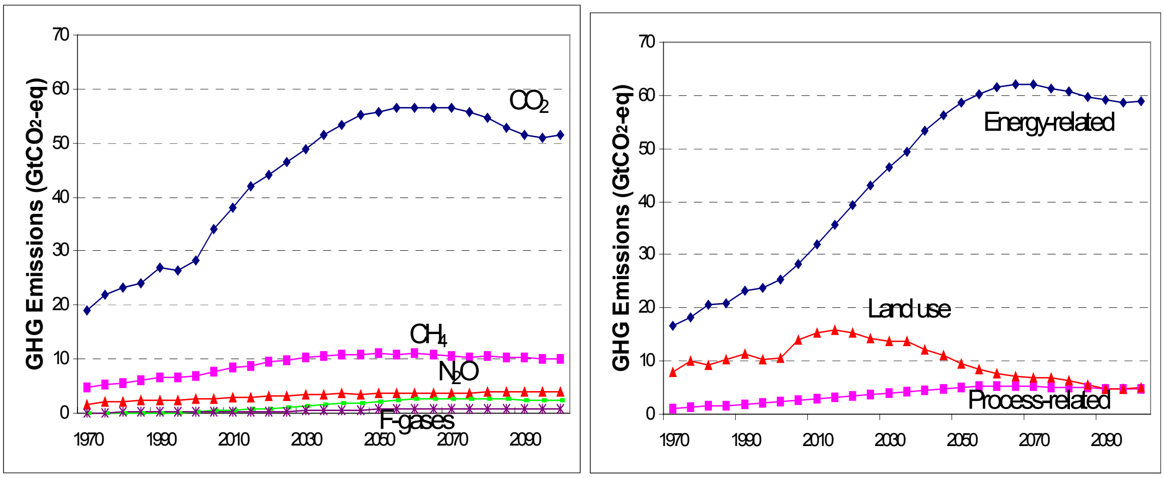

Figure 3.1: Greenhouse gas emissions in carbon-equivalents by gas (left) and sector (right). Source: IMAGE 2.2

Compared to the IPCC SRES baseline (here shown as elaborated by IMAGE 2.2 (IMAGE-team, 2001)) the CPI-baseline should be regarded as a medium emission baseline. The A1b and A2 scenario result in considerably higher emission throughout most of the century, the B2 and B1 scenario in considerable lower emissions.

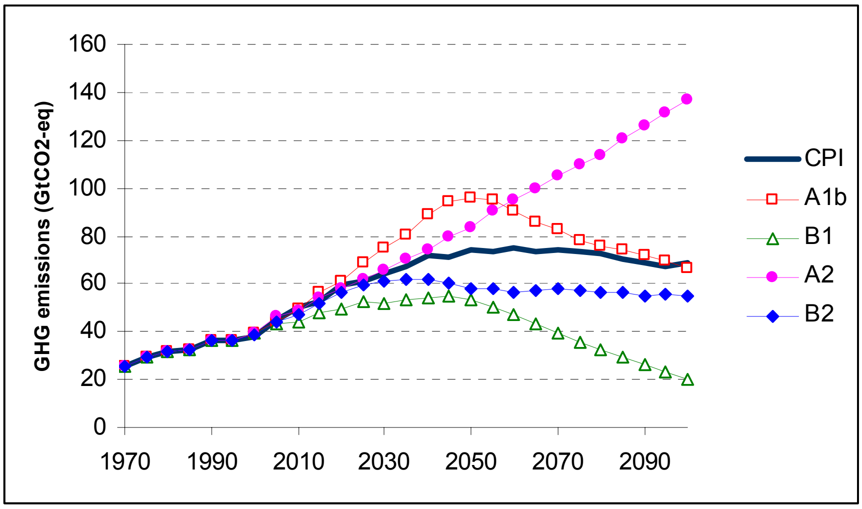

Figure 3.2: Greenhouse gas emissions of the CPI baseline compared to the IMAGE-SRES baselines. Source: IMAGE 2.2

The baseline scenario assumptions affect the emission profiles and burden-sharing results (presented in the next sections) in a number of ways. First of all, the baseline assumptions determine future land use, which, in turn, affects the carbon cycle, notably the uptake of carbon from the atmosphere by the biosphere (terrestrial carbon uptake) and non-CO_2 GHG emissions (e.g. methane from animals and rice paddies and N_2O from fertiliser use in agriculture). Second, in the analysis of the emission allocation schemes, baseline assumptions about future regional population levels and per capita income and emission levels are important, as they are used in the calculation of regional emission allowances (e.g. as participation and/or burden- sharing criteria) under the future commitment schemes. Finally, the baseline assumptions determine the global and regional emission reduction burden, i.e. the difference between global and regional emission constraints and baseline GHG emission levels.

3.3 Emission profiles for stabilisation of GHG concentration at 550 and 650 ppmv

The IMAGE 2.2 model (IMAGE-team, 2001) was used to construct emission profiles up to 2100 for stabilising GHG concentrations at 550 and 650 ppmv CO_2-equivalent in 2100 and 2150, respectively (see Figure 3.3).

The concept of CO_2 equivalent concentrations is used to express the contribution of all GHGs in the atmosphere on radiative forcing. In addition, the concept of CO_2 equivalent emissions is used to express the total GHG contribution to the emissions (using the Global Warming Potential). Box 3.1 explains the difference between the concepts in more detail. The years for stabilising GHG concentrations were adopted from IPCC for more-or-less congruent scenarios for CO_2 only. Construction of the profiles requires an initial estimation of the contribution of non-CO_2 GHGs to the CO_2-equivalent concentration level [10]. Hence, the 550 and 650 ppmv CO_2-equivalent profiles, hereafter referred to as IMAGE S550e and IMAGE S650e, respectively, were considered to be consistent with a stabilisation of the CO_2 concentrations at 450 and 550 ppmv CO_2, respectively. In the rest of the study we used total CO_2-equivalent emissions for our analyses, which led to the stabilisation profiles of IMAGE S550e and IMAGE S650e. Logically, the contribution of CO_2 and non-CO_2 on the basis of regimes and costs will differ from the assumptions explained here.

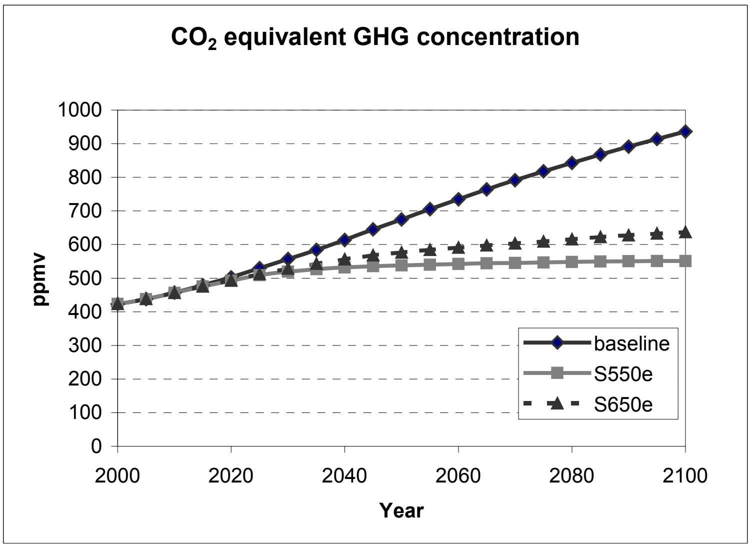

Figure 3.3: Global CO_2 equivalent concentration stabilisation profiles for S550e and S650e ppmv versus the CPI baseline scenario. Source: IMAGE 2.2

The profiles up to 2010 take account of the Annex I Kyoto Protocol targets, and the proposed GHG intensity target for the USA (-18% between 2002-2012) (van Vuuren et al., 2002; White-House, 2002). In the profiles, it is also assumed that about 80% of the excess emission allowances (hot air) by the Former Soviet Union and Eastern Europe is banked on the basis of revenue optimisation. Non-Annex I countries are assumed to follow their baseline emissions in this period.

In the profiles IMAGE S550e and IMAGE S650e, CO_2 emissions continue to rise in the first decades of the simulation. We have assumed that for stabilising the concentration at 550 ppmv CO_2-equivalents, the growth of CO_2 emissions shifts from an annual 1.95% increase in 2010 to a 2% decrease in 2020. The CO_2 emissions from 2020 to 2100 are determined by an inverse calculation with the IMAGE 2.2 model, determining the allowable emission levels resulting from a pre-described CO_2 concentration profile (i.e. 450 ppmv). The CO_2 concentration profile is determined with a similar method as described in Enting et al. (1994). The mitigation of non-CO_2 GHGs is based on assumptions to come to 100 ppmv CO_2-equivalents. Table 3.3 summarises the main characteristics of IMAGE S550e profile. For stabilisation in the IMAGE S650e profile, the CO_2 concentration is assumed to stabilise at 550 ppmv in 2150[11]. Since the GHG emissions need to decrease to a

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[10] This estimate was based on an assessment of the technical abatement potential for non-CO2 GHG emissions (see table 3.3). Note that at a later stage of the project this contribution has been re-assessed on the basis of a cost-optimal multi-gas abatement strategy (see Chapter 5).

[11] The year of stabilisation of the IMAGE S650e profile is similar to the IPCC characteristics of the S550 profile. The main reason for choosing 2150 is that stabilisation in 2100 can only be reached through high emissions in the first half of the 21st century and steep reductions in the second half. An emission profile with such characteristics will only lead to a more profound climate impact in 2100 than with IMAGE S650e.

lesser extent, the CO_2, emissions shift from an annual increase of 2.0% in 2010 to a 1.5% decrease, but not until 2040. Again, the non-CO_2 GHGs account for 100 ppmv CO_2-equivalent in 2150 assuming the same mitigation options as in IMAGE S550e. Because of higher temperatures in IMAGE S650e than in IMAGE S55e, the natural N_2O emissions are higher (IMAGE team, 2001). To compensate these higher non-CO_2 emissions in IMAGE S650e, we assumed higher emission reductions for the HFCs, PFCs and SF_6.

Box 3.1: CO_2-equivalent emissions and concentrations

The CO_2-equivalent emissions concept uses the so-called Global Warming Potentials (GWP) of each Kyoto gas (CO_2, CH_4, N_2O, SF_6, PFCs and HFCs). The GWP is a measure of the relative radiative effect of a given substance compared to CO_2 integrated over a chosen time horizon (IPCC, 2001). Consequently, the GWP of CO_2 is by definition 1.0. The most commonly used GWPs, which we will use here too, are those with a time horizon of 100 years (IPCC, 2001). Ever since the introduction of the GWP concept, a subject of continuous scientific debate has been whether this is an adequate measure for combining the different effects on the climate system of the different greenhouse gases and other radiative active substances, such as aerosols. The GWP concept is very sensitive for the time horizon selected. For example, GWPs based on a short time horizon give rise to relatively large contribution of short-lived greenhouse gases, such as methane and a low contribution of long-lived gases like some HFCs and SF_6. GWPs with a long time horizon do the opposite. However, despite its limitations, the GWP concept is very convenient and has been widely used in policy documents such as the Kyoto Protocol. To date, no alternative measure has attained a comparable status in policy documents.

In this report, we also use the concept of CO_2-equivalent concentrations. It should be noted that although this concept attempts to add up the contribution of different greenhouse gases (here, for concentrations), it is clearly different from that of the CO_2-equivalent emission concept. It is a measure of the contribution of the various GHGs to radiative forcing in any given year in terms of CO_2. One major advantage of CO_2-equivalent concentrations is the fact that it is defined for a given year and therefore does not incorporate a time horizon. Eickhout et al. (2003) analysed whether different contributions of the Kyoto gases to similar CO_2-equivalent emission profiles have led to different CO_2-equivalent concentrations and, hence, different climate impacts using the IMAGE 2.2 model. The study concludes that the uncertainty in the contribution of the different Kyoto gases to the CO_2-equivalent concentration levels does indeed have an impact on eventual warming, but that this impact is relatively small compared to the uncertainty arising from the uncertainty in the climate sensitivity. However, in the short term, a steep reduction in short-lived gases like CH_4 will lead to an underestimation of the emission reductions achieved using the GWP concept. Consequently, the CO_2 equivalent concentrations might be lower in 2100 than the CO_2 equivalent emissions would indicate. In the longer term, this effect seems to diminish.

The two emission profiles are plotted in Figure 3.4. 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. For stabilising CO_2 equivalent concentration at 550 ppmv global GHG emissions will need to peak around 2015. For the profile for stabilising at 650 ppmv CO_2 equivalent, this only needs to be around 2030. For stabilisation at 550 ppmv CO_2 equivalent, a further postponement of emission reductions will be difficult in order to avoid steep global emission reductions (>2%per year) or an overshooting of the targeted concentration stabilisation levels.[12]

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[12] It has been argued that while global GHG emission reductions beyond 2% per year would be technically feasible, they have not been found to be sustained over a long period of time in global GHG mitigation scenarios. In fact, for all greenhouse gases taken collectively, such rates tend to be even lower than for energy-related CO_2 emissions only (Alcamo, 1998).

Emission reduction rates beyond 2% per year over periods longer than 10 years are rarely found in mitigation scenarios; such high rates may require the introduction of new technologies at a rate beyond the natural replacement level of capital, leading to high costs. For stabilisation at 650 ppmv CO_2 equivalent, there are many alternative pathways possible, including those where global emissions peak later (up to 2050) ((Eickhout et al., 2003)).

Table 3.3: Main characteristics of the two constructed emission profiles

Characteristic	IMAGE S550e	IMAGE S650e
CO_2 emissions in 2010 ($GtCO_2$ per year)	37.6	37.6
Annual increase in 2010 (in %)	2.0	2.0
Target year of pre-described annual decrease CO_2	2020	2040
Level of annual CO_2 decrease in that target year (in %)	2.0	1.5
Year of stabilisation	2100	2150
Level of CO_2 concentration	450 ppmv	550 ppmv
Assumed levels of CH_4 reductions (compared to baseline)$^{1)}$	• Energy: 50% • Industry: 50% • Landfills: 100% • Sewage: 50%	• Energy: 50% • Industry: 50% • Landfills: 100% • Sewage: 50%
Assumed levels of N_2O reductions (compared to baseline) $^{1)}$	• Energy: 50% • Industry: 50% • Sewage: 100% • Fertiliser: 20%	• Energy: 50% • Industry: 50% • Sewage: 100% • Fertiliser: 20%
Level of reduction for HFCs and PFCs in 2100 (reduction percentage compared to baseline)	50%	100%$^{2)}$
Sulphur emission levels	Constant CO_2/SO_2 ratio	Constant CO_2/SO_2 ratio

$^{1)}$ Reached in 2025 for Annex I and 2040 for non-Annex I.
$^{2)}$ Reductions in F-gases are higher in IMAGE S650e to compensate for higher natural N_2O emissions resulting from a larger temperature increase.
Source: IMAGE 2.2

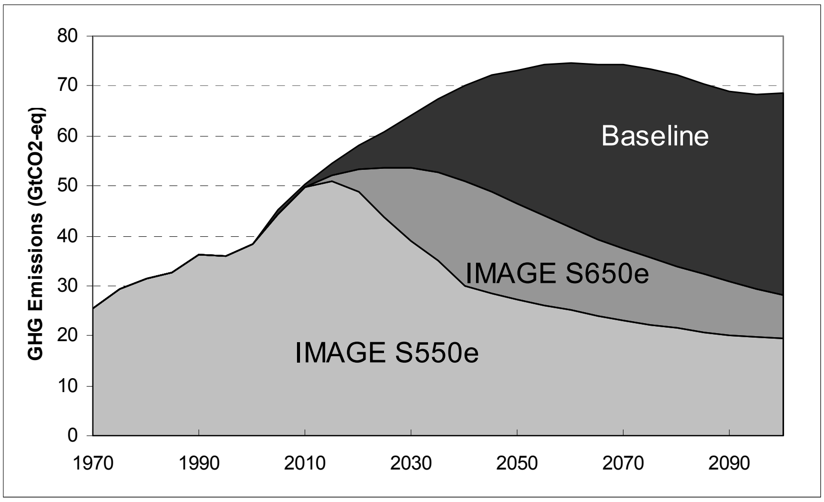

Figure 3.4: Global emission profiles for stabilising GHG concentrations at 550 ppmv (IMAGE S550e) and 650 ppmv (IMAGE S650e) versus baseline emissions.
Source: IMAGE 2.2

Comparison of the IMAGE S550e and IMAGE S650e profiles with the CO_2-only stabilisation profiles used in the IPCC Third Assessment Report (the so-called WRE450 and WRE550 profiles; (Wigley et al., 1996)) indicates that already incorporating climate policies up to 2010 into these new profiles must be interpreted as postponement of mitigation action (Table 3.4.).

Table 3.4: Conditions for stabilising CO_2 concentrations according to the WRE profiles

WRE CO_2 stabilisation profiles	Accumulated CO_2 emission 2001 to 2100	Year in which global emissions peak	Year in which global emission fall below 1990 level
450	365	2005	<2000
550	590	2020	2030
650	735	2030	2055
750	820	2040	2080
1000	905	2065	2135

Source: IPCC, 2001

3.4 Impacts on temperature

The IMAGE 2.2 model was used to calculate the GHG emission concentrations and resulting global averaged surface temperature increase in 2100, as consequence of both the CPI baseline and the two alternative stabilisation profiles. Greenhouse gas concentrations are projected under the baseline scenario to increase to about 930 ppmv CO_2 equivalent by the end of the century (see Figure 3.3). This has already resulted in a temperature increase of 3 degrees Celsius. This value results from the assumption of a median climate sensitivity of 2.5 degrees Celsius[13].

The uncertainty in the CS is important in evaluating the compatibility of the stabilisation profiles with the EU 2-degree Celsius target. Another uncertainty in projecting the temperature change resulting from the stabilisation profiles is caused by sulphur emissions, which have a cooling impact. Here the assumption was made of a fixed carbon-sulphur ratio, which leads to SO_2 emissions following the trend of CO_2 emissions. Figure 3.5 depicts the range of the global mean temperature increase up to 2100 resulting from the IMAGE S550e and IMAGE S650e profiles, taking into account the uncertainty in the climate sensitivity. The difference in temperature increase between the two profiles only becomes apparent in the second half of the century. The reasons are delays within the climate system, and the changes in the energy system for reducing CO_2 in the short term also causing a reduction of SO_2 emissions, and thus their cooling effect. In the case of both the IMAGE S550e and IMAGE S650e profiles, equilibrium has not yet been reached by 2100, meaning that warming will continue after this date.

From Figure 3.5, it can be concluded that, in principle, the IMAGE-550 profile can achieve (or at least stay near) the maximum global temperature increase of 2 degrees Celsius for a median and low climate sensitivity. The IMAGE-650 profile only achieves this increase if the climate sensitivity is on the low side (close to 1.5°C). However, this profile is likely to

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[13] The climate sensitivity (CS) is defined as the equilibrium global-mean surface temperature increase resulting from a doubling of CO_2-equivalent concentrations. The IPCC estimates the range of the climate sensitivity between 1.5 and 4.5°C, where the median is 2.5°C (sensitivities near the median are much more likely than those at either extreme).

overshoot the target by a considerable margin. If sensitivity is high, the EU target will not be met in either profile.

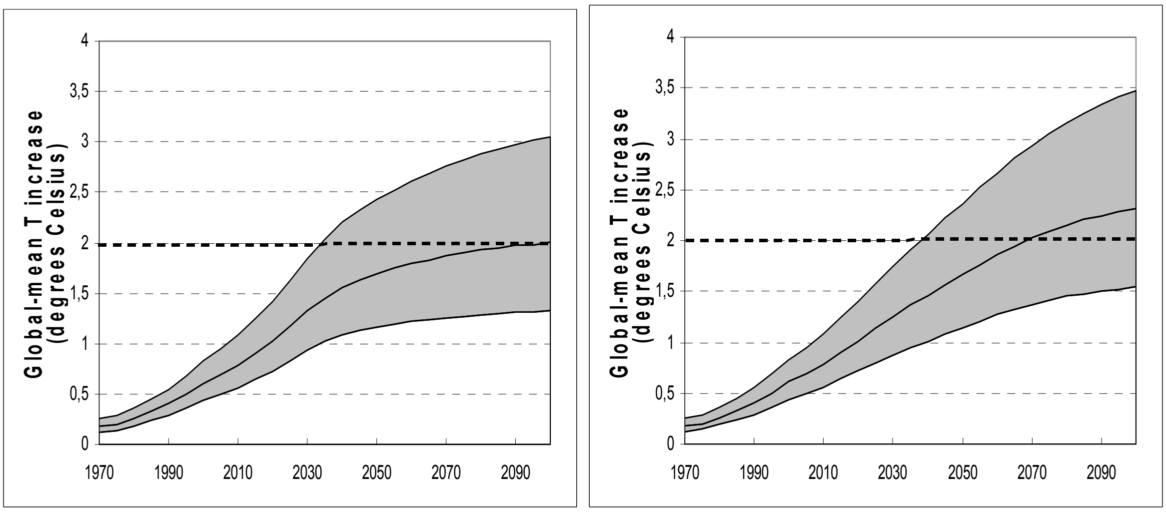

Figure 3.5: Global-mean temperature increase since pre-industrial levels resulting from IMAGE S550e (left panel) and IMAGE S650e (right panel) profiles for different climate sensitivity assumptions (1.5 , 2.5 and 4.5). Source: IMAGE 2.2
The upper curve indicates the temperature increase resulting from CS=4.5; the middle curve, from CS= 2.5 and the lower curve, from CS=1.5; the (flat) dotted line represents the EU 2 degree Celsius target.

In both cases, the temperature will further increase after 2100. Based on a climate sensitivity of 2.5, it can be estimated that stabilising the GHG concentration at 550 ppmv CO_2-eq. will lead to a final, so-called equilibrium, temperature around 2.4°C, thus 0.4°C above the 2100 level. A stabilisation at the 650 ppmv CO_2-eq corresponds to an equilibrium temperature of around 2.9°C, thus 0.6°C above the 2100 level.

3.5 Implications for emission reductions

Figure 3.6 shows the percentage change in *energy- and industry-related* greenhouse gas emission levels required under the IMAGE S550e and S650e profiles compared to both the CPI baseline and the1990 levels for 2025, 2050 and 2100. These emissions are used to analyse the implications of different climate regime options. Note that these levels are different from the reductions indicated in Figure 3.5 because of the exclusion of land-use change-related emissions. In fact, the reduction in land-use change-related emission in the baseline allow for relatively smaller future reductions in energy- and industry-related greenhouse gases. From Figure 3.6 we can conclude that:

- Substantial emission reductions from the CPI baseline will be needed for both stabilisation at 550 and 650 CO_2-equivalent concentrations, particularly in the long term (up to 60%).
- Global energy- and industry related GHG emission levels in 2025 can still increase to about 20% above 1990 levels for the S550e profile, although this implies an already substantial emission reduction of 30% compared to baseline levels. For S650e, the reduction compared to the baseline is lower, but still significant at around 15%.
- For stabilisation at 550 ppmv, GHG emissions in 2050 will have to be sharply reduced, not only compared to baseline level (ca. 65%), but also to 1990 levels (about 15%). In contrast, for stabilisation at 650 ppmv, GHG emissions at 50% above 1990 levels by

2050 are allowed. However, global emissions need to be reduced by about 35% in comparison with the baseline.

- By the end of the century, both stabilisation profiles for 550 and 650 CO_2-equivalent concentrations imply that global emissions be substantially reduced compared to CPI: i.e. about 70% and 55%, respectively. When compared to 1990, this implies a reduction of 30% for stabilisation at the 550 CO_2-equivalent, and stabilisation at 1990 levels at the 650 CO_2-eq.

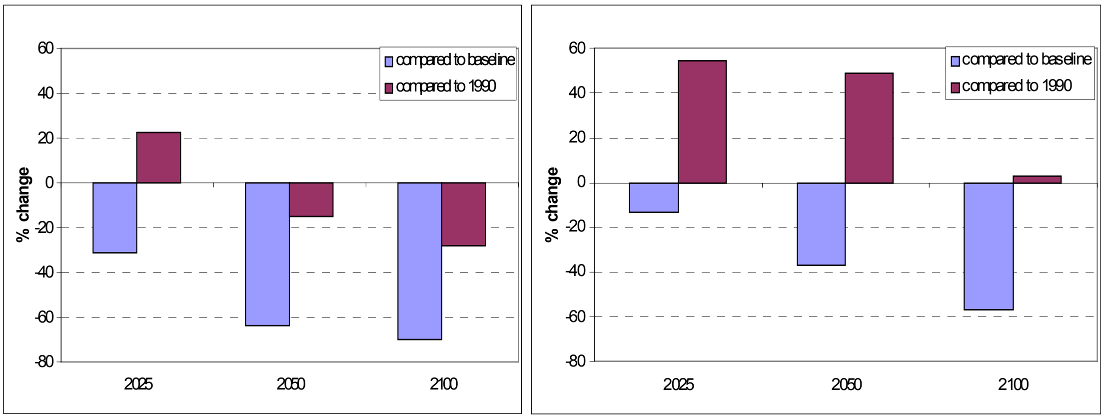

Figure 3.6: Reduction efforts of global energy- and process GHG emissions for stabilisation at 550 ppmv (left panel) and 650 ppmv (right panel) CO_2-equivalent levels. Source: IMAGE 2.2

3.6 Conclusions

- Continuation of GHG baseline emissions (i.e. without climate policies) will lead to a global temperature increase of over 3 degrees Celsius by 2100, which is well beyond the temperature target of 2^{o}C over pre-industrial levels.
- The case of the S550e profile can result in a maximum global mean temperature increase below 2 degrees Celsius, with a low to medium value of the climate sensitivity. The S650e profile only stays below this level if the value of the climate sensitivity is at the low end of the range, which means that this profile is unlikely to meet the target. In the case of a high climate sensitivity of 4.5 degrees Celsius, the target will not be met under either profile.
- 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. The emission profiles corresponding to a stabilisation of the CO_2 equivalent concentration at 550 and 650 ppmv peaks, by 2015 and 2030 respectively. Other pathways allowing emissions to peak later are possible for reaching the 650 ppmv equivalent; for the 550 ppmv equivalent a further delay would result in large reductions after 2025 (over an emission reduction of 2% per year) and/or a (temporary) overshoot of 550 ppmv level.

4 Climate regimes for differentiation of commitments

4.1 Introduction

In this chapter[14] we will analyse the implications in terms of allocating emission allowances of five variants of two different climate regime approaches for differentiating future mitigation commitments. Two of them are variants of the Per Capita Convergence approach (PCC), while the other three are new variants the so-called Multi-Stage (MS) approach. For the analysis we will use the two global emission profiles for stabilising atmospheric greenhouse gas concentrations at 550 and 650 ppmv equivalent (S550e and S650e) described in the previous chapter.

The MS approach comprises a system to divide countries into groups with different types of commitments (stages) and results over time in a gradual increase in the number of countries and their level of commitment according to participation and differentiation rules. In this study we will present three new variants of the Multi-Stage approach. It was developed in collaboration with IEPE on the basis of the original MS approach from RIVM (Berk and den Elzen, 2001; den Elzen, 2002) and elements from an alternative climate regime approach, called Soft Landing, developed by IEPE and NTUA (Criqui and Kouvaritakis (2000)).

The Per Capita Convergence approach, more commonly known as the 'Contraction & Convergence' approach, originating at the Global Commons Institute (Meyer, 2000). This approach allocates emissions on the basis of a convergence in per capita emission to equal per capita levels in the future under a contracting global GHG emission profile.

The two approaches have been selected because they show a number of structural differences. First, the MS approach is based on a gradual extension of the number of countries participating in global greenhouse gas emission abatement, while in the PCC approach, all countries participate from the start. Second, the MS approach defines different types of commitments, while in the PCC approach all countries have similar commitments (fixed targets). Third, where the MS approach concerns the allocation of emission abatement efforts (burden-sharing), the PCC approach is based on the allocation of rights to use the (constrained) capacity of the atmosphere to absorb greenhouse gas emissions (resource-sharing). Finally, the MS and PCC approaches are based on different equity principles, as will be discussed below.

4.2 The climate regimes explored

4.2.1 New Multi-stage variants

The Multi-Stage approach consists of a system to divide countries into groups with different levels of (mitigation) efforts and types of commitments (stages). The aim of such a system is to ensure that regions with similar circumstances, in terms of the economy, development and environment, have comparable responsibilities/ commitments under the climate regime. Moreover, the system defines when their level of commitment changes

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[14] Parts of this chapter are based on the study of den Elzen et al. (2003a), describing in more detail the analysis presented here.

according to a change in circumstances. Application of this approach thus results in an incremental evolution of the present climate change regime, i.e. a gradual expansion over time of the group of countries with (mitigation) commitments. In this approach countries also adopt different levels and types of commitments according to participation and differentiation rules that are based on criteria such as per capita income or per capita emission. The various levels of participation can be organised as different annexes to the UNFCCC. The approach was first developed by Gupta (1998). Later, the approach was elaborated into a quantitative scheme for defining mitigation commitments under global emission profiles compatible with the UNFCCC objective of stabilising GHG concentrations in the atmosphere (Berk and den Elzen, 2001; den Elzen, 2002).

Criqui and Kouvaritakis (2000) developed an alternative regime approach, called Soft Landing. It proposes a scheme for a progressive stabilisation of emissions in non-Annex I countries, where timing and level of commitment is differentiated on the basis of per capita emissions and per capita income levels, as well as on the population growth in the respective countries. Annex I countries keep reducing their emissions according to a Kyoto-type trend. In contrast to the MS approach, the Soft Landing approach has all non-Annex I countries participating immediately, however, their level of effort is differentiated by grouping them on the basis of both their per capita emissions and per capita income levels (Blanchard et al., 2001).

Designing new MS variants

As part of the project 'Greenhouse gas Reduction Pathways in the UNFCCC post-Kyoto process up to 2025' (GRP), RIVM and IEPE have collectively developed new variants of the MS approach. The criteria here were that the new variants should:

1. account for various equity principles;
2. result in a gradual shift from no emission control commitments to full participation in the emission-reduction stage via a transition stage;
3. be relatively simple in nature, that is, based on a limited number of policy variables.

It was felt that the elements of the Soft Landing approach could be used to further develop, and in fact simplify, the existing MS approach. Therefore the new variants are built on both RIVM's Multi-Stage approach and IEPE's Soft-Landing approach, but include several new elements. See below for a brief description of their features.

Accounting for equity principles

Equity principles were deemed important in designing the more simplified MS approach. The design of the MS regime can be related to various equity considerations (see Box 4.1). Moreover, as we have suggested elsewhere, there is some hierarchy in equity principles (den Elzen et al., 2003a). The basic *need* principle would come first, as it exempts one from contributing, not even proportionally, so as to avoid hindrance of attaining basic development needs. Next, the *capability* principle foregoes the responsibility principle, as one cannot be expected to contribute proportionally to one's responsibility if this would constitute a disproportional or abnormal burden. Finally, the *responsibility* principle would subordinate the *sovereignty* principle, as international law does not allow a state to continue to emit freely if this is known to be harmful to other states.[15] This hierarchy of equity principles is largely reflected in the design of the new Multi-Stage approaches:

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[15] See preamble of UNFCCC: 'Recalling also that States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within

- Stage 1 corresponds with securing basic needs by exempting the least developed countries from quantitative commitments and allowing them to follow baseline emissions;
- Stage 2 corresponds with contributing according to one’s capability (and avoiding disproportional burdens): allowing for a transition towards a full contribution. Commitments in this stage limit the growth in emissions, but do not yet require absolute reductions (emission limitation commitments);
- Stage 3 corresponds with the responsibility principle, by defining emission reduction commitments based on one’s contribution to climate change.

Box 4.1 Equity principles

Equity principles refer to general concepts of distributive justice or fairness. Many different categorisations of equity principles can be found in the literature (Ringius et al., 1998; Ringius et al., 2000). In den Elzen et al. (2003b) a typology of four key equity principles was developed that seem most relevant for characterising various proposal for the differentiation of post-Kyoto commitments in the literature and international climate negotiation to date:

- *Egalitarian:* i.e. all human beings have equal rights in the ‘use’ of 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 of the user 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.

The basic needs principle is included here as a special expression of the capability principle: i.e. the least capable Parties should be exempted from the obligation to share in the emission reduction effort so as to secure their basic needs. An important difference between the egalitarian and sovereignty principle, on the one hand, and responsibility and capability, on the other, is that the first two are *rights-based,* while the latter two are *duty-based*. This difference is related to the concepts of *resource-sharing*, as in the PCC approach, and *burden-sharing* in the MS approach.

Shifting gradually from no emission control to emission reductions

All three new MS variants developed are based on the following consecutive stages for the commitments of non-Annex I countries:

- Stage 1. No quantitative commitments (exemption stage);
- Stage 2. Emission limitation targets, e.g. intensity targets (transition stage), and
- Stage 3. Emission reduction targets, similar to those of Annex I countries (full participation).

However, the variants differ in the way the transition stage has been designed. All Annex I regions (including the US) are assumed to be in stage 3 after 2012.

Relatively simply in design

The MS variants are all based on a limited number of policy variables, as illustrated by the main characteristics of the three Multi-Stage variants in Table 4.1.

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their jurisdiction or control do not cause damage to the environment of other States or areas beyond the limits of national jurisdiction’.

Table 4.1: The main characteristics of the three Multi-Stage (MS) variants (den Elzen et al., 2003a)

	Multi-Stage 1 (‘dynamic threshold’)	Multi-Stage 2 (‘double CR threshold’)	Multi-Stage 3 (‘transition path’)
Stage 1 No commitments			
Stage 2 Emission-limitation targets			
First threshold (to Stage 2)	Capability-Responsibility (CR) index	Same as MS 1	Same as MS 1
Emission-limitation targets	Income-dependent intensity targets	Same as MS 1	Prescribed emission stabilisation profile
Stage 3 Emission-reduction targets			
Second threshold (to Stage 3)	% of world-average per capita emissions	CR-index value	--
Absolute targets, reductions proportional to burden-sharing key	Per capita emissions	Same as MS 1	Same as MS 1

Stage 1 to Stage 2: from no-constraint to emission limitation (carbon intensity) targets
A new feature of all MS variants considered is the Capability-Responsibility (CR) index. The CR index originates in the principles used by Criqui and Kouvaritakis (2000) in the Soft Landing approach. In practical terms, it can be defined as the sum of the per capita income (expressed in PPP€1000 per capita), which relates to the capability to act, and of the per capita CO_2-equivalent emissions (expressed in tCO_2 per capita), which reflects the responsibility in climate change (illustrated in Table 4.2). This index is used to define the threshold for the transition from Stage 1 to 2. Compared to a single capability-oriented threshold, like per capita income in RIVM’s original Multi-Stage, the CR index generally tends to result in an earlier participation of low-income countries, in particular, those that have relatively high per capita emission levels.

Table 4.2: Regional Capability-Responsibility (CR) index values in 1995 and in 2025 for the CPI scenario. regions ranked by decreasing value in 1995

	1995			2025		
	Per capia GDP	Per capia emissions	CR-index	Per capia GDP	Per capia emissions	CR-index
	1000 PPP€	tCO2-eq		1000 PPP€	tCO2-eq	
USA	28	26	54	47	27	73
Canada	24	21	45	39	21	60
Oceania	17	19	36	30	20	51
Japan	24	11	35	39	13	52
OECD Europe	20	11	31	37	12	50
Former USSR	5	12	18	13	17	30
Eastern Europe	7	9	15	17	11	28
Middle East	5	7	12	9	11	20
South America	7	5	12	12	8	19
Central America	5	5	10	10	6	17
South Africa	2	4	7	3	6	9
East Asia (China)	3	4	7	11	7	18
North Africa	3	3	6	6	5	11
South East Asia	3	3	6	8	5	14
South Asia (India)	2	2	4	5	3	8
West Africa	1	1	2	1	2	4
East Africa	1	1	2	1	2	3

Source: IMAGE 2.2

In Stage 2 the MS 1and MS 2 variants share income-related intensity targets. The stringency of the greenhouse gas (GHG) intensity improvement targets is now defined as a linear function of per capita income level income (in PPP€ per capita per year). Also a maximum de-carbonisation rate was adopted to prevent de-carbonisation rates outpacing economic growth rates, resulting in absolute emission reduction targets for countries in the emission-limitation stage. The second stage in the MS 3 case differs from the previous MS

1 and MS 2 variants. Instead of de-carbonisation targets, allowable emissions in the transitional emission-limitation stage are determined by a prescribed slowing down of the emission growth to a final stabilisation as in the Soft-Landing approach. The length of this stabilisation period is given by the transition constant *TC* and is calculated by dividing the *TC* by the per capita emission levels (in tCO_2-eq per capita) before the first CR threshold is met.

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

The three MS variants differ in the way the transition from Stage 2 to Stage 3 is defined:

- In MS 1 the entry to Stage 3 depends on a second threshold, defined as a proportion of the world average per capita emission level. As the level of this threshold changes over time due to mitigation actions by other parties, it is not a fixed (like the CR values), but a dynamic threshold.
- MS 2 uses a second CR index, with a value that is about twice that used for the Stage 1 to Stage 2 threshold.
- In MS 3 the entry to Stage 3 is not defined by a threshold, but begins after the fixed and pre-determined stabilisation period has ended.

Given these characteristics, we have labelled MS 1 variant as ‘dynamic threshold’, MS 2 as ‘double CR threshold’ and MS 3 as ‘transition path’.

All new MS variants in Stage 3 assume the same burden-sharing key: per capita GHG emissions. This key tends to result in some convergence of per capita emission levels over time[16].

Assumptions of MS variants

The levels chosen for the various thresholds and other policy parameters have been adjusted to the different global emission profiles. Table 4.3 provides an overview of the assumptions made in implementing the various MS variants under the IMAGE S550e profile. The parameter values for the MS variants for the S550e profile, as listed in Table 4.3, were selected on the following grounds: (i) meeting the global emission profile; (ii) timely participation of the non-Annex I regions and (iii) realising some convergence in the per capita emissions for the Annex I and non-Annex I regions before 2050. 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 in the S650e case compared to their values in 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 indicated in bold in the tables).[17]

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[16] As referred to in the preamble of the Marrakesh Accords: ‘Emphasising that the Parties included in Annex I shall implement domestic action in accordance with national circumstances and *with a view to reducing emissions in a manner conducive to narrowing per capita differences between developed and developing country Parties* while working towards achievement of the ultimate objective of the Convention’ (italics added).

[17] For background information for these assumptions and a sensitivity analysis of their impacts on the emission allowances, please refer to den Elzen et al. (2003a).

Table 4.3: Assumptions for the Multi-Stage (MS) variants for the S550e profile (den Elzen et al., 2003a)

Key parameters	*Multi-Stage 1*	*Multi-Stage 2*	*Multi-Stage 3*
Stage 1 No quantitative commitments			
Stage 2 Emission limitation targets:			
adoption of intensity targets	**CR = 5**	Same as MS 1	Same as MS 1
Participation threshold			
De-carbonisation rate / Stabilisation	Max. de-carbonisation rate of **3%** (**)	Same as MS 1	**Stabilisation period (TC=70)**
Stage 3 Emission Reduction targets: participation threshold	**100% of world average per capita emissions**	**CR = 12**	
Burden-sharing key	per capita CO_2 emissions	Same as MS 1	Same as MS 1

(**)The de-carbonisation rate (in percentage) is a linear function of per capita income (PPP€ per cap): 0.33 * PPP€ per capita, with a maximum de-carbonisation rate of 3.0 percent per year.

Table 4.4: Assumptions for the Multi-Stage (MS) variants for the IMAGE S650e profile (den Elzen et al., 2003a)

Key parameters	*Multi-Stage 1*	*Multi-Stage 2*	*Multi-Stage 3*
Stage 1 No quantitative commitments			
Stage 2 adoption of intensity targets		Same as MS 1	
Participation threshold	**CR = 12**		Same as MS 1
De-carbonisation rate / Stabilisation	Income-dependent intensity targets (**)	Same as MS 1	**Stabilisation period (TC=100)**
Stage 3 Emission-reduction regime Participation threshold	**120% of world average per capita emissions**	**CR = 20**	
Burden-sharing key	per capita CO_2 emissions	Same as MS 1	Same as MS 1

(**)The de-carbonisation rate (in percentage) is a linear function of per capita income (PPP€ per cap): 0.25 * PPP€ per capita, with a maximum de-carbonisation rate of 2,5 percent per year.

4.2.2 The Per Capita Convergence variants

The Per Capita Convergence (PCC) approach or ‘Contraction & Convergence’ approach (Meyer, 2000), as it is commonly called, starts from the assumption that the atmosphere is a global common to which all are equally entitled. It defines emission rights on the basis of a convergence of per capita emissions under a contracting global emission profile. In the PCC approach all Parties participate immediately in the regime (in the post-Kyoto period), with per capita emission permits (rights) converging to equal levels over time. More specifically, over time, all shares converge from actual proportions in emissions to shares based on the distribution of population in the convergence year.

The PCC approach is based on a combination of both the egalitarian and sovereignty principles. The egalitarian principle is used within this approach to underpin the final convergence of per capita emission allowances. However, as the approach starts from the current distribution of emissions and only approaches this convergence in time, it also clearly relates to the sovereignty principle.

Assumptions of PCC variants:
The assumptions for the PCC variants are indicated in Table 4.5. The two PCC variants assume a convergence of per capita CO_2 equivalent emissions by 2050 and 2100 for the both emission profiles.

In the original Contraction and Convergence approach of the GCI, based on a non-linear convergence formula, the actual degree of convergence in per capita depends on the rate of convergence selected. This rate of convergence determines whether most of the per capita convergence takes place at the beginning or near the end of the convergence period. Another important parameter in the approach is (accounting for) population growth. GCI has indicated that the approach may be combined with the option of applying a cut-off year, after which population growth is no longer accounted for. For reasons of transparency, in the PCC regime variants explored here a linear converge of per capita emissions has been assumed and no cut-off year for population growth has been applied. Population projections used are of the CPI baseline scenario.

Table 4.5: Two alternative variants of the Per Capita Convergence (PCC) approach for the IMAGE S550e profile.

Key parameters	*PCC50*	*PCC100*
Year of convergence	2050	2100
Rate of convergence	Linear	Linear
Population growth cut-off year	Not applied	Not applied

Note: these assumptions are the same for the S650e variants.

4.3 Emission allowances under the S550e profile

4.3.1 The Multi-Stage results

Timing of participation

Table 4.6 gives a brief overview of the participation of the non-Annex I regions in the emission-limitation and emission-reduction stage. For the emission-limitation stage all three Multi-Stage (MS) variants show an early entry – before 2020 - of most non-Annex I regions, except for West and East Africa, which only enter after 2050.

Table 4.6: Participation of non-Annex I regions in the emission limitation and emission reduction stage for the MS variants under the S550e profile (white-boxes show the earliest entry, dark-grey, the latest, and light-grey, in between)

Regions	Central America	South America	Northern Africa	West Africa	East Africa	Southern Africa	Middle East	South Asia	East Asia	SE Asia
Stage 2	2012	2012	2012	2055	2065	2012	2012	2015	2012	2012
Stage 3										
MS1	2035	2012	2040	2060	2075	2030	2012	2045	2020	2035
MS2	2015	2012	2050	2100	2100	2060	2012	2050	2015	2030
MS3	2025	2025	2030	2085	2095	2030	2020	2045	2025	2030

Source: FAIR 2.0 model

Emission targets for the Multi-Stage variants

As far as the regional emission allowances for the MS variants are concerned, the impacts are analysed according to distinct time horizon, short-term (2025) and long-term (2050) (Table 4.5). Figure 4.1 depicts the reduction efforts or growth percentage for ten aggregated regions compared to the 1990 levels (more detailed figures can be found in annex I).

In 2025, the Annex I regions need to reduce their emissions by about 30-60% compared to 1990 levels. The lowest reductions are for MS 2, whereas MS 3 shows the highest reduction levels. This is a direct result of the respectively early and late entry into stage 3 of middle- and high-income non-Annex I regions. These regions show an opposite pattern, whereas the emissions from low-income non-Annex I regions occur close to their baseline emissions.

In 2050, the differences for the Annex I regions are relatively small, with reductions in the order of 70-80% for the MS variants. The middle- and high-income non-Annex I regions show high reductions. For the low-income non-Annex I regions, the MS 3 case represents the regime with the strongest constraints due to higher reductions in stage 2.

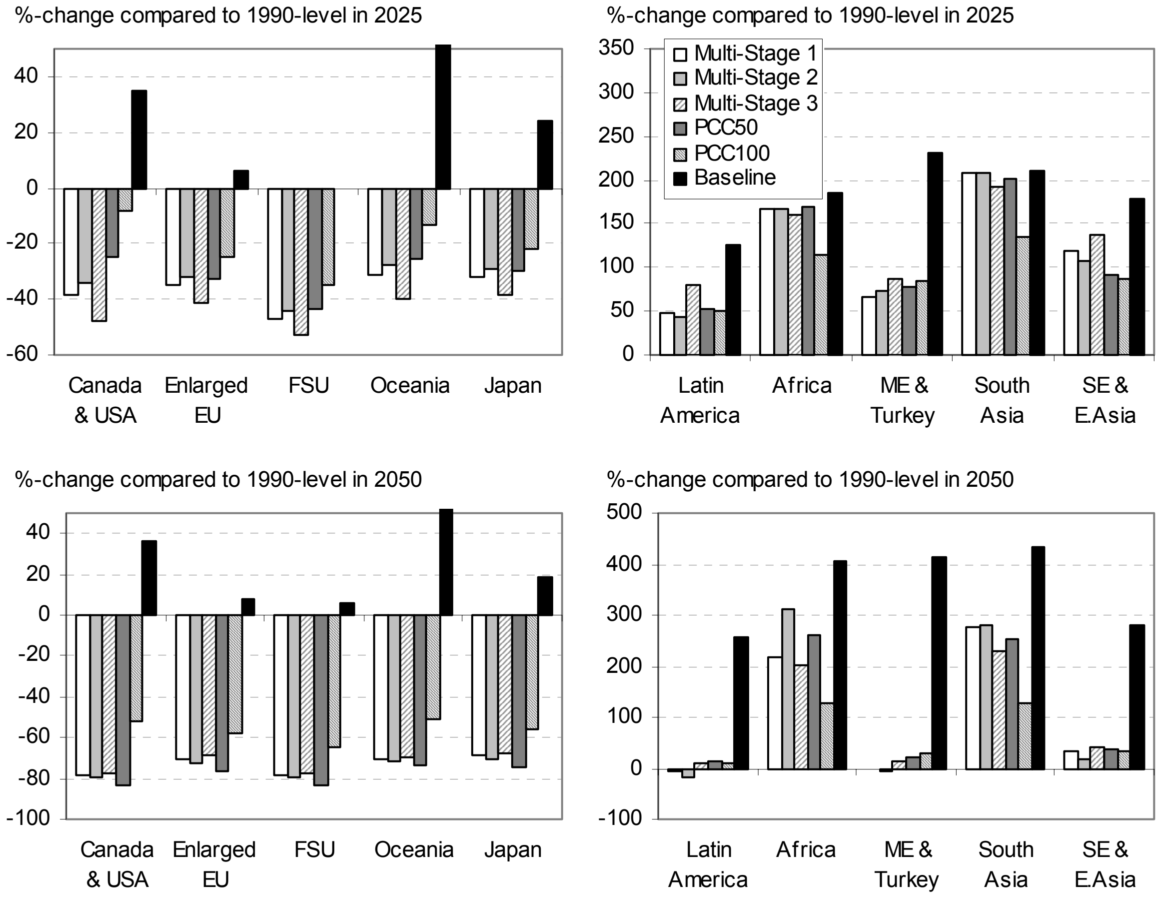

Figure 4.1: Percentage change in the CO_2-equivalent emission allowances relative to the 1990 level for the MS and PCC cases in 2025 and 2050 under the S550e profile. Source: FAIR 2.0 model

4.3.2 The PCC results

The PCC variants generally show larger differences in regional emission allowances than the MS variants. By 2025 Annex I reductions from 1990 levels range from 25 to 45% for the PCC50 case and less than 10% to 35% for the PCC100 case. The difference in convergence year appears to have a major influence on the distribution of emission allowances among Annex I and non-Annex I regions. A delay in the convergence year results in much smaller reductions in Annex I emission allowances on both the short and longer term. The PCC100 case results in substantial smaller emission reductions for the Annex I regions than the PCC50 case and also than the MS variants, and vice versa for the non-Annex I regions. The results of PCC50 case are comparable to the MS variants, with some qualifications. First, for Annex I, the emissions reductions for the PCC50 variant tend to be smaller in the short term and larger in the long term than the MS variants. Particularly in the case of the USA/Canada, the MS cases in the short term result in much larger reductions than the PCC50 case. Second, for SE& East-Asia, the PCC50 also results in larger emission reductions (from baseline levels) than in the MS variants, since their per capita emissions are close to the world-average. Finally, it is interesting to note that West and East Africa gain from the excess emission allowances (not shown). However, under the considered baseline and S550e profile, the PCC50 case does not lead to significant amounts of excess emissions. In fact, due to the higher per capita emissions of Southern Africa, there are no excess emissions for Africa as a whole. In contrast, Africa, like South Asia, would already need to substantially limit its emissions in the PC100 variant.

4.4 Analysis of emission allowances for the S650e profile

4.4.1 The Multi-Stage results

Timing of participation

Table 4.7 gives a brief overview of the participation of the non-Annex I regions in the emission limitation and emission reduction stage. For the emission limitation stage, most middle- and high-income non-Annex I regions show similar early entry dates to those under S550e (in the second commitment period); however, SE Asia shows this ten years later and North- and East Africa 30 years later. For the emission reduction stage, the middle- and high-income non-Annex I regions participate much later 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 2100 for West and East Africa.

Table 4.7: Participation of non-Annex I regions in the emission-limitation and emission-reduction stage for the Multi-Stage variants under the S650e profile (white-boxes show the earliest entry, dark-grey, the latest and light-grey, in between)

Regions	Central America	South America	North Africa	West Africa	East Africa	South Africa	Middle East	South Asia	East Asia	SE Asia
Stage 2	2015	2012	2040	----	----	2040	2012	2050	2015	2025
Stage 3										
MS1	----	----	2090	----	----	2045	2012	----	2045	----
MS2	2055	2045	2075	----	----	----	2045	2080	2040	2050
MS3	2035	2030	2065	----	----	2060	2025	2075	2035	2050

Source: FAIR 2.0 model

Emission targets for the Multi-Stage variants

Figure 4.2 depicts the reduction efforts or growth percentage compared to the 1990 levels for ten aggregated regions (see again Annex I for more details). Compared to the MS 2 and MS 3 variants, MS 1 results for the Annex I regions in the largest allowances in both the short and long term due to the earlier participation in the burden-sharing of some non-Annex I regions. For the Middle East, MS 1 is the most stringent because here it almost directly enters stage 3 (emission reductions). The MS 3 case provides higher allowances for high-income non-Annex I regions as it allows for some transition time (Figure 4.2). For the low-income non-Annex I regions, there are almost no differences in the outcomes for the three MS variants, since these regions do not participate before 2050.

In 2025, the emission allowances for the Annex I regions vary from a growth of 10% for the USA to 30% reduction compared to 1990 levels for the FSU. Most non-Annex I regions hardly have to limit their emissions in 2025, except for the African regions and South Asia.

In 2050, the Annex I emissions are 40-60% below 1990 levels, resulting in a reduction of 45-70% compared to the baseline levels. The low-income non-Annex I regions have very low required reductions compared to their baseline. In the other non-Annex I regions, the reductions compared to the baseline emissions remain globally lower than for Annex I, at 40%, 50 % and 60 % for South-East & East Asia, Latin America and the Middle East, respectively.

4.4.2 The PCC results

The PCC variants again show large differences in outcomes, particularly in the long term. For the PCC50 case, the emission reductions by 2025, compared to 1990, for Annex I regions range from a few per cent for USA/Canada and Oceania to about 30% for the FSU, which is comparable to the MS cases. The PCC100 variant again results in much lower emission reduction efforts for the Annex I regions than the PCC50 case, and the least of all five cases. The allowable emissions for USA/Canada and Oceania are even still above 1990 level by 2025. In contrast, the PCC50 case results in emission reductions for the Annex I regions that are higher than in the MS variants, making it the most stringent scheme for these regions in both the short and long term. An important reason for this is that under the S650e profile, the PCC50 case results in large amounts of surplus emissions, not only for all African regions but also for South Asia, and not only in the short term but now also in the long term. The PCC50 case provides the low-income non-Annex I regions with the highest emission allowances of all PCC and MS cases. The middle-income non-Annex I regions are less sensitive to the convergence year, since their per capita emissions are closer to the world average. For Latin America and the Middle East, the PCC variants result in more emission allowances than the MS cases (except for MS 1 for the Middle East), while for South-East & East Asia the PCC cases result in fewer emission allowances.

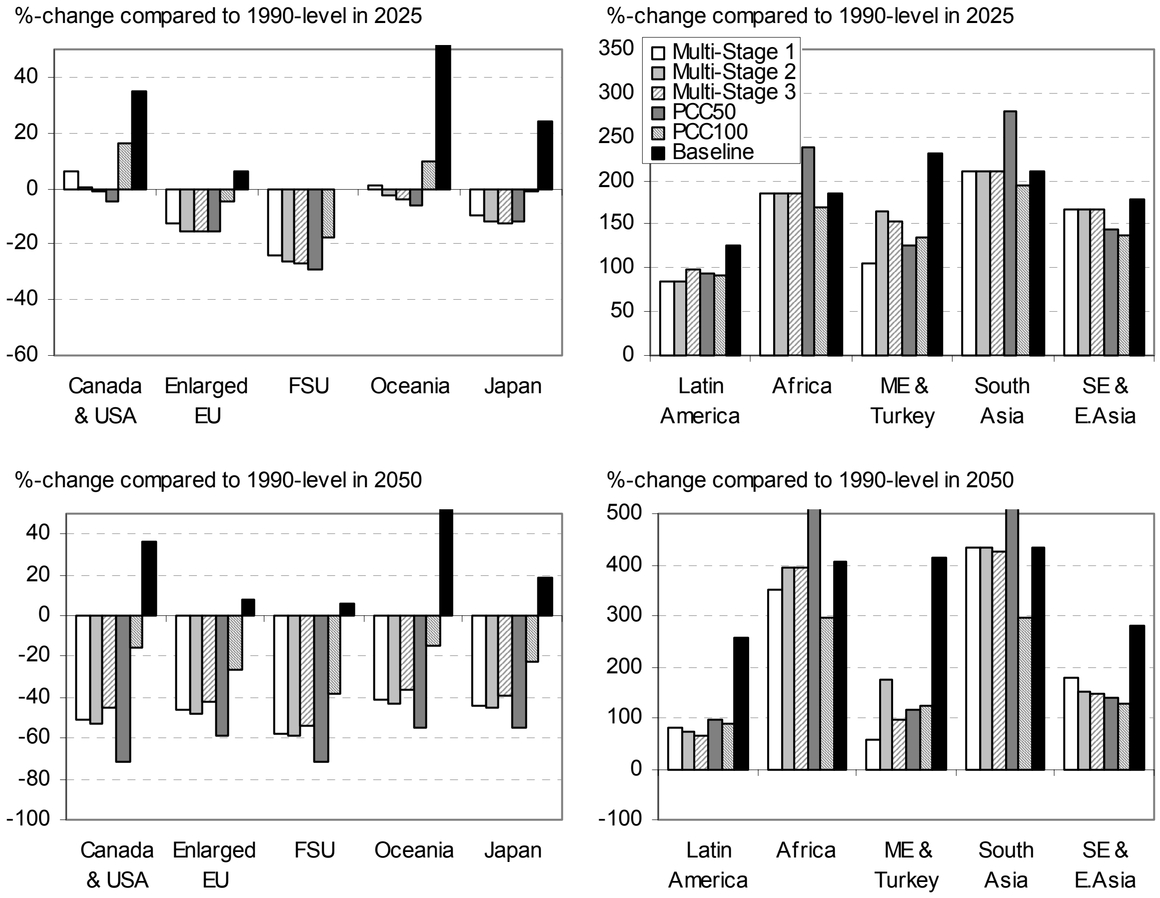

Figure 4.2: Percentage change in anthropogenic CO_2-equivalent emission allowances relative to the 1990 level for the Multi-Stage and PCC variants in the target years, 2025 and 2050, under the IMAGE S650e profile. Source: FAIR 2.0 model

4.4.3 Robustness of results

As the results found are based on various assumptions, we explored the robustness of our findings by performing a sensitivity analysis by varying the key parameters. We focused on the assumptions for the MS variants since the sensitivity of the PCC results to the selection of the convergence year is already shown. We varied the values of a number of key parameters in the MS variants for the S550e and S650e profile. A more extensive sensitivity analysis can be found in den Elzen et al. (2003a).

Robustness of results for the S550e profile: Figure 4.3 shows the sensitivity of the results for varying the main participation thresholds of Stage 3 for MS 1 and MS 2 variants, as well as the transition constant for MS 3 (first three column bars).[18]
The results will be discussed for three different groups: Annex I, the middle- and high-income non-Annex I regions, and the low-income non-Annex I regions.

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[18] More specifically, for MS 1, the second threshold value was varied between 80-120% of world-average per capita emissions; for MS 2, the second CR threshold value was varied between 10-15; and for MS 3, the TC value was varied between 50-100.

Figure 4.3 shows that for the Annex I regions, MS 3 retains the highest reductions in the short term. In general, the difference in the outcomes of MS 1 and MS 2 are small. Depending on the parameter settings of MS 1 and MS 2, PCC50 may now no longer result in fewer reductions than the MS cases in the short term, and the largest reduction in the long term. PCC100 remains the variant with the lowest reductions in both the short and long term.

For the middle- and high-income non-Annex I regions, changes in the parameter values do affect the outcomes, but MS 3 still leads to the smallest reductions. For these regions, different thresholds for the entry to stage 2 can have a significant influence on the allowances under the MS 1 regime, since their per capita emissions are close to the world average (especially for the South-East and East Asia and the Middle East). Changing the Capacity-Responsibility threshold (MS 2) seems to have a smaller impact on the outcomes.

For the low-income non-Annex I regions, changes in parameter values for the MS 1 and MS 2 variants do not affect the outcomes in the short-term, since they do not yet participate in the emission-reduction stage. The effect of changing the Transition Constant in MS 3 is also small, except for South Asia in the long term.

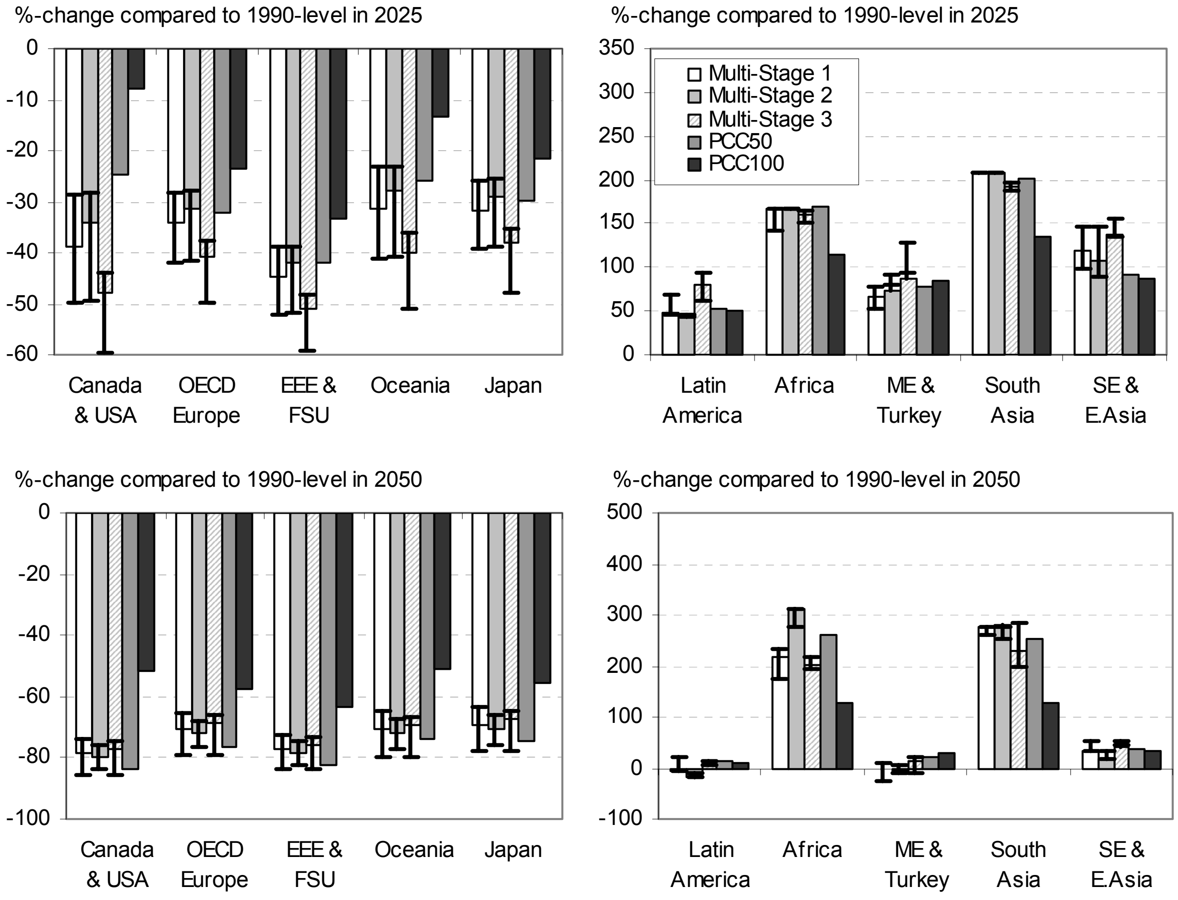

Figure 4.3: Robustness of results for the Multi-Stage variants under the S550e profile. Source: FAIR 2.0 model

Robustness of results for the S650e profile: A similar analysis has been done for the S650e profile (Figure 4.4). In general, the results are fairly robust in the short term, since changing the participation thresholds or transition constant has only a small impact on the emission allowances of the high-income non-Annex I regions (Middle East & Turkey, Latin America) and Annex I regions. In general, the pattern of relative efforts resulting from the variants remains unaffected. For the Annex I regions, the PCC50 in the long term remains the approach that provides the largest emission reductions and the PCC100 the variant with the smallest reductions. The MS variants have an intermediate position. Among them, MS 1 is no longer the one presenting systematically the largest allowances. For the middle-and high-income non-Annex I regions, there are less clear differences between the variants, but the MS 1 case shows the highest sensitivity. The low-income non-Annex I regions become less sensitive for the MS parameter settings as they generally only enter the regime at a late stage (beyond 2050).

The sensitivity analysis shows that the future emission reductions of the three MS variants depend just as much on the MS case chosen as on the exact parameter values used. The most important parameters are the threshold levels and the burden-sharing keys.

In general, the emission reductions under S550e profile are more sensitive to changing the participation thresholds for the emission reduction stage in the short term than in the long term. An opposite pattern is found for the S650e profile (not shown) due to the delayed entry dates of the non-Annex I regions in the emission reduction stage.

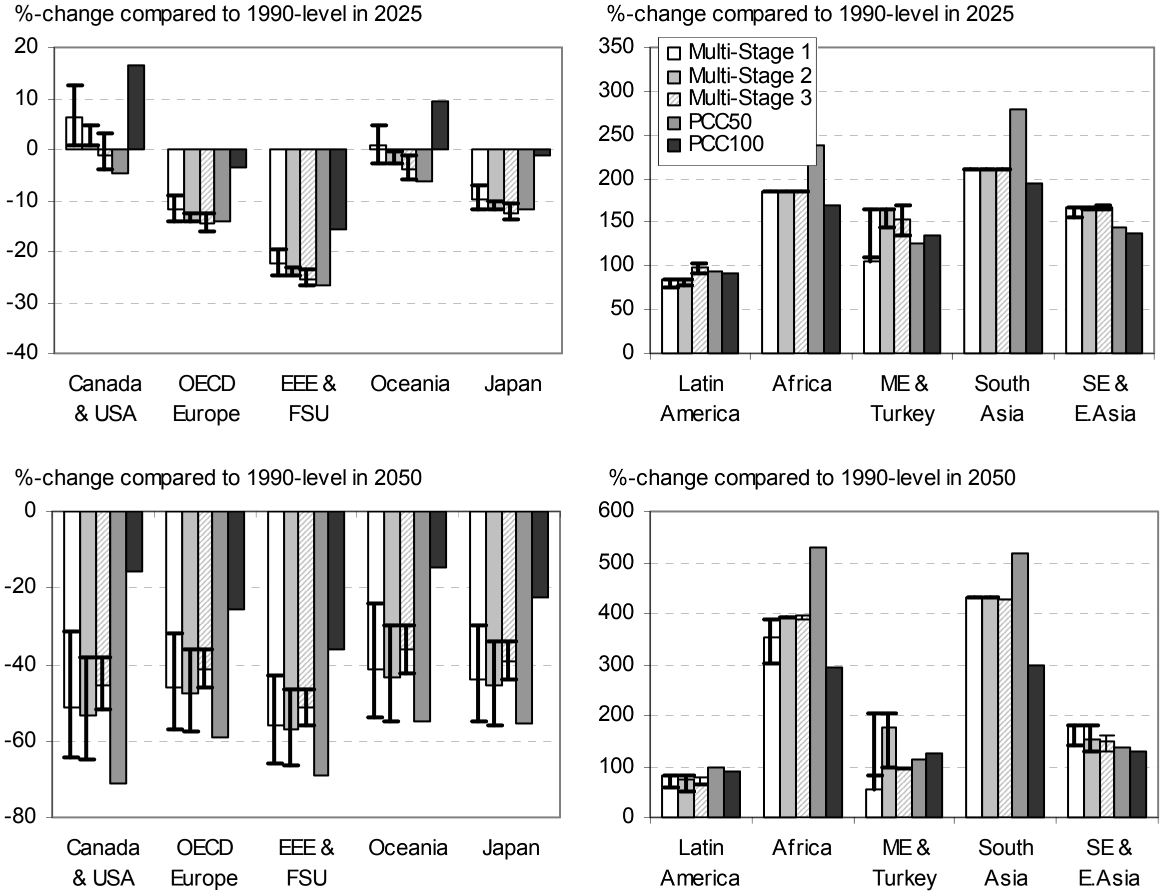

Figure 4.4: Robustness of results for the Multi-Stage variants under the S650e profile. Source: FAIR 2.0 model

4.5 All results of the S550e and S650e profiles compared

We will now compare the results of all MS and PCC variants for the two different emission profiles. Figure 4.5 shows the relative outcomes resulting from the MS and PCC under the S550e and S650e profiles for the various regions in the short and long term. The approaches resulting in relatively the least emission reductions (or largest emission allowances) are indicated in grey. The approaches resulting in the relatively largest emission reductions (or smallest emission allowances) are indicated in black. White indicates an intermediate position.

From these results it can be concluded that changing from the S550e to the S650e emission profile significantly influences the relative reduction efforts under the MS variants and the PCC50 case. Only the relative reductions under the PCC100 case for both the Annex I regions and non-Annex I regions remain unaffected. For the low-income non-Annex I countries, the change from the S550e profile to the S650e profile has the largest influence on the relative reductions resulting from the various approaches. Under the S650e profile, the large number of excess emission allowances (even in the long-term) occurs for the PCC50 case, making the latter more favourable than the MS cases.

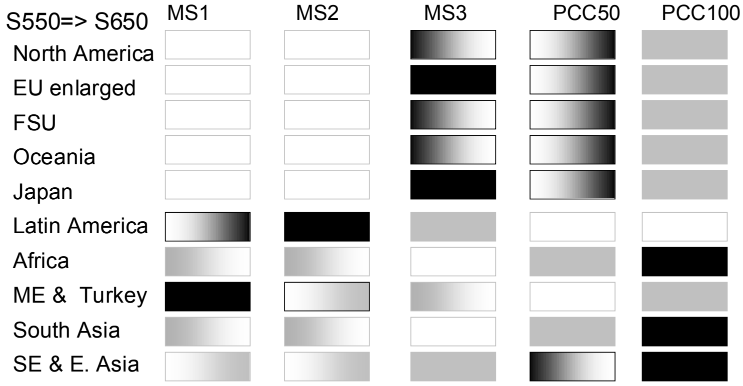

Figure 4.5: Regional relative scores for the Multi-Stage and PCC reference variants by 2025 under the IMAGE S550e profile (left-hand side bars) and the IMAGE S650e profile (right-hand side bars).Source: FAIR 2.0 model

4.6 Pros and cons of the Multi-Stage and Per Capita Convergence approaches

In the previous sections we analysed and compared the implications of the Multi-Stage and Per Capita Convergence variants quantitatively. Here, we will evaluate the pros and cons of the three MS variants and the PCC variants qualitatively.

The Multi-Stage variants

First, all variants have in common the CR-index threshold for entering the emission-limitation stage. This threshold looks for a middle road somewhere between the principle of need (justifying that countries are being exempted) and the desirability of early entrance of developing countries into the emission-limitation stage. It allows for an easier adjustment of the overall stringency of the regime if needed[19]. Moreover, it also allows for a more cost-effective global emission control via emission trading (compared to the CDM mechanism). Early participation can be attractive for the developing countries if emission trading results in net benefits. For this to work in practice, however, countries will need sufficient institutional and technical capacity, in particular, concerning the monitoring of national emissions. This is likely to be a key limit in early participation of developing countries in emissions trading.

Regarding the emission-limitation stage, the main difference between the MS variants is the dynamic intensity targets in MS 1 (dynamic threshold) and MS 2 (double CR), and the prescribed emission growth limits in the MS 3(transition path) variant. The simulation results show that the MS 3 approach allocates more emissions to the developed non-Annex I regions than the MS 1 and MS 2 cases. Nevertheless, the dynamic intensity targets of MS 1 and MS 2 have the advantage of accounting for baseline uncertainty on economic growth. Since developing countries experience particularly large fluctuations in economic performance, they are likely to be more willing to adopt dynamic than fixed targets. At the same time, intensity targets have drawbacks as well (Müller et al., 2001; van Vuuren et al., 2002). They introduce uncertainty about environmental effectiveness and complicate the measurement of the target itself, and ultimately also the use of the emission-trading instruments. However, as they generally provide more certainty about economic costs, it would seem that intensity targets provide a better chance than fixed targets to involve developing countries at an early stage[20].

An advantage of the MS 3 approach is that it creates a rather smooth transition from the emission-limitation stage to the emission-reduction stage. The other MS approaches may result in a still more drastic shift from increasing emissions in the emission-limitation stage to decreasing emissions in the emission-reduction stage. However, the fixed transition pathways make the MS 3 variant less flexible and can lead to large Annex I emission reductions. Another drawback of the MS 3 approach is that it is based on a rather artificial (dimensionless) identity: the transition constant. It is neither directly related to (per capita) emissions (responsibility) nor to income (capability). From a policy point of view the abstract nature of the TC makes it less suitable for negotiations[21].

The main difference between MS 1 and MS 2 is the use of a dynamic threshold versus a fixed threshold for the emission-reduction stage (CR index). The dynamic world-average per capita emission threshold can result in early entrance of relatively poor country with high per capita emission levels (South and North Africa, Middle East) in the emission-

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[19] It is expected that adjusting the threshold levels once adopted will be more difficult than adjusting the stringency of emission limitation and reduction targets.

[20] Some of the drawbacks may be overcome through more sophisticated arrangements, such as dual-intensity targets (Kim and Baumert, 2002), indexed absolute targets (Philibert and Pershing, 2001) or including clauses to deal with risks resulting from situations of economic recession.

[21] However, the Multi-Stage 3 approach may still be workable when negotiations focus on the principle of relating the length of the transition period to per capita emission levels, and derive the TC level from negotiations on the overall stringency of emission control desired.

reduction stage, leading to relatively large emission reductions and disproportional burdens. 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 Capability-Responsibility index approach (MS 2) tends to give a more evenly distribution of emission reductions across the non-Annex I regions, because it accounts for both per capita emissions and per capita income.

Finally, the results show that the use of per capita emissions as burdens-sharing key in all MS variants can lead to (relatively) large emission reduction burdens for regions with relatively high per capita emissions, notably Oceania, USA/Canada, FSU and Middle East already in the short term, and North and South Africa in the long –term. In the design of Multi-Stage systems, it may thus be necessary to allow for adjustment factors in the burden-sharing key, or a change of the burden-sharing key used to avoid disproportional burdens and make these regimes acceptable for all Parties.[22]

The Per Capita Convergence variants

The PCC approach is based on a compromise between two opposing equity principles: sovereignty and egalitarian. The balance between the two principles is largely determined by the convergence year. Due to the reduction in the global emissions over time, the convergence year not only determines the relative share of Annex I and non-Annex I in total emissions, but also the cumulative distribution of absolute emissions over time (Müller, 1999).

The analysis has shown that the results of the PCC approach are strongly dependent on the convergence year chosen and the global emission profiles. An ‘early’ convergence year (2050) combined with a stringent global emission constraint (S550e profile) can result in high emission reductions for Annex I regions. When combined with a less stringent global emission constraint (S650e profile), it can result in substantial amounts of excess emissions. On the other hand, a ‘late’ convergence year (2100) combined with a stringent global emission constraint (S550e profile) can result in substantial emission limitations for the low-income non-Annex I regions. When combined with a less stringent global emission constraint (S650e profile), a ‘late’ convergence year can result in allowing some Annex I regions (USA/Canada, Oceania) to still increase their emissions in the short term, while non-Annex I regions already have to limit their emissions. If this is to be avoided, there needs to be a match between the convergence year and stabilisation profile. However, it is not easy beforehand to set the proper convergence year when there is uncertainty about long-term climate goals and baseline emission levels.

The pros and cons of the MS and PCC cases compared

The PCC approach’s main strengths are its clear concept, the certainty that it provides regarding the environmental effectiveness of the regime and developing country participation, and cost-effectiveness resulting from global participation in emission trading. At the same time, the early participation of especially the least developed countries causes many implementation problems. These countries lack the institutional capacities to properly implement policies and monitor emissions. This in turn will make them illegible to participate in emissions trading. Another drawback of the approach is that it can result in

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[22] One option to be further explored would be to relate not only the thresholds, but also the burden-sharing key, to both per capita emissions (responsibility) and per capita income (capability) to reach a more balanced distribution among all Parties.

surplus emissions that increase abatement costs for Annex I and richer developing regions and result in large financial transfers. Neither does the approach take any national circumstances into account. Finally, the resource-sharing concept is likely to meet principal policy objections from some key developed countries (like the USA) that do not adhere to a top-down regulation of global commons and the concept of rights Some of these problems can be remedied, like by inclusion of national adjustment factors and/or regional allocations of emissions (allowing for a regional redistribution under emission bubbles) and by restriction of the illegibility of emission trading of the least developed countries in relation to the certainty about emission levels (to avoid overselling) [23].

The strengths of the MS approach are its linkages and balanced coverage of different equity principles (capability, responsibility and egalitarian) and its flexible concept, with types and levels of commitments adjusted to development levels and offering room for negotiation. In this way a balance is struck between early participation of developing countries and adjustment to countries capacities to take on and implement commitments. Moreover, the approach is well compatible with the UNFCCC and KP, Its main weaknesses are the large reductions for Annex I countries with high per capita emissions (particularly under stringent emission profiles) and the need to divide the group of developing countries (G77/China). Another weakness is the complications resulting from the use of intensity targets, and this approach's limited ability to adjust to more stringent targets over time (particularly in the MS2 and MS3 variants). Adopting another burden-sharing key (like per capita income) or even a mix of criteria could reduce the first weakness. The problems with the intensity targets might be remedied by allowing developing countries either to trade only after the commitment period (ex-post) or by adopting a dual-intensity target approach (Kim and Baumert, 2002) that would further reduce economic uncertainty.

Table 4.8: Pros and cons of the Multi-Stage and Per Capita Convergence approaches

	Pros	Cons
Multi-Stage	• Approach covers different equity principles • Flexible concept for adjusting commitments to national capabilities and offering room for negotiation • Compatible with KP/UNFCCC	• Intensity targets reduce certainty about environmental effectiveness and complicate implementation • Large reductions for Annex I countries with high per capita emissions • Need to divide the developing countries into groups
Per Capita Convergence	• Certainty about DC participation • Certainty about environmental effectiveness • Clear concept • High cost-effectiveness due to for full participation	• Implementation problems for LDCs • Risk of surplus emissions resulting in extra costs for Annex I / middle-income DCs • Political resistance against resource- sharing concept • No accounting for national circumstances

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[23] In principle, the PCC approach could be detached from the egalitarian concept of equal human entitlements to the use of global commons, by providing countries allowances instead of rights but this seems hard to conceive given the ideological origins of the concept.

4.7 Conclusions

In this chapter we have described and analysed the implications of a number of alternative Multi-Stage (MS) and Per Capita Convergence approaches for the differentiation of future climate commitments under two alternative global emission profiles for stabilising greenhouse gas concentrations at 550 and 650 ppmv CO_2-equivalent.

The analysis of the three Multi-Stage variants shows that:

- For all Annex I countries in 2025, the reductions in assigned amounts of at least 30-55% compared to the 1990 levels are necessary to achieve the 550-ppmv target and 10-20% for the 650-ppmv target. In 2050, the reductions are at least 70% (S550e) and 40% (S650e).
- Among the MS variants, MS 3 results in the largest reductions in the short term for Annex I, due to the late entry of the middle- and high-income non-Annex I regions.
- Participation of the major middle- and high-income non-Annex I countries in reductions is needed before 2025 (S550e) and 2050 (S650e). For S550e, this implies that countries will start to participate at significant lower per capita income levels than for Annex I under the Kyoto Protocol.
- With respect to the emissions for non-Annex I regions, the results of the Multi-Stage variants are quite sensitive to particular assumptions, such as participation thresholds and the global emission profile. No general conclusion for this group as a whole can be drawn. For the S550e profile, the MS 3 case tends to result in fewer reductions for the more middle- and high-income non-Annex I regions, while for the low-income non-Annex I regions, the MS 2 case requires the least efforts. For the S650e profile, the results of the different variants in the short term (2025) are quite similar due to the late participation of most non-Annex I regions.
- Finally, the robustness analysis shows that the future emission reductions of the three MS variants depend just as much on the MS case chosen as on the exact parameters used. The most important parameters are the threshold levels.

The main findings for the Per Capita Convergence variants:

- The results of the PCC approach are strongly dependent on the convergence year chosen and the global emission profiles.
- An ‘early’ convergence year (2050) combined with a stringent global emission constraint (S550e profile) can result in high emission reductions for Annex I regions, while when combined with a less stringent global emission constraint (S650e profile), this can result in substantial amounts of excess emissions. On the other hand, a ‘late’ convergence year (2100) combined with a stringent global emission constraint (S550e profile) can result in substantial emission limitations for the low-income non-Annex I regions; when combined with a less stringent global emission constraint (S650e profile), it can result in allowing some Annex I regions (USA/Canada, Oceania) to continue to increase their emissions in the short term when non-Annex I regions need to limit their emissions as well.
- If this is to be avoided, there needs to be a match between the convergence year and stabilisation profile. However, it is not easy beforehand to set the proper convergence year when there is uncertainty about long-term climate goals and baseline emission levels.

When we compare the MS variants and the PCC variants, the main findings are that:

- For the Annex I regions, the differences in emission allowances between per capita convergence by 2050 and the MS variants are relatively small. Only the 2100 convergence regime is an exception, leading to the lowest reduction efforts.
- For the more developed non-Annex I regions, the convergence approaches can lead to substantial emission limitations reductions under the S550e profile, especially for the SE & E Asia region (including China). For the middle- and high-income non-Annex I regions (Latin America, Middle East & Turkey and SE & E. Asia), the MS 3 variant is more attractive in the short term than the PCC cases. This is because their per capita emissions are higher than those of the low-income non-Annex I regions and close to the world average. In the long term, the differences between these two approaches are small.
- For the least developed non-Annex I regions, the convergence of 2050 approaches are generally more attractive than the MS variants because their allowable emission levels are larger than their baseline emissions. However, a 2100 convergence leads to the highest efforts.

In addition to the quantitative analysis we also evaluated the strengths and weaknesses of the specific Multi-stage and Per Capita Convergence variants, and of the two approaches in general. From this analysis we can conclude that:

- The CR index threshold in the new Multi-Stage approach results in a more balanced transition of developing countries into the emission limitation states than per capita income only. The double Capability-Responsibility index approach (MS 2) also tends to give an evenly distribution of emission reductions across the non-Annex I regions, but the fixed thresholds makes it less flexible to adjust to more stringent future climate policies than the dynamic world average threshold (MS 1).
- The transition pathway approach in MS3 secures a smooth transition toward the emission reduction stage, but is even less flexible than the double CR index (MS 2) and results into high Annex I burdens under stringent stabilisation profiles.
- The per capita emissions burden-sharing key in all MS variants leads to (relatively) large emission reduction burdens for regions with relatively high per capita emissions that can be disproportional and unacceptable. The burden-sharing key will have to be adjusted to better account for different national circumstances.
- For a balanced distribution of emission reductions, avoiding excess emissions, there needs to be a match between the convergence year and stabilisation profile. As shown in this study, with a ‘proper’ match the results of the PCC approach do not have to be very different from a MS approach. However, it is not easy beforehand to set the proper convergence year when there is uncertainty about long-term climate goals and baseline emission levels.
- The PCC and MS approaches both have their strengths and weaknesses. Overall, the MS approach better fits in with the current approach taken under the KP and the UNFCCC and seems to provide a more flexible, technically feasible and politically acceptable approach for differentiating future commitments than the PCC approach. However, the PCC approach may provide more certainty about sufficiently early developing country participation that is needed to meet stringent climate policy goals and more flexibility for policy adjustments. Moreover, there are options for remedying some of the problems related the approach.
- Both the MS and PCC approach will have to be further refined to be able to deal with different national circumstances and to avoid disproportional burdens.

5 Emissions trading, abatement costs and the impacts on the energy system

5.1 Introduction

Chapter 4 showed the different climate regimes explored in this study to lead to a wide range of future emission allowances per region. In this chapter, we will explore the consequences of these climate regimes in terms of abatement costs, emissions trading and the effects of GHG abatement on the energy system. As explained in Chapter 2, we used the abatement costs and emissions trading model of FAIR 2.0 in combination with the marginal abatement curves from TIMER and other sources to determine the internal market equilibrium permit price (permit price), the traded emission reductions and the total regional abatement costs. The net regional costs or gains for the different climate regimes result from the costs of domestic abatement combined with the costs or gains from emissions trading. Given the large differences in income between the regions, the costs (or gains) are expressed as a percentage of regional GDP (further referred to as the effort rate), which gives an indication of the impact of the climate policies taken on the local economies. GDP can be expressed either in Market Exchange Rates (MER) or in PPP (Purchasing Power Parity) terms[24]. According to our current understanding, comparison of abatement costs to GDP measured in PPP terms might be more relevant as an indication of potential economic impacts where all reductions result from domestic abatement. However, in the case of emission trading, MER-based GDP estimates would be more relevant for comparison. As the lion's share of the reduction efforts are taken domestically, GDP in PPP terms would seem most favourable. Section 5.2.5 will go further into the implications of the use of MER or PPP-based measurement of the effort rate.

All regions are assumed to follow a least-cost approach in meeting their reduction targets. This implies that the reduction objective will be spread over the different emission sources in a cost-effective way and that full advantage will be taken of the flexible mechanisms, i.e. international emissions trading (IET), joint implementation (JI) and the clean development mechanism (CDM). The PCC variants implicitly assume that all countries participate in the future commitment regime from 2012 onwards, and therefore can all fully participate in emissions trading. For the MS variants, regions only participate in emission trading after they have reached the first threshold. CDM allows participating regions to fulfil some of their abatement effort by buying emission reductions of non-participating regions on a project basis. In this study, it was assumed that only a limited abatement potential of the non-participating regions was accessible for CDM projects (10-30%).

In FAIR, the cost-optimal distribution of abatement options over the different regions, gases and sources makes use of Marginal Abatement Costs (MAC) curves. MAC curves reflect the costs of abating the last ton of CO_2-equivalent emissions, and so describe the potential and costs of the different abatement options considered. Different sets of MAC curves for the different emission sources and abatement options are used. The international permit price is calculated using demand and supply curves derived from these MAC curves,

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[24] GDP levels of different countries are normally compared on the basis of conversion to a common currency (mostly US$) using Market Exchange Rates (MER). However, this is known to underestimate the real income levels of low-income countries. Therefore, an alternative conversion has been developed on the basis of purchasing power parity (PPP). In this article, we have usually used PPP-based GDP estimates, but where required, MER-based estimates for comparison are used.

applying the same methodology as Ellerman and Decaux (1998). The main assumptions regarding the cost calculations are presented in Table 5.1.

In the final step of our calculations, the permit price is used as a carbon tax in the TIMER energy model to determine the implementation of the emission reductions in the energy system, inducing a range of mitigation measures. These include fuel switches, faster introduction of zero-carbon options, energy efficiency improvement and the application of clean fossil fuels (using carbon capture and storage technology).

Box 5.1: Major assumptions underlying our cost calculations

Estimating costs of future policies is beset with uncertainties. This is already an important issue for short-term calculations for clearly defined policy cases like the Kyoto Protocol, but the uncertainties clearly increase for medium- to long-term calculations as discussed in this study. Some of the differences between different studies result from methodological differences, others simply reflect the uncertainties we are facing (see also (IPCC, 2001a)). In calculating cost levels in this analysis, several important assumptions had to be made. Given the status of current research, it is more useful to assume a cost-optimal implementation of emission abatement options than to introduce all kinds of policy implementation barriers into the calculations, which need to be assumed. For this, and other reasons indicated below, the cost levels should be interpreted as a lower limit of total abatement costs (not taking into account the uncertainties included in the marginal abatement curves and the TIMER model). The most important assumptions are:

- All countries participating in emission abatement under one of the regimes can fully participate in emission trading, without any restriction of the accessibility of reduction options. This is an optimistic assumption given: 1) the current barriers to abatement options (in particular energy efficiency) in developed but especially developing countries, and 2) the current state of conditions that need to be met for effective emission trading.
- High international permit prices result in a convergence of discount rates for high- and low-income regions.
- Strategic behaviour of suppliers in emission trading is not assumed, except with regard to banking of surplus emission allowances under Kyoto.
- It is assumed that, even without new climate policies, the energy sector will use the reduction option to reduce their costs, as applied in niche markets on the basis of existing policies and subsidies, resulting in further technology development.
- The costs calculated only represent the direct-cost effects based on MAC curves but not the various linkages and rebound effects via the economy or impacts of carbon leakage; i.e. there is no direct link with macro-economic indicators such as GDP losses or other measures of income of utility loss.

Table 5.1: Main assumptions for emissions trading

Marginal abatement curves	Response curves from the TIMER model are used as MAC curves for CO_2 emission from the energy/industrial system[25], while for the non-CO_2 GHGs, MAC curves from the GECS project (Criqui, 2002) are used. For these last MACs, we have assumed a technological improvement of 2% reduction increase per five years. For the large agricultural emission sources of CH_4 and N_2O, MAC curves were not available. As it is unlikely that these sources will remain unabated under ambitious climate targets, we assumed a linear reduction towards a maximum of 35% compared to the baseline levels within a period of 30 years, when the permit price reaches a value of approximately €25 per ton CO_2eq.
Transaction costs	For the use of the flexible instruments (IET, JI and CDM), we assume transaction costs. These transaction costs represent the sum of a constant €2 per tCeq plus 2% of the total abatement costs.
CDM accessibility	The CDM accessibility factor is set at 10% of the theoretical maximum in 2010 and increases in time to 30% in 2030.
Kyoto Protocol	The Kyoto targets are calculated by applying the Kyoto emission reductions formulated on the 1990 CO_2-equivalent emissions estimates for the Annex I regions without the USA (assuming 80% hot air banking by the CIS and Eastern Europe). The USA emission intensity improves according to the Bush Climate Change plan[26]. To be eligible under CDM in non-Annex I countries ARD projects are capped at a level of 1% of the base-year emissions. Estimates on sinks for the Protocol are based on FAO estimates and Appendix Z of the Marrakesh Accords (den Elzen and de Moor, 2002).
Sinks in the future commitment regimes	For emission reductions through sinks, we only account for the carbon credits from forest management and ARD projects. The sinks credits from ARD projects are determined by using the MAC curves derived from IMAGE 2.2 (Graveland et al., 2002). We apply conservative estimates for forest management. For the Annex I regions, credits are assumed to remain constant after Kyoto on the basis of FAO data and Appendix Z of the Marrakesh Accords. For the non-Annex I regions, we apply the lowest Annex I forest management credit per area unit, and multiply this by the forest area. The costs of sinks are assumed to be negligible.

5.2 Emissions trading and abatement costs

The different climate regimes and the stabilisation profiles lead to clear differences with respect to the level of emissions trading, domestic abatement and total abatement costs. In this section, the results will first be discussed on a global scale, followed by a more detailed regional analysis for both short- (2025) and long-term periods (2050).

5.2.1 International permit prices and global effort rate

Figure 5.1 shows the international permit price and the global effort rate for the selected climate regimes and stabilisation levels. The international permit price and the global effort

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[25] In order to take on the role of path dependency in the emission reductions, a large number of response curves have been calculated assuming a linear increase of the permit price after the first commitment period and the final value in the evaluation year. The response curves are converted into MAC curves to be used in FAIR (van Vuuren et al., 2003). Under the baseline, regional differences in pay-back times for energy-efficiency investments are used to introduce differences in energy efficiency levels among regions. In the mitigation cases it is assumed that the high carbon prices and the emergence of an international permit market will lead to converging pay-back times, with full convergence at €80 per ton CO_2.

[26] This is the climate policy proposed by the Bush Administration, which aims to improve the GHG intensity of the US economy by 18% in the 2002-2012 period (van Vuuren et al., 2002; White-House, 2002).

rates for the S550e profile are much higher than for the S650e profile, which can be explained by:

(i) the much larger emission reduction objective for the S550e profile;
(ii) the exponential form of the global MAC curve with rapidly increasing prices for the higher emission reduction objectives.

The permit price for the S550e profile shows a sharp increase (from €2 per tCO_2eq to €120-130 per tCO_2eq), due to the fast increase in the global emission reduction objective (from $1GtCO_2eq$ to $45GtCO_2eq$). The permit price for the S650e profile increases almost linearly (from €2 per tCO_2eq to €35 per tCO_2eq) as a result of a more gradual increase in the emission reduction objective (from 1 $GtCO_2eq$ to $25GtCO_2eq$). The permit price shows a continuous increase after 2050 for both stabilisation levels, despite the slowdown in the increase of the global emission reduction objective. This can be explained by a sharper increase in abatement costs for higher reduction objectives.

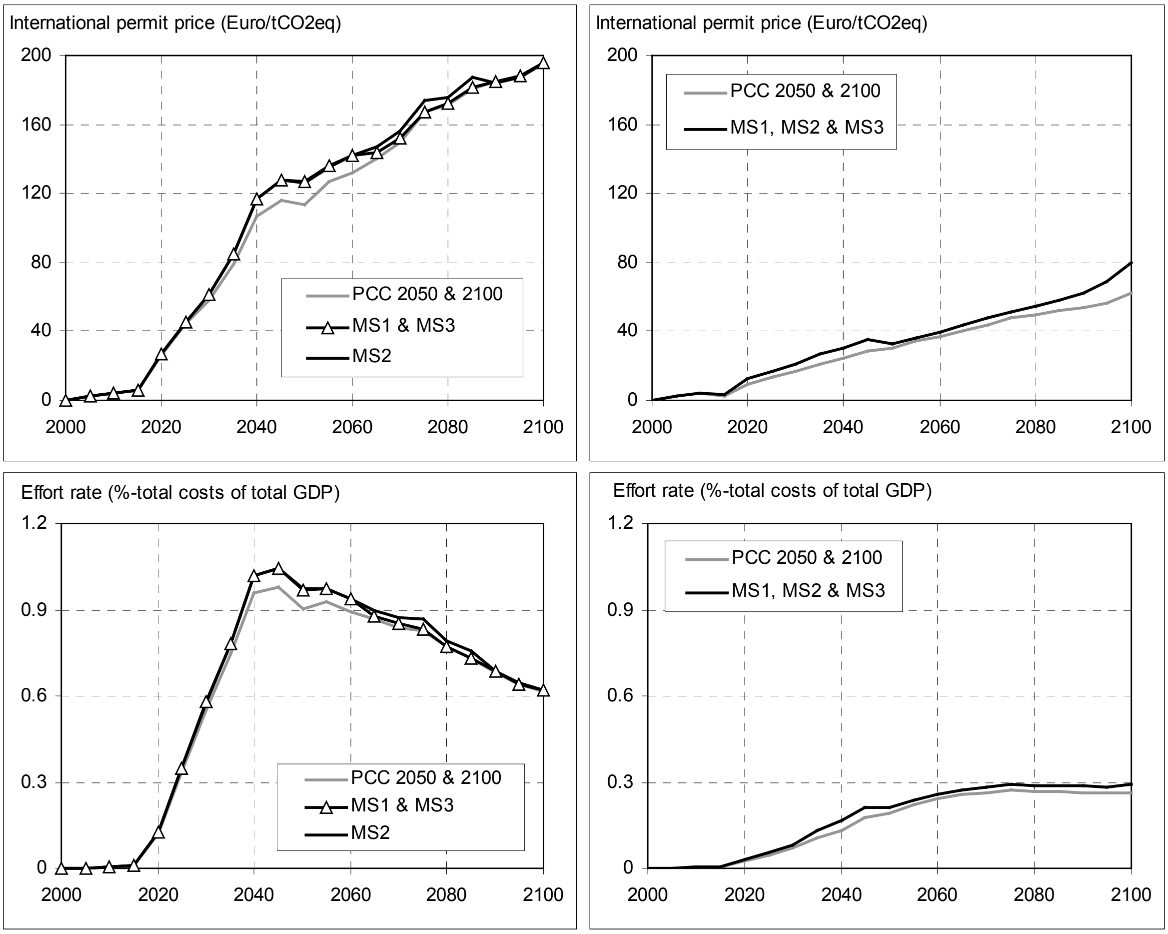

Figure 5.1: The international market equilibrium permit price (top) and the global effort rate (bottom) between 2000 and 2100 for the S550e (left) and S650e profile (right). Source: FAIR 2.0/TIMER 1.0[27]

For the PCC variants, the permit price remains somewhat below the permit price for the MS variants for both stabilisation levels, during most of the century. This difference results from the participation of the non-Annex I regions on the emissions trading market. For the

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[27] The calculations are done using the FAIR model on the basis of marginal abatement curves derived from the TIMER model.

PCC variants, all non-Annex I regions fully participate, whereas for the MS variants, participation increases with time. The non-participating non-Annex I regions have no commitments and can therefore only participate through CDM projects, for which a lower accessibility to emission reduction options is assumed (10-30%). This lowers the supply of emission reductions on the international market, thereby increasing the permit price. For the S550e profile, all regions participate in emission trading at the end of the 21st century, while for the S650e profile some African regions remain on the sideline.

The abatement costs per unit of GDP (global effort rate) shows approximately the same trend as the international permit price. For the S550e profile, the global effort rate increases fast towards 2040 (1.1%). After 2040 total abatement costs increase more slowly than global GDP, resulting in a gradual decrease of the global effort rate. For the S650e profile, the effort rate increases more gradually and stabilises after 2070 at approximately 0.3%. The differences in permit prices for the two approaches can also be seen for the effort rates, which are slightly lower for full participation (the PCC variants).

The costs as calculated here could be compared to other costs categories. The total energy system costs, for instance, are globally around 7-8% of GDP throughout the 2000-2050 period (with a decreasing cost ratio to GDP in most high-income countries, but a constant or increasing ratio in several low-income regions) (IMAGE-team, 2001). The estimates for costs of environmental policies in the EU-countries (mostly for waste and water water management) range from 1.5%-2.75% (CBS/RIVM, 2001; Wieringa, 1995). It should be noted that these are not full macro-economic costs. In the Third Assessment Report IPCC presents some estimates for costs of stabilisation of the CO_2-concentration but these estimates also cover a considerable range. For stabilisation the CO_2-concentration at 550 ppmv (comparable to 650 CO_2-equivalent) global GDP reduction were found in the order of 0.5-1.0% in 2050 for baseline that are comparable to the one used here. For stabilisation the CO_2 concentration at 450 ppmv (comparable to 550 CO_2-equivalent) GDP reduction for 2050 range in the order of 2.5-3.0% (IPCC, 2001a).

While the differences in the permit prices between the different regimes for the S550e profile are in a range of €10 per tCO_2eq in 2040, the difference between both profiles is in the range of €100 per tCO_2eq. The same holds for the global effort rate, where the differences within the S550e profile in 2040 amounts 0.1%, while the difference between both profiles amount to approximately 1%. Therefore both the international permit price and the global effort rate are more dependent on the emission reduction objective than on the climate regime considered.

5.2.2 Regional abatement costs and emissions trading

Most developments on the trading market can be explained by differences in emission reduction objectives and marginal abatement costs between regions. As seen in the previous section, the international permit price depends much more on the stabilisation level than on the differences in the climate regimes. Figures 5.2 and 5.3 show the required emission reductions compared to baseline levels on a regional level for the five climate regimes and both stabilisation profiles. The reductions compared to 1990 levels are shown at Annex 3. The figures show the domestic (the blue bars) and the acquired emission reductions through trading (the red bars). Negative reductions indicate the sellers of emission reductions, while the positive red bars indicate the buyers. As a result of emission trading (full trading under the PCC variants; and under the MS variants between the regions that participate in reductions combined with CDM) the emission reductions after trading are comparable for most variants – as emission trading ensures the most cost-efficient implementation of emission reduction options across the different regions.

The relative reductions obtained from trading are higher in the case of a less ambitious stabilisation target (S650e) than for a more ambitious one (S550e). The smaller the global reduction effort (and thus a lower permit price), the larger the difference in marginal abatement costs between regions and therefore the larger the profitability of trading. Conversely, with larger global reduction efforts (and thus a higher permit price) the marginal abatement costs of the different regions converge, making it less attractive to trade. Therefore, along with the increasing emission reduction objectives in time, the share of emission reductions achieved through trading decreases. This effect can be seen for both stabilisation profiles.

The S550e profile:
The patterns for the Annex I regions in terms of emission reductions provide a direct reflection of the relative emission reduction objectives discussed in Chapter 4. In the short term, significant reductions are needed for the current Annex I regions for all climate regimes (40-60%). In the long term, these reductions increase further (60-80%), while the differences between the regimes become smaller. Except for the PCC 2100 case, all Annex I regions are buyers of emission.

The non-Annex I regions show larger differences in emission reductions between regions, both in the short and long term. Africa and South Asia, and to a lesser extent, SE & E Asia are major sellers, while Latin America and Middle East & Turkey are buyers on the market. While under the PCC 2100 case, the emission allowances are larger for the Annex I regions, they are smaller for the non-Annex I regions. This results in higher emission reduction objectives for Africa and South Asia, reducing their share on the global emission market.

The same data for the PCC regimes in 2025 are also presented in Table 5.2. It shows that the actual regional reductions are almost similar between the two cases as emission trading leads to most cost optimal implementation of emission reduction options in the different regions (the remaining differences are caused by transaction costs). The third column for each variant represents the domestic reduction ratio. A domestic reduction ratio greater than 100% implies that the region is a permit-exporting regions, reducing more than they are obliged to. The importing regions show a domestic reduction ratio of less than 100%. It should be noted that under this stringent emission profile, in fact, the majority of the reductions for the regions that buy permits is done within the region itself (60-80% of the reductions in Annex I regions for the PCC 2050 variant; 80-110% for the PCC2100 variant). For the PCC2100 variant, the domestic reduction ratios among Annex I and non-Annex I regions strongly converge and some of the Annex I regions in fact become net sellers of emission permits.

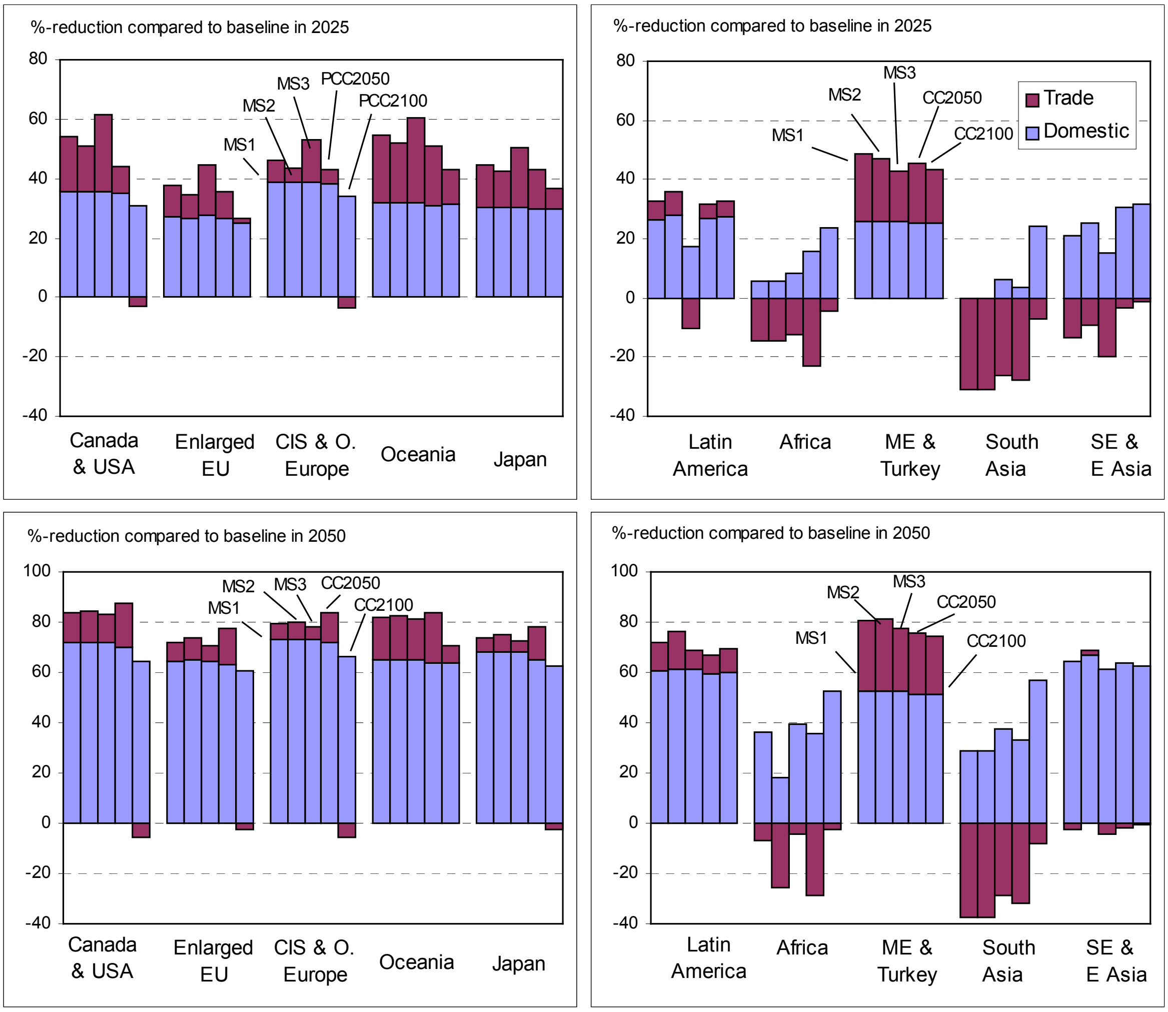

Figure 5.2: Relative reductions compared to baseline in 2025 (top) and 2050 (bottom) for the S550e profile. Source: FAIR 2.0/TIMER 1.0

Table 5.2: Reduction objectives, reductions after trade and domestic reduction ratios for the PCC2050 and PCC2100 cases in 2025 under the S550e profile

	PCC2050			PCC2100		
	Reduction objective (%)	Reductions after trade (%)	Domestic reduction ratio (%)	Reduction objective (%)	Reductions after trade (%)	Domestic reduction ratio (%)
Canada & USA	44	35	80	32	34	106
Enlarged EU	37	26	70	29	25	86
CIS + O. Europe	44	38	86	34	37	109
Oceania	51	31	61	43	31	72
Japan	44	30	68	37	30	81
Latin America	32	27	84	33	27	82
Africa	6	27	450	25	27	108
ME & Turkey	46	27	59	44	27	61
South Asia	3	31	1033	25	31	124
SE & E Asia	31	34	110	33	33	100

The S650e profile:

As already explained in the introduction to this section, compared to the S550e profile, a larger share of the emission reduction objectives is achieved through trading for both the short and the long term, while the net sellers and buyers remain the same. In the short term, some African regions and South Asia do not yet participate in the three MS variants and can therefore only join emission trading through CDM projects. This results in a limited supply of emission permits. In the long-term, these regions join the intensity target regime, which increases their supply on the international market.

The PCC 2050 case results in large surplus emission allowances for Africa and South Asia, explaining their relatively large emission supply. These large surplus emission allowances are accompanied by a relatively high emission reduction objective for the Annex I regions, raising their demand on the international market.

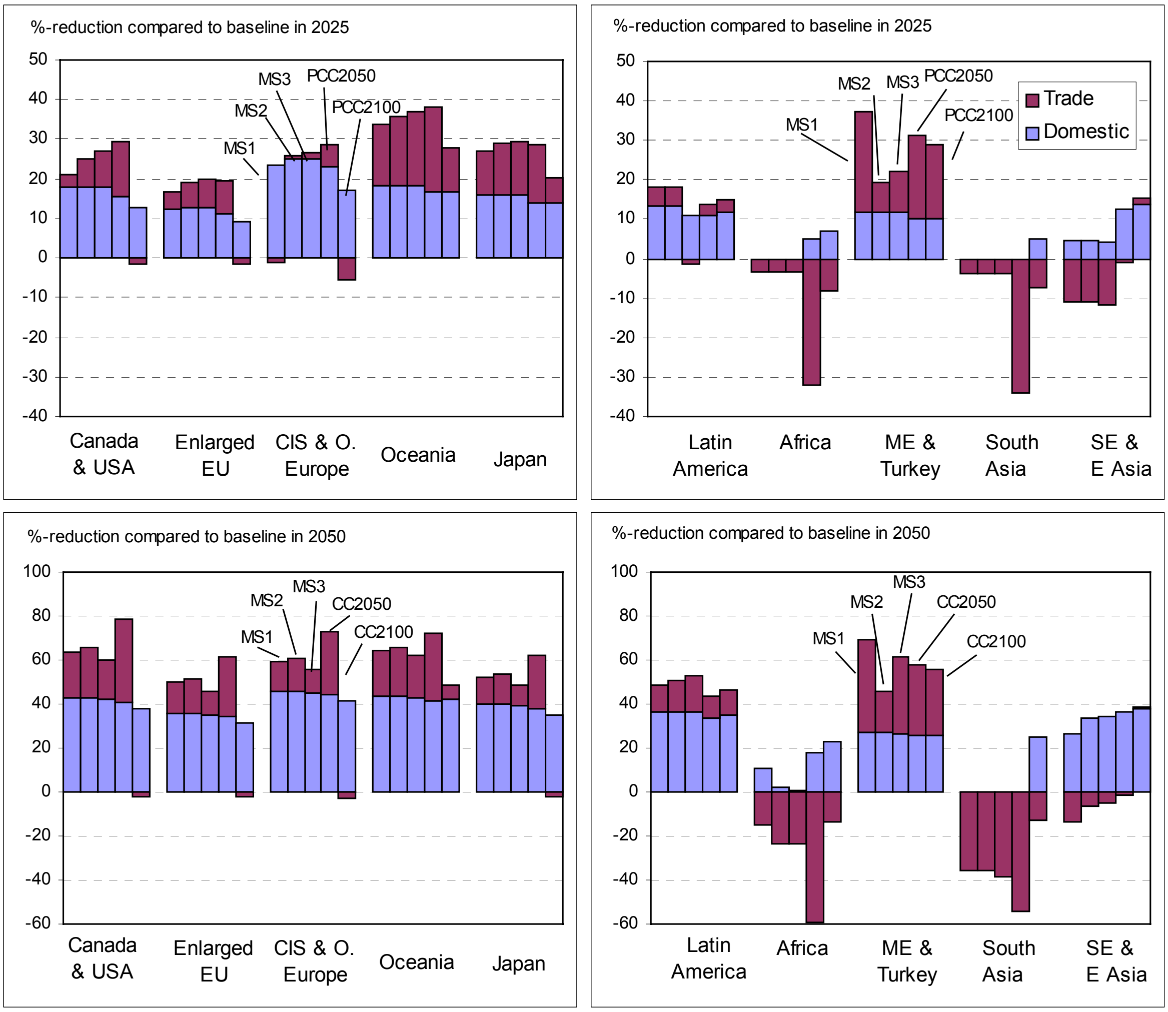

Figure 5.3: Relative reductions compared to baseline in 2025 (top) and 2050 (bottom) for the S650e profile. Source: FAIR 2.0/TIMER 1.0

5.2.3 Financial flows

The trading of emission permits results in a financial flow from the demanding regions to the supplying ones. The financial flows are equal to the regional traded volumes multiplied by the international permit price, while further taking the transaction costs into account. Therefore, the financial flows follow the same pattern as the traded emission permits in Figures 5.2 and 5.3 (red bars). Figures 5.4 and 5.5 show the financial flows between the different regions on the trading market (in billions of euro) for the five climate regimes and the two global emission profiles explored. Although fewer emissions are traded for the more stringent S550e profile, their financial flows are much larger (50-225 billion euro for S550e versus 10-50 billion euro for S650e) due to the much higher permit prices.

The S550e profile

The financial flows involved in trading increase in time as a result of the larger emission reduction objectives and larger permit prices. In the short term, the regional imported permits for the main importing regions (North America, the Enlarged EU and the Middle East) amount to 10-100 billion euro per year. The exported permits of the major exporting regions (Africa, South Asia and SE & E Asia) amount to 50-150 billion euro. In the long term the imported permits for the largest importing regions even increase to 100-200 billion euro, while the exported permits of South Asia come to between 300-500 billion euro. The volume of globally traded permits is lowest in the PCC 2100 (50 billion euro in the short term and 225 billion euro in the long term); it is highest for the MS3 case in the short term (250 billion euro) and for the MS2 case in the long term (700 billion euro). For the MS3 case, the financial flows decline in the long term due to higher emission reduction objectives for the major supplying regions (South Asia and Africa) and accompanying lower objectives for the demanding regions (Annex I). This is the other way around for MS2.

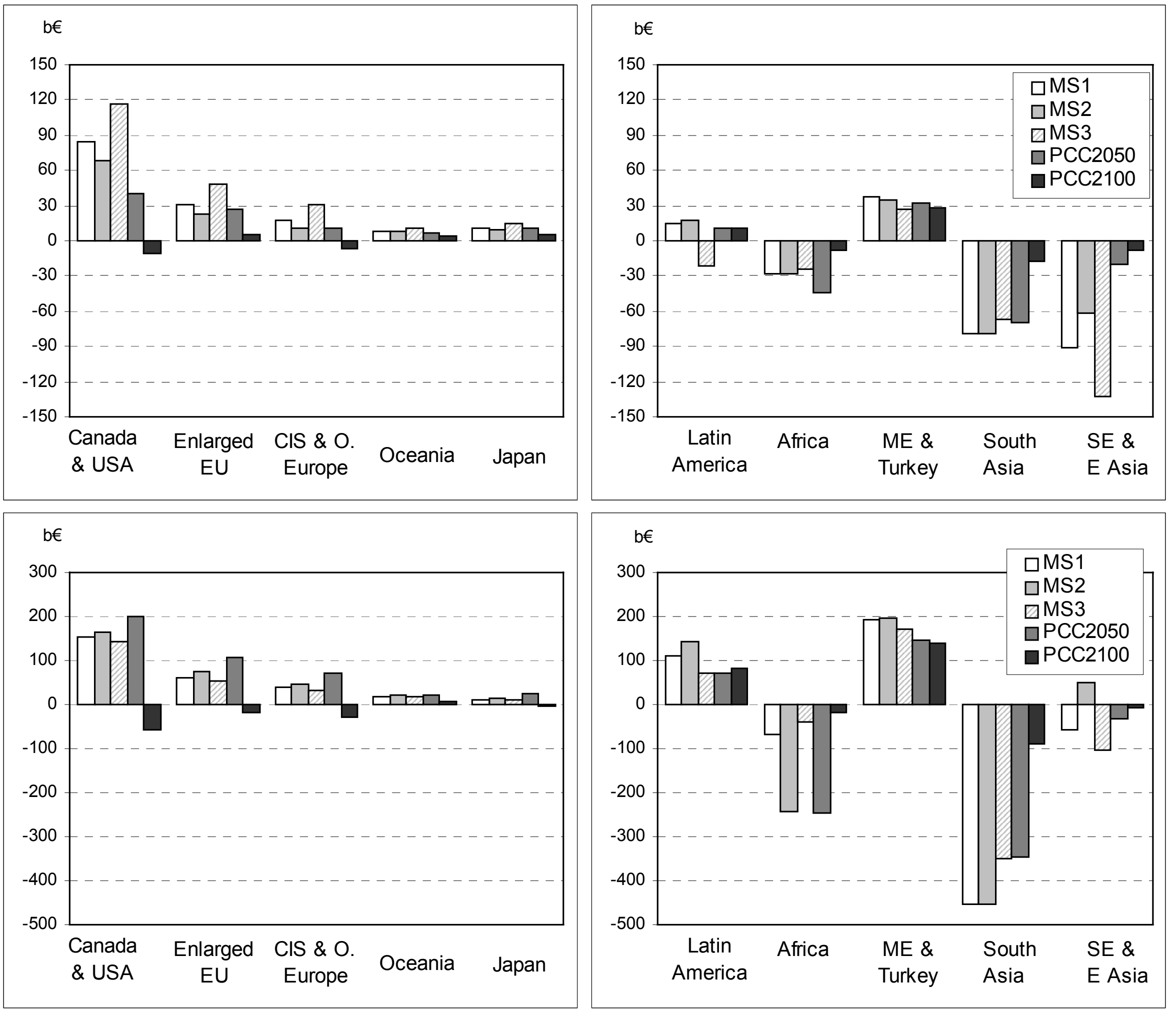

Figure 5.4: Financial flows resulting from emission trading for the 10 regions in 2025 (top and 2050 (bottom) under the S550e profile. Source: FAIR 2.0/TIMER 1.0

The S650e profile

In terms of its relative volume (percentage of emission reductions acquired through trading), emission trading plays a more important role under the S650e profile than under the S550e profile in the total emission reductions. Nevertheless, the financial flows are much smaller due to the lower international permit price. By 2025, the total traded permits of the main importing regions will amount to 0-20 billion euro. By 2050, these will have increased to about 0-100 billion euro. At the same time, the trade pattern between the various cases is not much affected. The relative position of the different regions (in terms of major sellers and buyers of permits) is similar, as discussed for the S550e profile. Comparing the different variants shows that the large amount of surplus emission allowances for Africa and South Asia in the PCC 2050 case increases their revenues significantly. Again, the volume of globally traded permits is lowest in the PCC 2100 case (10 billion euro in the short term and 75 billion euro in the long term), while it is highest for the PCC 2050 (45 billion euro in the short term and 300 billion euro in the long term) due to the surplus emission allowances.

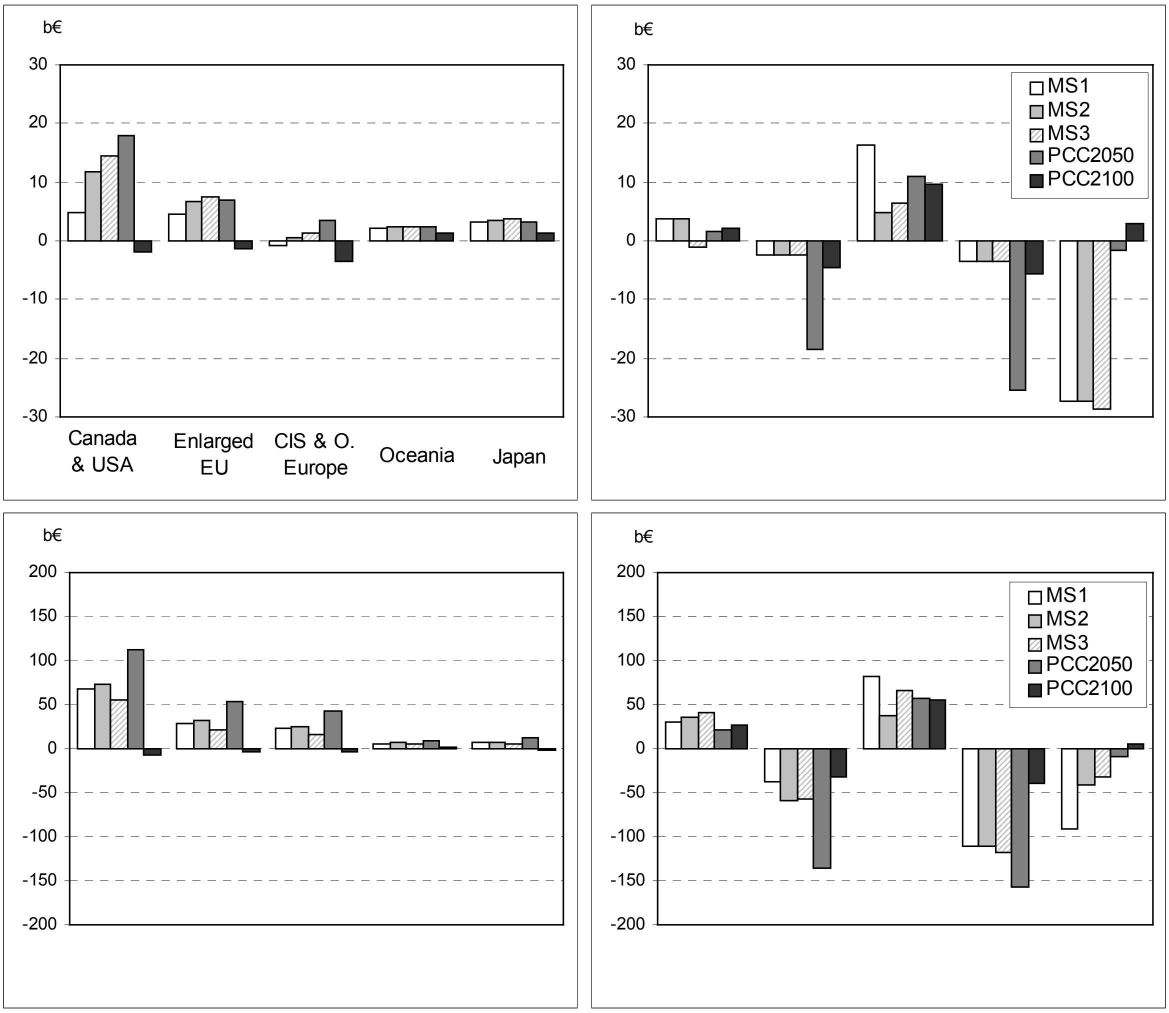

Figure 5.5: Financial flows resulting from emission trading for the 10 regions in 2025 (top) and 2050 (bottom) under the S650e profile. Source: FAIR 2.0/TIMER 1.0

5.2.4 Abatement costs

As explained earlier, the net regional costs or gains for the different climate regimes result from the costs of domestic abatement combined with the costs or gains from emissions trading. In this study we expressed the net costs for the different regions as a percentage of their GDP, thereby taking into account the size of their economies. This indicator is called the ‘effort rate’. As our cost calculations only take direct abatement costs into account (using marginal abatement curves), the effort rates do not include any macro-economic effects. Figures 5.6 and 5.7 show the effort rates for both global emission profiles and the five climate regimes explored.

The S550e profile:
The effort rates of the Annex I regions are generally between 0.5 and 1.0% in the short term, and between 1.0 and 2.0% GDP in the long term. Total costs tend to be relatively high in all variants for Canada & USA and Oceania (regions with the highest per capita emissions), and somewhat lower for the Enlarged EU and Japan (regions with medium per capita emissions).

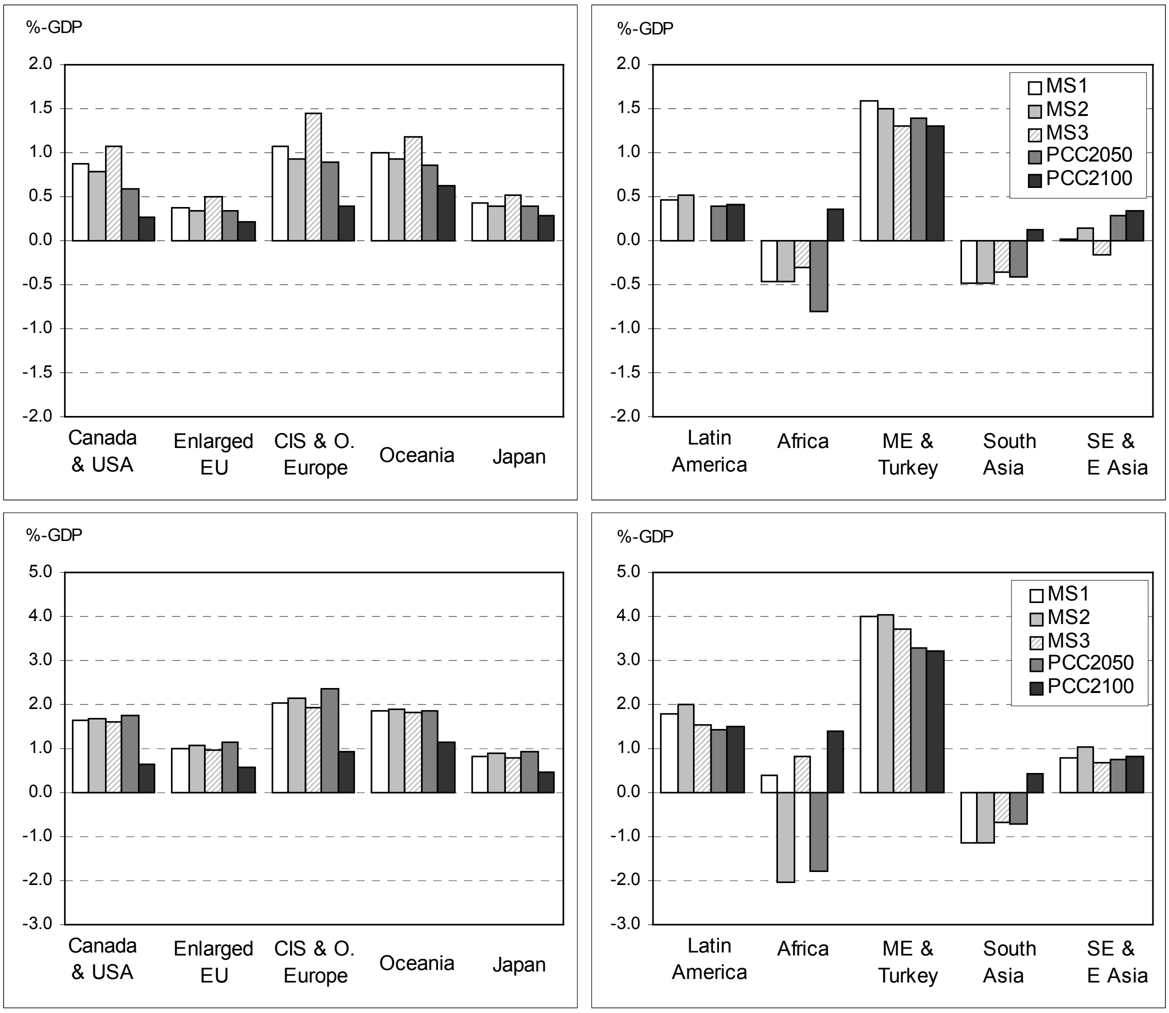

Figure 5.6: Effort rate for the 10 regions in 2025 (top) and 2050 (bottom) for the S550e profile. Source: FAIR 2.0/TIMER 1.0

The effort rate is the highest for CIS & O Europe due to their relatively high emissions per capita and low GDP. The relative position of the different regimes is similar for all regions: MS results in the highest costs, while the PCC 2100 case results in the lowest costs. The differences between the regimes become smaller in the long term.

There are large differences in effort rates between the non-Annex I regions. Over the whole period, Middle East & Turkey are confronted with the highest effort rates (1.5% in the short term, and 3-4% in the long term), mainly due to their relatively high emission reduction objectives (as a result of relatively high per capita emissions) and low GDP (in 2050 still lower than the 1990 Annex I per capita income). In the short term, the effort rate of Latin America is below 0.5%, while in the long term, the emission reductions and thereby the abatement costs become much higher. This combined their relatively low GDP results in relatively high effort rates (1.5% to 2%). Except for the PCC 2100 case, South Asia gains in all regimes, both on the short term as on the long term. The effort rate of Africa, on the contrary, differs largely between the various regimes. This results from large differences in emission reduction objectives, i.e. surplus emission allowances for the PCC 2050 case and late entrance in the climate regime for MS2. Furthermore, the effort rates show more extremes, due to their relatively low GDP. The effort rate of SE & E Asia is rather low (or can be even negative) and is comparable to the level of the Enlarged EU and Japan (under 0.5% on the short term and 1% on the long term).

The S650e profile:
The overall effort rates are much smaller for the S650e profile than for the S550e profile. For the Annex I regions they range from 0.1% to 0.2% in the short term and from 0.1-0.8% in the long term. Among these regions, effort rates are again somewhat lower for the enlarged EU region and Japan and the highest for CIS & O. Europe. The PCC 2100 case gives by far the lowest effort rates (below 0.05%), while the PCC 2050 case the highest (0.1-0.2%).

For the non-Annex I regions, again the differences are larger between the regions. The effort rates of the Middle East & Turkey are higher in all variants than the effort rates of the Annex I regions: the region needs to buy a large share of its emission reduction objective abroad. The effort rate of the Latin America region is comparable to most Annex I regions. For SE & E Asia the situation shifts from net profits under most regimes in the short term to net costs in all regimes in the long term, although these costs and gains are relatively low (0.1-0.2%). For the three MS variants, Africa and South Asia profit more in the long term due to their late entrance and less stringent emission reduction objectives, while the large surplus emission allowances for both regions, concerning the PCC 2050 case, results again in large negative effort rates (for Africa 0.5% in the short term and 1.5% in the long term).

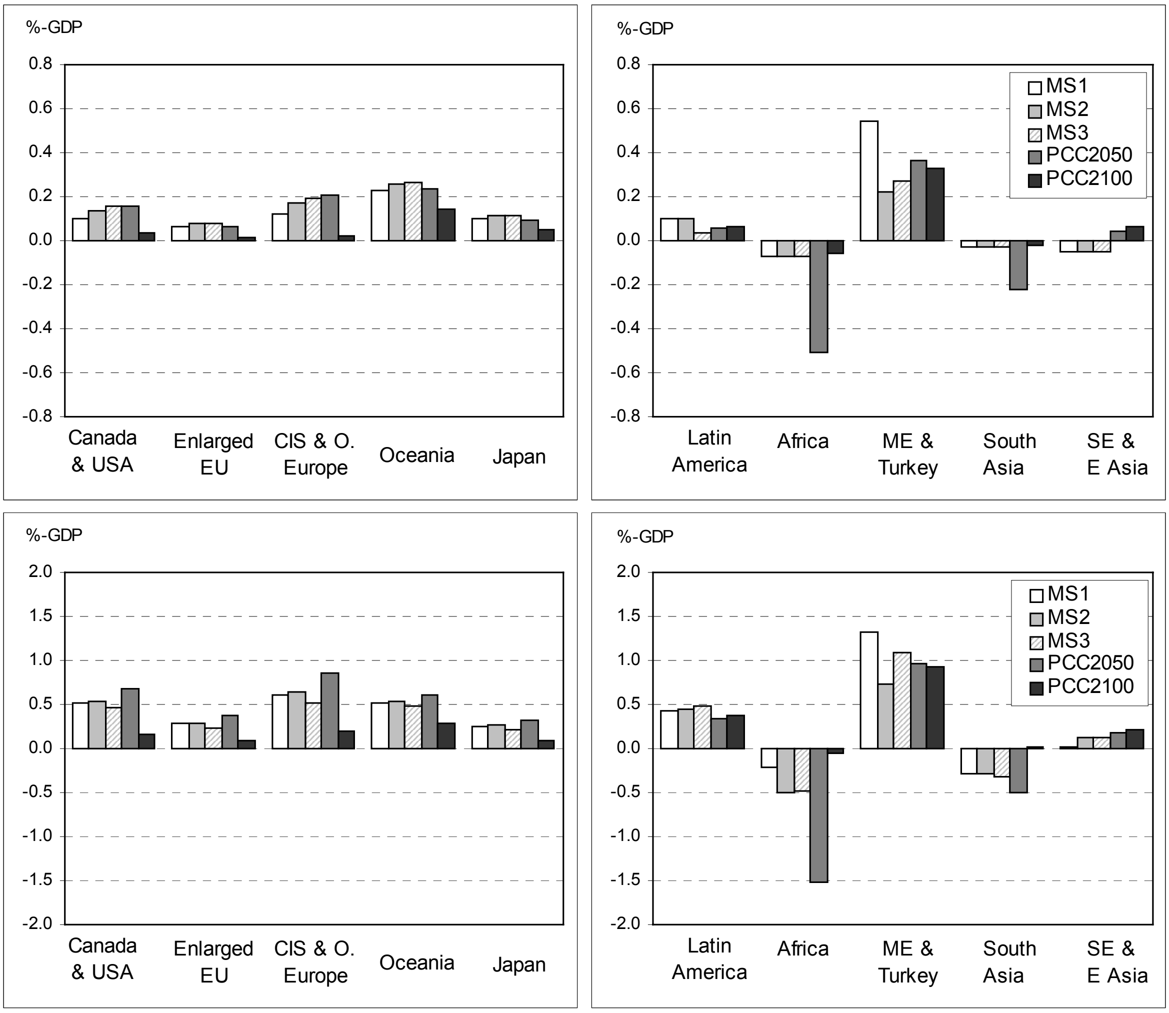

Figure 5.7: Effort rate for the 10 regions in 2025 (top) and 2050 (bottom) for the S650e profile. Source: FAIR 2.0/TIMER 1.0

Comparison of regions:

Below, we systematically analyse the effort rates of the regimes for the various regions by comparing the effort rates with the world average (see Table 5.3 and Table 5.4). Based on this table four groups of regions with similar efforts can be identified:

1) Regions with high income and high per capita emission generally show average costs when compared to other regions (Annex I regions excluding the FSU);
2) Regions with medium to high per capita emissions but medium income levels are confronted with the highest costs (Middle East & Turkey, FSU, and to a lesser extend Latin America);[28]
3) Regions with low to medium income levels and per capita emissions (South-East & East Asia), are confronted with low to average costs;
4) Regions with low per capita emissions and a low income (Africa and South-Asia) show net gains from emissions trading.

The regions in the first two groups are net buyers of permits on the trading market, while the regions in the other groups are the sellers.

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[28] Based on the arguments that Latin America has costs higher than the world average, however, since their costs are less compared to the costs of the other group 2 regions, this region could also be placed in group 3.

Table 5.3: Attractiveness of different regimes under the S550e profile

S550e profile	2025					2050				
Regions	MS1	MS2	MS3	PCC50	PCC100	MS1	MS2	MS3	PCC50	PCC100
Canada & USA	--	--	--	-	<	-	-	-	-	<
Enlarged EU	0	0	<	0	<	0	0	0	0	<
CIS + O. Europe	--	--	---	--	0	--	--	-	--	0
Oceania	--	--	--	--	-	-	-	-	-	0
Japan	0	0	-	0	0	0	0	<	0	<
Latin America	-	-	+	++	0	-	--	-	-	-
Africa	+	+	+	++	0	<	++	<	+	-
ME & Turkey	---	---	--	--	--	---	---	--	--	--
South Asia	+	+	+	+	<	+	+	+	+	<
SE & E Asia	<	<	+	0	0	<	0	<	<	0

* ++: high gains; +: low gains; <: low-average costs; 0: average costs; -: average-high costs; --: high costs; and ---: very high high costs.[29]

Table 5.4: Attractiveness of different regimes under the S650e profile

S650e profile	2025					2050				
Regions	MS1	MS2	MS3	PCC50	PCC100	MS1	MS2	MS3	PCC50	PCC100
Canada & USA	0	-	-	-	<	--	--	--	--	0
Enlarged EU	0	0	0	0	<	-	-	0	-	<
CIS + O. Europe	-	--	--	--	<	--	--	--	---	0
Oceania	--	--	--	--	-	--	--	--	--	-
Japan	-	-	-	0	<	-	-	0	-	<
Latin America	-	-	<	<	+	--	--	--	-	-
Africa	+	+	+	++	+	+	++	++	++	+
ME & Turkey	---	--	--	---	--	---	--	---	---	---
South Asia	+	+	+	++	+	+	+	+	++	<
SE & E Asia	+	+	+	<	<	<	<	<	0	0

* ++: high gains; +: low gains; <: low-average costs; 0: average costs; -: average-high costs; --: high costs; and ---: very high high costs.

5.2.5 Robustness of results

The results presented in the previous sections depend on model assumptions like the baseline scenario and the cost curves used. To assess the impacts of the different parameters, a sensitivity analysis was performed in which, per turn, one assumption was varied. Figures 5.8 and 5.9 show the results of this analysis for the international permit price and the global effort rate for the PCC 2050 case combined with the S550e profile. Figure 5.10 presents a comparison of the regional effort rates of the FAIR/TIMER and the Poles analysis for the five climate regimes explored.

Figure 5.8 shows the analysis of the impacts of the baseline scenario and the CO_2 MAC curves on the permit price and the global effort rate. Two different baseline scenarios were used: i.e. the high IMAGE SRES A1b baseline scenario and the low IMAGE SRES B2 baseline scenario (IMAGE-team, 2001). In addition to the TIMER-based CO_2 MAC curves, the curves from the POLES model (Criqui et al., 1999) and a second set of TIMER CO_2

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[29] *High gains*: more than twice the world average costs; *low gains*: less than twice the world average costs; *low-average costs*: cost at least 20% world average; *average costs*: costs less than 20% different from the world average; *average-high costs*: costs less than twice the world average costs, *high costs*: costs more than twice the world average costs; and *very high high costs*: costs more than four times the world avearge costs.

MACs were used. In this second set, we assumed a more limited convergence of discount rates for mitigation measures in different parts of the worlds (that would result from high permit prices). The main result of this is higher cost levels for mitigation measures in low-income countries.

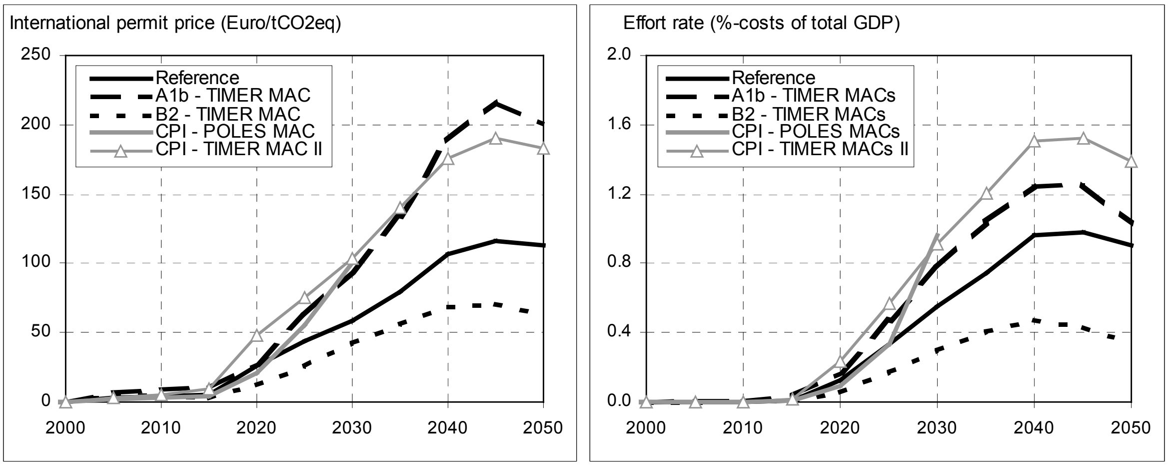

Figure 5.8: Sensitivity of the international market equilibrium permit price (left) and the global effort rate (right) for the baseline assumptions and CO_2 MAC curves for the S550e profile and the PCC 2050 case. Source: FAIR 2.0/TIMER 1.0

Figure 5.8 shows the baseline and the energy-related CO_2 MAC curves to have a large influence on both indicators (the POLES CO_2 MAC curves are used only till 2025). Changing the baseline affects the outcomes in different ways. The baseline scenario influences: 1) the emission reduction objective, 2) the MAC curves and 3) the GDP growth (denominator of the effort rate). The low emission B2 baseline scenario results in a lower permit price than the CPI baseline, while the high emission A1b baseline scenario results in a considerable higher price. In terms of effort rates, the differences with the CPI baseline are much less – certainly for A1b with a high GDP growth rate. Figure 5.8 also shows that depending on the choice of the baseline, global effort rates varies between 0.25% and 0.75% in 2025 (CPI at the lower end) and 0.5-1.3% in 2050 (CPI in the middle). Using the POLES CO_2 MAC curves or the other set of TIMER MAC curves, instead of the original MACs from the TIMER model, increases the effort rate and international permit price by about a third. In the case of the POLES model, the main cause is most probably the more limited set of abatement options considered in that model. For the second set of MAC curves of TIMER, this results from a different assumption on the costs of investing in energy efficiency options in low-income countries. In both cases, the differences provide a good reflection of the costs uncertainties that are associated with this type of calculations.

Figure 5.9 shows the results of the analysis of the impacts of the non-CO_2 MAC curves and the exogenous assumptions of sinks and non-CO_2 land-use emissions on the international permit price and the global effort rate. Instead of the non-CO_2 curves from the GECS project, use is made of the non-CO_2 MAC curves from the EMF21 project (EPA, 2003). Regarding the exogenous assumptions on sinks and non-CO_2 land-use emissions, an alternative assumption was made, i.e. no availability of sinks abatement options and no emission reductions for the non-CO_2 land-use emissions.

The impact of the non-CO_2 MAC curves, the non-CO_2 land-use emissions and sinks on the international permit price and the global effort rate is much smaller than the impact of the baseline scenario and the CO_2 energy MACs. Apparently, the two different sources of non-

CO_2 MACs have, on an aggregate level, a high level of agreement. Assuming no sinks and non-CO_2 land-use abatement options results in a 10-20% higher cost level than the standard calculations. It should be noted that in all cases, changes in regional results may differ from these global results.

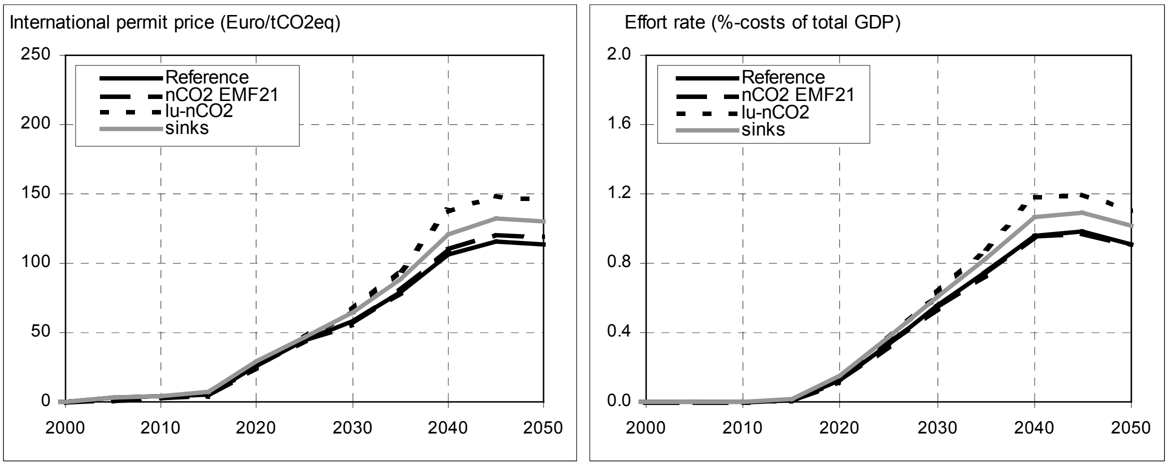

Figure 5.9: Sensitivity of the international market equilibrium permit price (left) and the global effort rate (right) to assumptions about non-CO_2 mitigation options and sinks for the S550e profile and the PCC2050 case. Source: FAIR 2.0/TIMER 1.0

The 2025 calculations as presented above have been done using the POLES model (Criqui et al., 2003). In Figure 5.10 we compare the results of our calculations to those of POLES. Not only do the effort rates show the same trend, but also the magnitudes are very comparable for both models. The differences between the models are larger for the non-Annex I regions than for the Annex I regions, because there is more uncertainty on the reduction costs and potential for those regions. The similarity in trends states that the conclusions regarding the differences in effort rates between regions and regimes are rather robust.

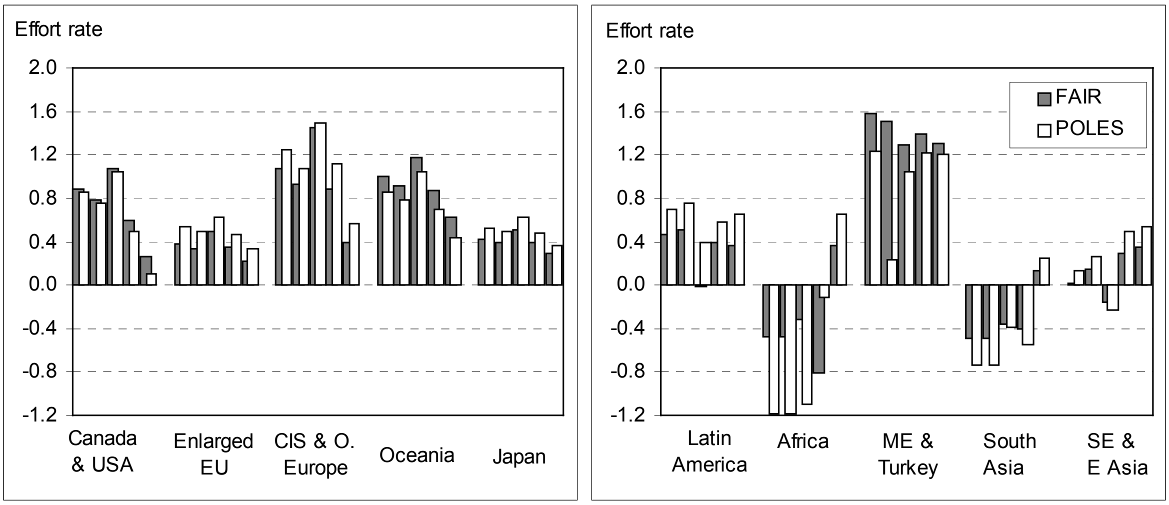

Figure 5.10: Sensitivity of the regional effort rates to both the FAIR/TIMER and POLES analyses for the S550e profile and the five climate regimes considered in 2025.

A final element that play an important role in the presentation of our costs results (effort rates) is the comparison to GDP. In our standard figures so-far we have compared costs to a purchasing power parity based (ppp) income measure. However, one might also argue that a comparison to income measures based on market exchange rates might be preferable.

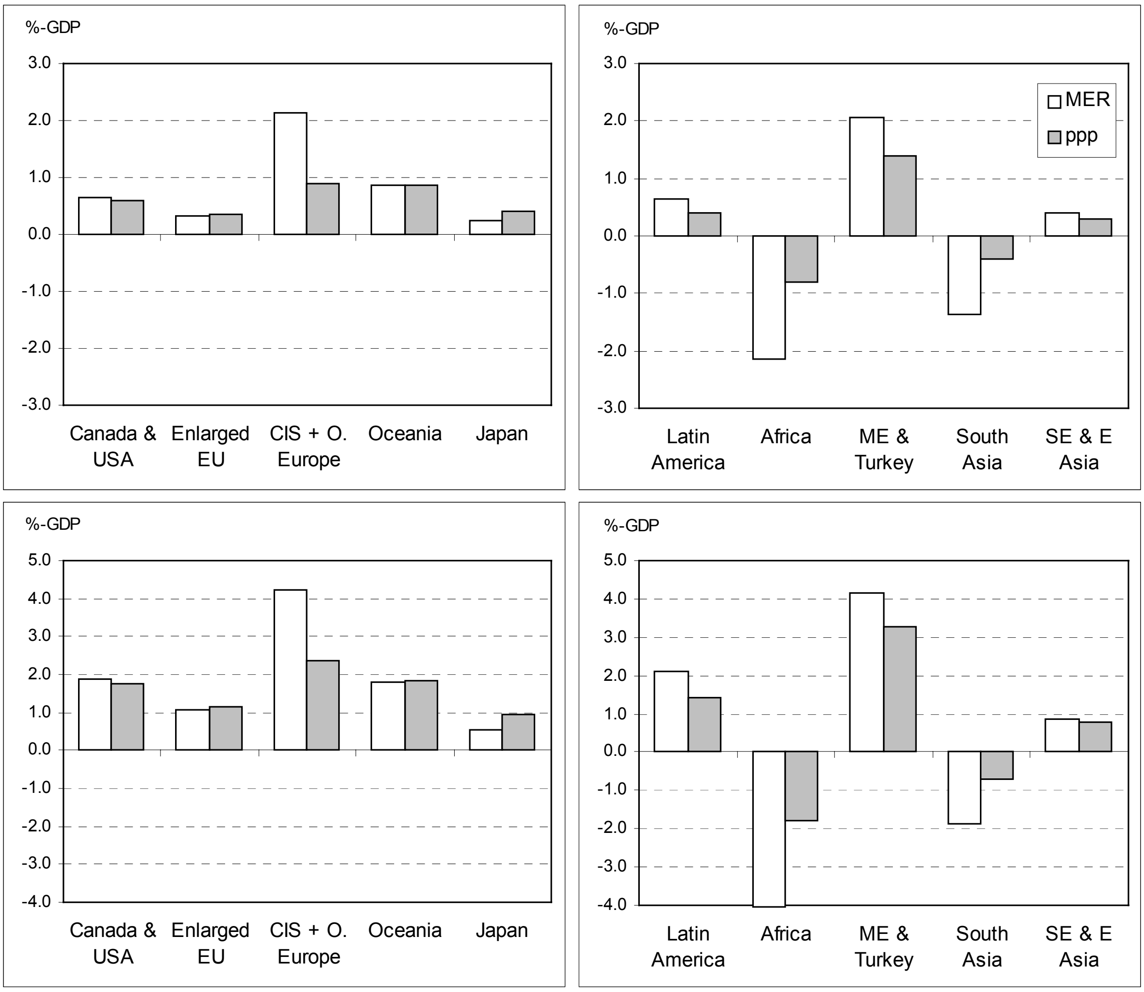

Figure 5.11: Comparison of effort rates based on market exhange rate (mer) GDP estimates and purchasing power parity (ppp) GDP estimates.

The choice of comparing costs to MER-based GDP instead of PPP-based GDP has a significant impact on the effort rates of the non-Annex I regions and FSU, enhancing the gains of Africa and South Asia, and the losses of the FSU, Latin America and the Middle East & Turkey. This difference can be more than a factor two. Since the MER and PPP GDP-values converge in time with rising income levels in low-income countries, the difference with the reference case becomes somewhat less in 2050.

5.3 Emission reductions for the different gases

Several studies have shown that cost-effective implementation of the Kyoto Protocol would lead to more than proportional reductions of the non-CO_2 greenhouse gases (Lucas et al., 2002; Reilly et al., 1999). In fact, while the non-CO_2 gases make up only 25% of the 2010 emissions, they could contribute to almost 50% of the total emission reductions.

Figure 5.12 shows the shares of the different gases in the global emission reductions between 2010 and 2050 for both emissions profiles. The abatement distribution is analysed only under the PCC 2050 regime, because the abatement efforts in the different regions are far more dependent on the global emission reduction objective than on the climate regimes assumed.[30] The figure shows the contribution of the non-CO_2 abatement action in the total reduction burden to decrease sharply towards 2050, where the decrease is much larger for the S550e than for the S650e profile. The decreasing trend can be explained by the fact that the potential of relatively cheap non-CO_2 emission reduction options is limited, simply because non-CO_2 gases from industrial and energy use represent only a limited share of total emissions (approximately 25%). For the S550e profile, the low-cost emission reductions are almost fully exploited around 2030, while for the S650e profile this happens by 2050.

For sinks, the results also indicate a declining relative contribution to the overall emission reduction (from 40% in 2010 to less than 5% in 2050). The total potential of enhancement of sinks is assumed to be limited to about 0.5-1 GtC per year. Furthermore, only a small share of the total potential (10-30%) is used due to socio-economic barriers (Graveland et al., 2002). Taking both limitations into account results in a total of 50-300 MtCeq sinks per year by 2050, which is an important but small contribution to the 10 GtCeq emission reduction needed at that time.

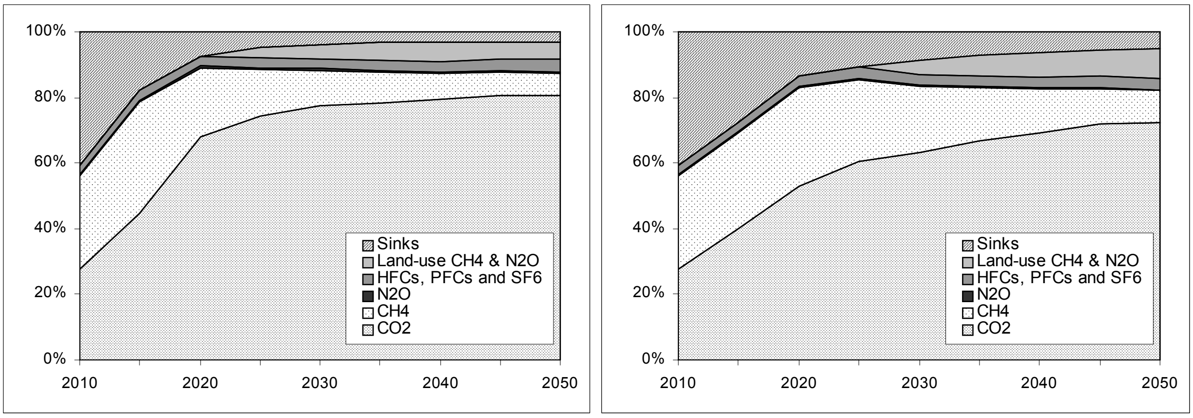

Figure 5.12: Share of greenhouse gases and abatement options in the overall emission reduction between 2000 and 2050 for the IMAGE S550e profile (left) and the IMAGE S650e profile (right). Source: FAIR 2.0/TIMER 1.0

Information on the abatement potential for the land-use related non-CO_2 emissions is currently still limited. As it is unlikely that abatements for these emissions will not occur under the stringent climate targets explored in this report, exogenous assumptions on emission reductions for these sources were made. We assumed that when the international permit price reaches a value of approximately €100 per tCeq, emissions from non-CO_2 land-use sources start to be reduced linearly towards a maximum of 35% compared to the baseline (as indicated under the assumptions in the introduction to this chapter).

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[30] The assumption about international emission trading implies the global emission reduction objective to be distributed over the different regions, gases and sources following a least-cost approach. Taking into account the assumptions about the emission trading market, the actual emission reductions in the different regions, gases and sources are hardly dependent on the climate regime assumed. Only the level of participation plays a role (but has only a small impact compared to the stabilisation level).

5.4 Abatement action within the energy system

This section discusses the abatement action taken within the energy system in more detail using the TIMER 1.0 model. Again, the abatement applied in the different regions is far more dependent on the global emission reduction objective than on the climate regime assumed. Therefore, in this discussion we will concentrate on the different implications of the two stabilisation levels and the PCC 2050 case. The climate policy scenarios in TIMER are simulated by introducing the carbon tax, determined by the FAIR model, into the model, inducing a range of changes within the system (increased investments into energy efficiency, fuel switches, changes in fuel trade patterns etc.). We also assume that with increasing permit prices, the unfavourable investment criteria for investments into energy efficiency in low-income regions can be reduced (in TIMER investments are simulated by a low accepted pay-back time). This low accepted pay-back time simulates investment barriers in these regions, resulting from a range of factors including large relative risks for long-term investments, lack of information and lack of capital. The emergence of a global emission trading market is likely to reduce these barriers. This is because investors from high-income countries (with stringent reduction objectives) are willing to invest in potentially low-cost reduction options in developing countries, thereby slowly reducing existing barriers as a function of an increasing global permit price. This will open up a large potential for investments into energy efficiency world-wide.[31]

Figure 5.13 shows the S550e profile to lead to substantial changes in the energy system compared to the baseline. Global primary energy use is reduced by more than 35% in 2050. Clearly, the reductions are not similar across the different energy carriers. The largest reductions occur for coal (70% in 2050), with the remaining coal consumption being primarily used in electric power stations using carbon capture and storage. Reductions of oil and natural gas are 50 and 45%, respectively (compared to baseline). Other energy carriers gain market share, in particular solar, wind and nuclear-based electricity and modern biomass.[32] As the S650e profile requires less reduction of carbon dioxide emissions, the changes in the energy system under this scenario are also not as sharp. In 2050, the primary energy use and oil consumption are both reduced by 20%, while the reduction of coal consumption amounts to 50% of baseline consumption (resulting in 2050 consumption levels, being slightly above current levels). As a result of the less constraining emission profile, natural gas use is higher than in the baseline scenario until 2035. However, by the time further emission reductions are required, natural gas will be replaced by non-zero carbon options, leading to a reduction of natural gas use of 10% in 2050.

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[31] We will look into the impact of this assumption in section 5.2.5 using an alternative set of TIMER-based cost curves.

[32] Modern biomass relates to gaseous or liquid fuels (commercially) produced from plants or trees. It differs from traditional biomass (gathered wood, straw, dung, charcoal, etc).

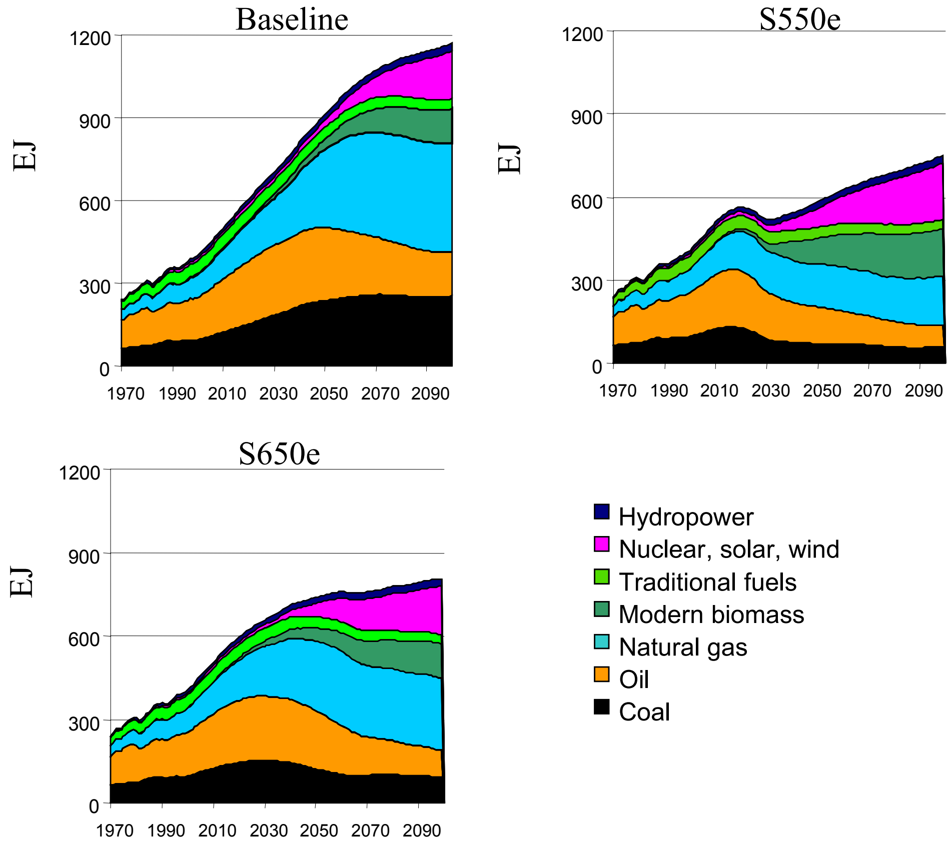

Figure 5.13: Total world primary energy supply for baseline and stabilisation at 550 and 650 CO_2-equivalent (PCC2050 case). Source: TIMER 1.0

Figure 5.14 shows the contribution of different abatement options to the overall reduction objective.[33] Over the whole simulation period, but in particular, in the first two decades, the lion's share of the reductions come from energy efficiency improvement (particularly outside the OECD regions). By 2030, other options start to become important: using biofuels instead of fossil fuels and non-thermal electricity modes (solar/wind and nuclear power) instead of fossil-based electricity.[34] The largest reductions are likely to occur in the electrical power sector. Several fully competitive non-carbon-emitting options exist at the carbon taxes used, i.e. renewables, nuclear and thermal power using carbon capture and storage. Carbon capture and storage plays an important role in the S550e profile throughout the century. Compared to other options, the largest contribution is in the first half of the century. In contrast, in the S650e profile, only in the second half of the century are carbon taxes high enough to build plants with carbon capture and storage competitive against normal electricity generation. In both emission profiles, renewables become a more attractive option during the second half of the century. In the S650e profile, fuel-switches from coal to natural gas also play a role, in particular during the first half of the simulation period.

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[33] The actual size of each option depends somewhat on the order of attribution. We first determined the total contribution from efficiency improvement, then the contribution from penetration of solar/wind and nuclear power and biofuels, followed by the contribution from biofuel penetration and, finally, the option of fuel switching among the different fossil fuels.

[34] We have allowed additional use of nuclear power as a mitigation option in these calculations. In fact, as the cost of this option is lower for most of the simulation period than the solar/wind power option, it represents a very attractive alternative in terms of a first response. The 'learning' capacity of this option is, however, assumed to be lower than for solar/wind power.

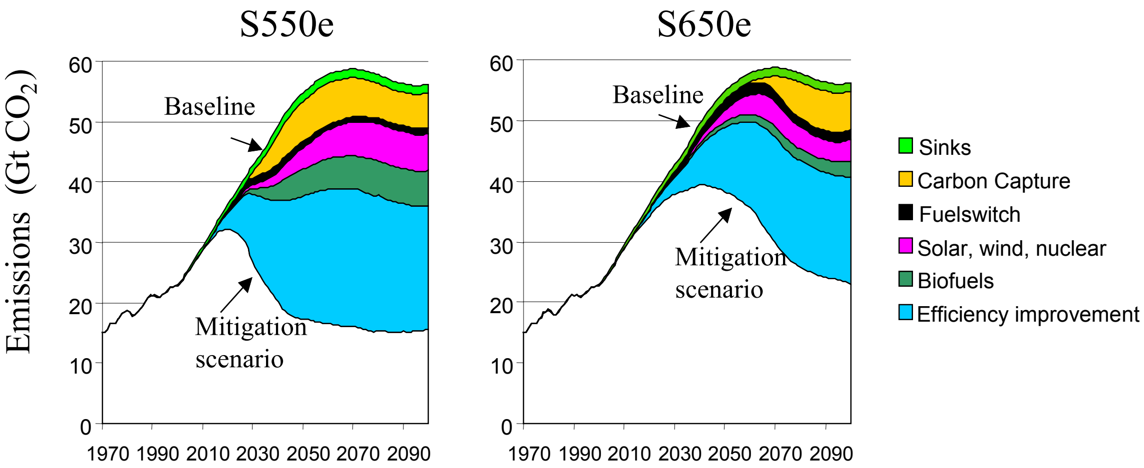


Figure 5.14: Emission reduction by mitigation measures for stabilising GHG concentrations at 550 (left) and 650 (right) ppmv CO2-equivalent (PCC2050 case). Source: TIMER 1.0

Climate policies can have considerable impacts on energy production and trade flows. Figure 5.15 and Figure 5.16 show the changes in imports and exports of oil (billions of dollars) and other fuels.

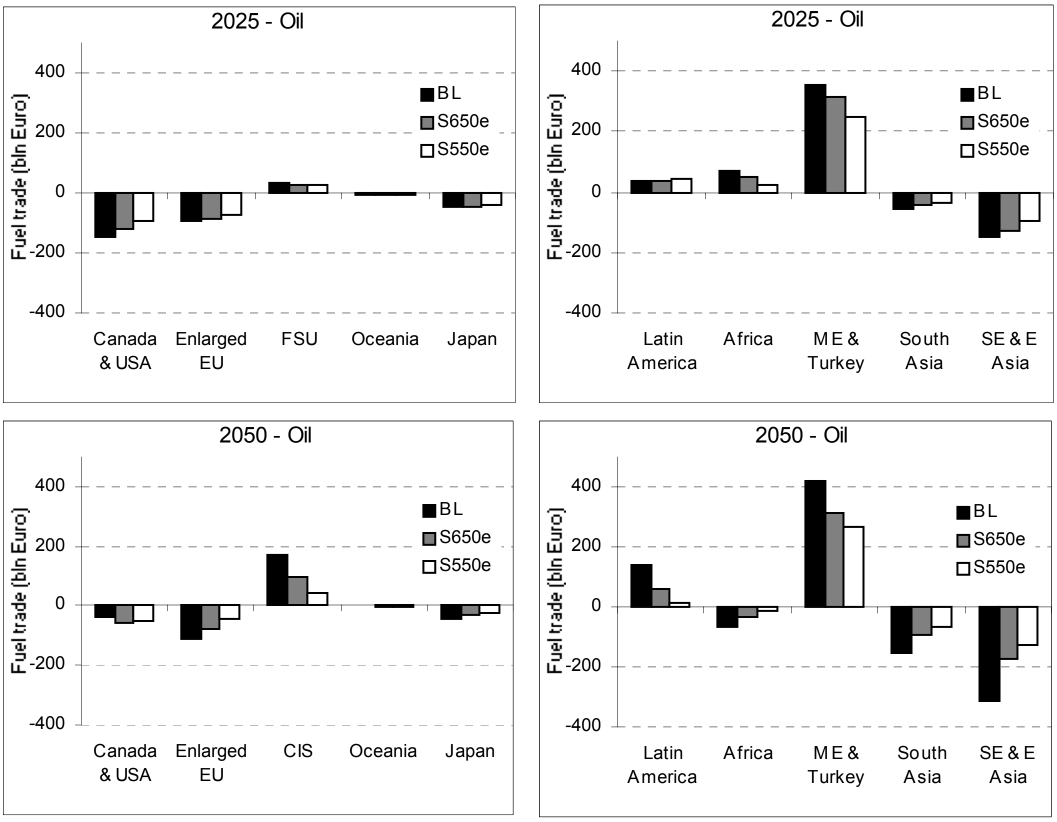


Figure 5.15: Oil exports and imports (exports are indicated as positive) under baseline and the GHG concentration stabilisation scenarios (PCC2050 case). (BL = Baseline). Source: FAIR 2.0/TIMER 1.0

In 2025, the revenues from oil-exporting regions, in particular the Middle East & Turkey region, are expected to be reduced by about 10% under the S650e profile and by about 25%

under the S550e profile. The impacts in 2050 on oil trade are larger, both for the S550e and S650e profiles. The loss of oil revenue is now, respectively, 20 and 35% for the Middle East & Turkey. Interestingly, however, losses for other oil-exporting regions can be even higher. The CIS and Latin America, regions with slightly higher production costs than the Middle East & Turkey, but projected to become major oil exporting regions after 2025, are confronted with a significant loss of demand (under the S550e profile even 80-90%). By the same token, oil import costs of importing countries are significantly reduced. Regions that could benefit from their reduced oil imports are, in particular, SE & E Asia, South Asia, the enlarged EU and Canada & USA.

Changes in the trading of other fuels may exhibit a somewhat different image. In the medium term (2010-2030), trade in natural gas represents the largest share within this category, and impacts of climate policies seem to be somewhat smaller than for oil. In the longer run, however, also natural gas trade is significantly reduced, which also strongly affects the large exports of liquefied natural gas from the Middle East & Turkey. By 2050, biofuel trade has also become a major factor. While both Latin America and the CIS see losses in oil exports, increased biofuel export at least partly offsets these losses (assuming that both regions can capture their potential in biofuel production).

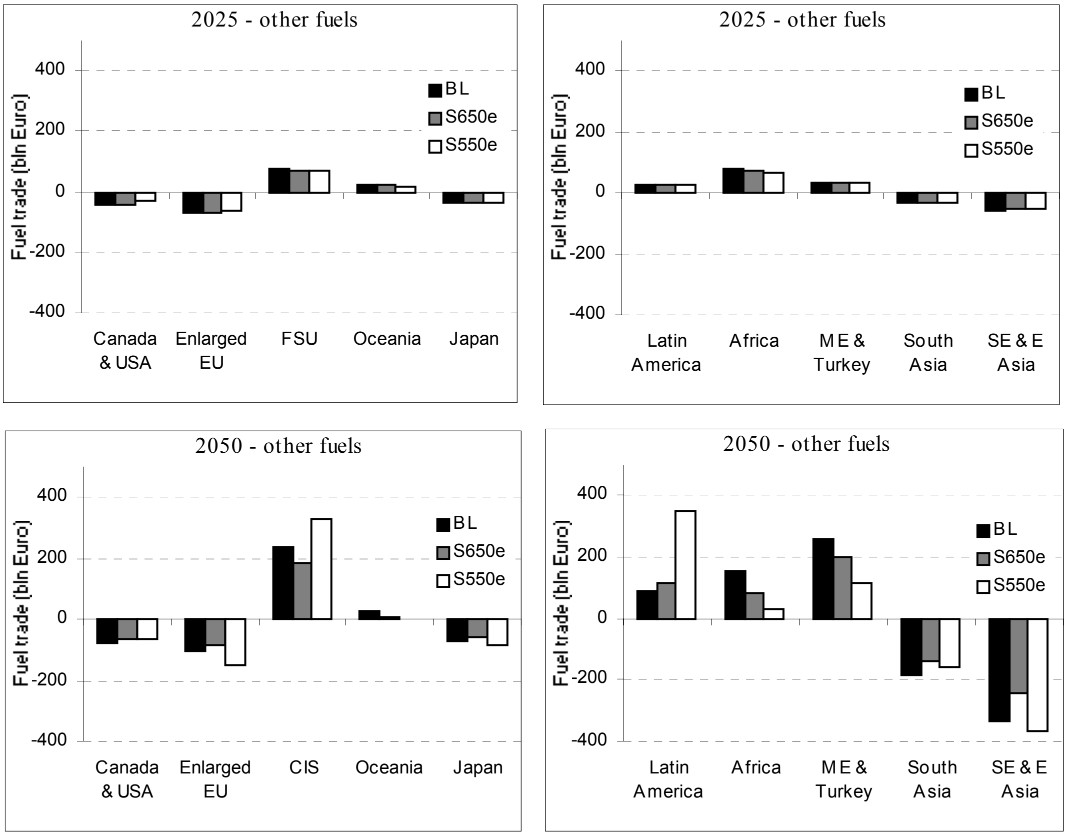


Figure 5.16: Exports and imports of energy other than oil (exports are indicated as positive) under baseline and the GHG concentration stabilisation scenarios (PCC2050 case). (BL = Baseline). Source: FAIR 2.0/TIMER 1.0

The financial flows involved in changing fuel trade are substantial compared to the direct costs of climate policies. Table 5.5 compares the regional costs of the different regions in 2025 for two different climate regimes (PCC 2050 and PCC 2100) to the changes in the costs or revenues of fuel trade in 2025 and 2050. In 2025, the reduced oil imports are important in Canada & USA, the enlarged EU, South Asia and SE & E Asia. The loss of oil export revenues seems, in particular, to be important for Africa (loss of oil exports from Northern and Western Africa and loss of coal exports from South Africa) and the Middle East & Turkey. For the last two regions, the loss of oil revenue could be much larger than direct costs of climate policies. In 2050, a different picture emerges, as modern biofuel trade could offset losses of oil trade (resulting in revenues that may amount to 185 and 240 billion euro for CIS and Latin America, respectively). In our calculations, impacts of changes in the trade of fuels are, in particular, important for the CIS (loss of oil revenues), Oceania (loss of coal revenues), Latin America (loss of oil revenues but major gains from exports of modern biofuels), Africa (loss of oil exports), Middle East and Turkey (loss of oil exports) and South Asia and SE & E Asia (reduced imports of oil). In 2050, the financial consequences of changes in fuel trade for some regions (notably Middle East & Turkey) could be larger than the direct costs of climate policies of these regions.

Table 5.5: Costs of climate policies and impacts of fuel trade under the S550e profile

			Canada & USA	Enlarged EU	CIS	Oceania	Japan	Latin America	Africa	Middle East & Turkey	South Asia	SE & E Asia	World
								(billion €)					
2025	Climate policies	PCC 2050	92	48	32	10	18	27	-27	49	-40	59	267
		PCC 2100	39	31	9	7	13	29	8	46	11	71	265
	Fuel trade	Fossil	-52	-33	13	6	-13	-9	62	108	-23	-59	0
		Biofuels	-8	5	-4	0	2	2	0	0	1	2	0
2050	Climate policies	PCC 2050	406	204	199	35	55	196	-144	264	-173	306	1350
		PCC 2100	142	103	70	22	26	208	90	259	88	338	1346
	Fuel trade	Fossil	-27	-112	223	27	-54	102	52	276	-168	-319	0
		Biofuels	26	95	-185	4	42	-241	21	17	52	169	0

Source: TIMER 1.0

5.5 Overall conclusions

Emissions trade and abatement costs for MS & PCC variants

- The international permit price and the global effort rate are substantially higher for the S550e profile than for the S650e profile. This can be explained by: (i) a much lower emission reduction burden for the S650e profile and (ii) the exponential form of the global MAC curve with fast increasing prices for the higher emissions reductions.
- For a given stabilisation profile, the international permit price is almost independent of the different climate regimes, assuming that emissions trading results in a distribution of the global emission reduction objective over the different regions, gases and sources following a least-cost approach. Nevertheless, there is a small difference between the PCC variants and the MS variants, which results from the level of participation. In the PCC variants all non-Annex I regions fully participate, whereas for the MS variants some non-Annex I regions have no commitments, and can only participate in CDM projects which have a lower accessibility.
- For the S550e profile the global effort rate (abatement costs per unit of GDP) increases very rapidly from 2010 to 2040 to a maximum level of 1.0% of GDP, after which the effort rate gradually decreases. For the S650e profile, the effort rate increases gradually and stabilises after 2070 at only 0.3% of GDP. It should be noted, however, that the costs levels as mentioned here a subject to considerable uncertainty. Sensitivity analysis with different marginal abatement costs shows a range for the global costs between 1.0% and 2.0% of world GDP in 2050 for S550e.

- The regional effort rates differ greatly across the different variants and regions, which can be explained by differences in required emission reductions, the ability to abate emissions domestically and the regional GDP levels.
- For the abatement costs as per cent of GDP (effort rates), four groups with similar effort rates can be identified, i.e.: 1) regions with high per capita emissions and a high income (Annex I regions excluding the FSU) are confronted average costs when compared to other regions (0.5-1.0% of GDP in 2025); 2) regions with medium to high per capita emissions, but a medium to low income (FSU, the Middle East & Turkey, and to a lesser extent, Latin America) are confronted with average to high costs (1.0-2.0% of GDP in 2025 and lower for Latin America); 3) regions with low to medium income levels and per capita emissions (South-East & East Asia) show low to medium cost levels (0-0.3% of GDP in 2025); and 4) regions with low per capita emissions and a low-medium income (Africa and South-Asia) show net gains from emissions trading (0.5-1.0% of GDP in 2025). An exception is formed by the Per Capita Convergence-2100 scheme under the S550e profile – which creates considerable costs for the third and fourth group regions. The Annex I regions, and Latin America and Middle East & Turkey (group 1 and 2) are in most cases net buyers on the international trading market, while (in most cases) the sellers are the low-income non-Annex I regions (South Asia and Africa), and South-East & East Asia (group 3 and 4). The financial flows between these regions can become quite large, ranging between 125 to 400 billion euro in 2025 to 600-800 billion euro in 2050.

Implications for the energy system

- The climate regimes do not have much influence on the implication of global emission GHG emission constraints on the energy system, since emissions trading results in the implementation of the most cost-effective options world-wide.
- Changes in the energy system as a result of climate policies will be substantial, certainly in the case of the S550e profile. In particular, coal use is projected to decrease by, respectively, 70% and 50% in 2050, under S550e and S650e.
- The majority of CO_2 emission reduction comes from energy efficiency improvement – in particular from investments in low-income countries. In the longer run (in particular after 2050) changes in energy production become more important. Carbon capture and storage can make an important contribution as well.
- Climate policies will also have significant impact on fuel trade. Some regions will benefit from reduced imports, while others will suffer from reduced exports. Oil exports from the Middle East, Latin America and the CIS are projected to be significantly reduced. The latter two regions, however, might benefit from exports of modern biofuels. For the Middle East, losses of oil revenues are projected to be higher than GHG abatement costs.

6 Benefits and co-benefits of mitigation actions

The climate impacts of the two stabilisation profiles (S550e and S650e) introduced in Chapter 3 have been found to be clearly different – but also strongly influenced by the so-called climate sensitivity. In constructing these initial profiles, we assumed an arbitrary contribution of 100 ppmv CO_2-equivalents of non-CO_2 GHGs. Next, in Chapter 5 we have determined the exact contribution of each GHG on the basis of a cost-optimal allocation of the reduction target. The climate impact of the global emission profiles might depend (somewhat) on the contribution of various GHGs under the profile for two main two reasons:

- Reductions of short-lived methane can lead to a more rapid response than reduction of long-lived gases, such as some of the HFCs (substituting these gases on the basis of their normal 100-year global warming potentials). In particular, if the shares of the different gases in abatement action strongly differ from those assumed originally under the profile, differences in climate impacts can be substantial.
- A second reason is that changes in the energy system resulting from carbon dioxide emission abatement action also lead to changes in emissions of other gases that can impact global warming. Examples are sulphur dioxide, aerosols and substances involved in the formation of ground-level ozone.

Section 6.1 will discuss the specific benefits of the stabilisation scenarios constructed in Chapter 4. Next, sections 6.2 and 6.3 will discuss the potential co-benefits of the changes in the energy system in terms of impacts on emissions of regional air pollutants. This is partly done on the basis of results of the IMAGE model. In addition, results of the TIMER/IMAGE model have been linked to the RAINS-Asia model to obtain more detailed results on changes in acidification risks in these regions.

6.1 Climate benefits of the two stabilisation scenarios

Figure 6.1 shows the impacts of the baseline and the two stabilisation scenarios discussed in sections 5.3 and 5.4 for the global-mean surface temperature increase. From Figure 6.1 we can verify that the conclusions on global-mean temperature increase in Chapter 3 are still valid, although the implementation of the two regimes leads to a somewhat lower global-mean temperature increase than visualised in Figure 3.4 (about 0.1°C). The reasons are discussed in Box 6.1.

Box 6.1: Temperature differences between the emission profiles (Chapter 3) and the actual cost-optimal implementation (Chapter 5)

There are two main reasons for the differences in temperature increase between the emission profiles (Chapter 3) and the actual implementation of the profiles by mitigation measures (Chapter 5). First, the somewhat higher share of the short-lived methane in the total emission reductions in the cost-optimised multi-gas scenarios than in the default profiles from Chapter 3 results in a quicker response of the climate system and fewer reductions in (cooling) sulphur emissions. The temperature change in 2100 is therefore somewhat lower in the two scenarios than in the original profiles. It should be noted that temperature impacts of different shares of short and long-lived gases to be very time-dependent (Sygna et al., 2002). In fact, in the long term (22^{nd} and 23^{rd} centuries) a scenario relying more on reduction of CO_2 is likely to result in a lower temperature increase. The second reason for the lower temperature increase is that reductions in the energy system have additional effects on reductions in the NO_x emissions, which influence the formation of tropospheric ozone, an another radiative substance.

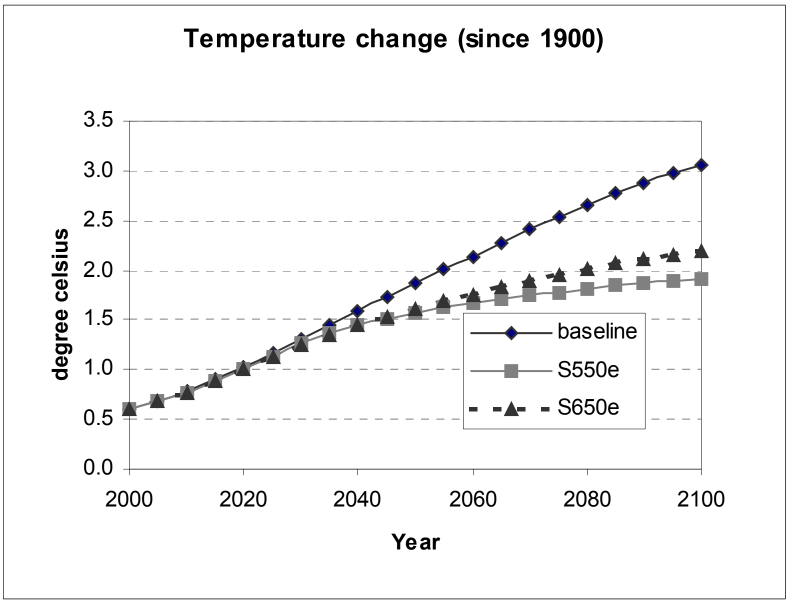


Figure 6.1: Global-mean surface temperature increase in the implementation of the IMAGE S550e and IMAGE S650e scenarios versus the CPI-baseline scenario.
Source: IMAGE 2.2

It should be noted that Figure 6.1 shows only global mean temperature change. Local warming, particularly at higher latitudes, can be substantially higher than this average (IPCC, 2001). This has been shown in Figure 6.2 for the S550e and S650e scenarios on the basis of the IMAGE results downscaled to the grid level using the outcomes of a General Circulation Model (GCM). While the global mean temperature increase for the S650e scenario is 1.8 degrees Celsius above the 1990 level (i.e. 2.2 degrees Celsius above pre-industrial minus 0.4 degrees Celsius increase in 1990), many locations are actually exposed to much higher temperature increases. This holds particularly for North America and Russia, but also for large parts of South America, Africa and India.

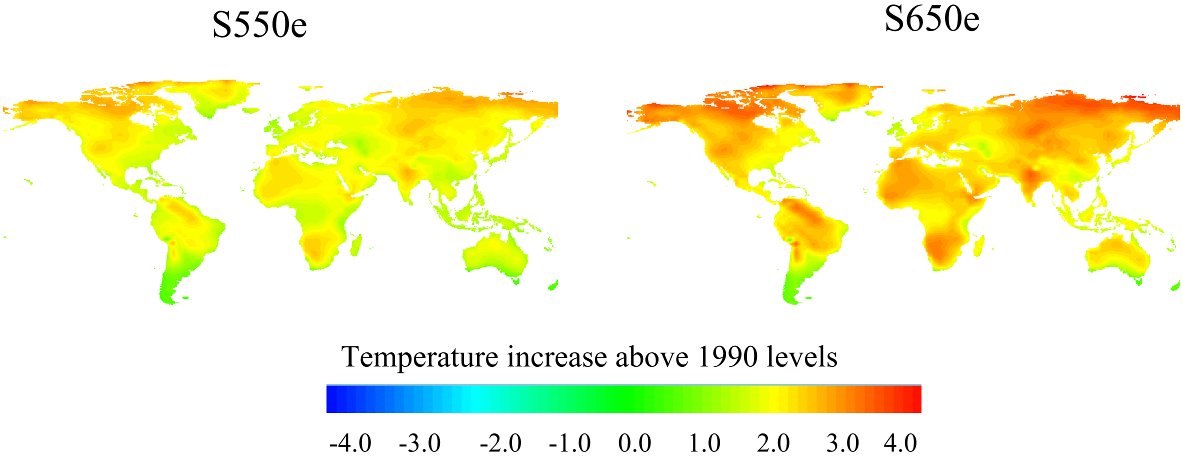
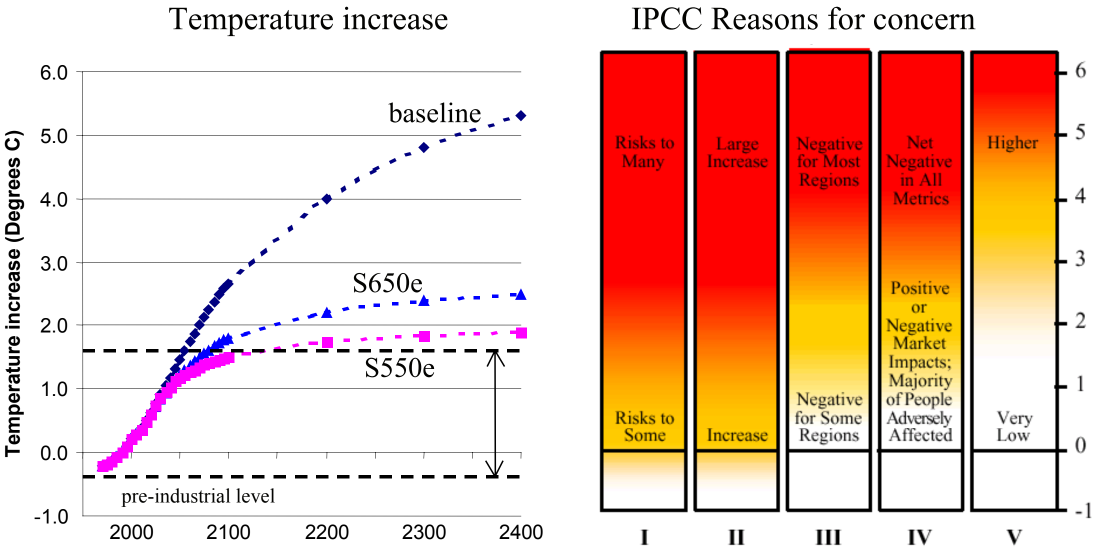


Figure 6.2: Surface temperature increase in the S550e and S650e implemented scenarios (increase of 1990 levels).
Note: The global mean temperature has been downscaled to the grid level using the HADCM2 pattern – and taking into account regional differences in sulphur emissions (see IMAGE 2.2).

Estimating the risks involved in different stabilisation levels is very diffcult. IPCC’s recent Third Assessment Report has tried to summarise some of the risks of adverse impacts from climate change, using global mean temperature change as a proxy for the magnitude of climate change. These risks were divided into five different categories related to: 1) unique and threatened systems, 2) extreme climate events, 3) distribution of impacts, 4) global aggregate impacts and 5) large-scale high impact events. Based on underlying studies, an estimate was made to indicate for which global mean temperature ranges these risks could occur (see Figure 6.3). For comparing these temperature increases with those of the CPI baseline scenario and S550e and S650e mitigation scenarios as used in this report, one needs to realise that even after stabilisation of GHG concentrations, a considerable further temperature increase will still occur. For this reason we have extrapolated our scenarios using comparable scenarios from the IPCC report, however, taking into account the improved estimates for the contribution of non-CO_2 gasses.



Temperature increase

IPCC Reasons for concern

Figure 6.3: Estimates of long-term temperature change for baseline and emission profiles and reasons for concern according the IPCC.

Note: The temperature increases in this figure are compared to 1990 (in contrast to other figures in this report). The left-hand figure shows the temperature pathways as calculated up to 2100 – extended after 2100 using comparable IPCC scenarios[35]. The two horizontal lines indicate the pre-industrial temperature level (-0.4 degrees Celsius compared to 1990) and the temperature target of a maximum increase of 2.0 degrees Celsius compared to pre-industrial). The right-hand panel summarises the reasons for concern for different levels of temperature increase, as shown in IPCC's Synthesis Report. The colour white means little or no impacts, yellow indicates moderate impacts and red stands for serious impacts. Five different categories of concerns are shown: I, the risks to unique and threatened systems; II, the risks from extreme events; III, the distribution of impacts; IV, the aggregated (economic) impacts and V, the risks from future large-scale discontinuities.

Source: This report and IPCC (2001)

The figure shows that the two mitigation scenarios would clearly reduce the risks of adverse climate impacts compared to the baseline scenario. In addition, the S550e scenario would generate greater benefits in terms of less damage than the S650e scenario. While the

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[35] We have extrapolated the S550e and S650e scenarios using the temperature increase after 2100 of the corresponding IPCC scenarios. The CPI baseline has reaches a CO_2-equivalent concentration of almost 940 ppmv in 2100. We have (arbitrarily) used the temperature increase of the IPCC-TAR 1000 ppmv stabilisation scenario after 2100. This means that the temperature increase of the CPI could actually be considerably higher than shown in the figure.

S650e scenario would reduce the risks of the future large-scale discontinuities, such as a shut-down of the North-Atlantic thermohaline circulation, it would still be in the category of moderate impacts. The same holds for the category of global-aggregated negative impacts and the risks of distributed impacts. The S550e scenario reduces these risks further and is able to keep the risk of future large-scale discontinuities in a low category. An important example in this category is the risk of disintegration of the West Antarctic Ice Sheet which - according to (O'Neill and Oppenheimer, 2002)- would require a limit of 2 degrees Celsius above 1990 levels based on a precautionary approach – a condition that is fulfilled under the S550e but not under the S650e profile.

It should also be noted that the S550e profile might not be able to limit temperature increase in the long term to a maximum of 2 degrees Celsius above pre-industrial levels for medium climate sensitivity. For this to happen, either concentrations need to be reduced after stabilisation or a lower stabilisation level needs to be chosen. As indicated in Figure 6.3, a global average warming of 2 degrees Celsius can already have strong negative impacts, particularly for sensitive, unique ecosystems (coral reefs, polar and mountainous ecosystems) and results in an increase in the risks from extreme weather events. However, from this figure we can also conclude that with a medium climate sensitivity, the IMAGE S550e scenario would keep the risks from future large-scale discontinuities, such as a shut-down of the North-Atlantic thermohaline circulation (Gulfstream), low.

Finally, it is also possible to assess the benefits of our stabilisation scenarios for the climate system by looking at the rate of temperature change (Figure 6.4). The CPI baseline has a rate of temperature increase ranging from 0.25 – 0.30 degrees Celsius per decade for most of the century, dropping only to 0.2 degrees Celsius per decade around 2100. In the mitigation scenarios, the temperature increase stays below this baseline for the whole century and temperature increase per decade finally stops at a rate of change below 0.1 degrees Celsius per decade. This rate has been referred to as ‘the maximum level ecosystems are historically adapted to’(Rijsberman and Swart, 1990). Higher levels are likely to result in ecosystem deterioration. This level is only reached in 2055 under the IMAGE S550e profile and in 2090 under the IMAGE S650e profile.[36]

Concluding, the climate benefits of both the mitigation profiles are substantial in 2100 compared to the CPI baseline. However, most of the climate benefits do not occur until 2050, and even with these stabilisation scenarios, it remains uncertain whether we will attain the climate stabilisation goal of 2 degrees Celsius.

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[36] Note that under the S550e profile, the rate of change initially increases more sharply than under the S650e profile. This is due to the quicker reduction in sulphur emissions (see section 6.3).

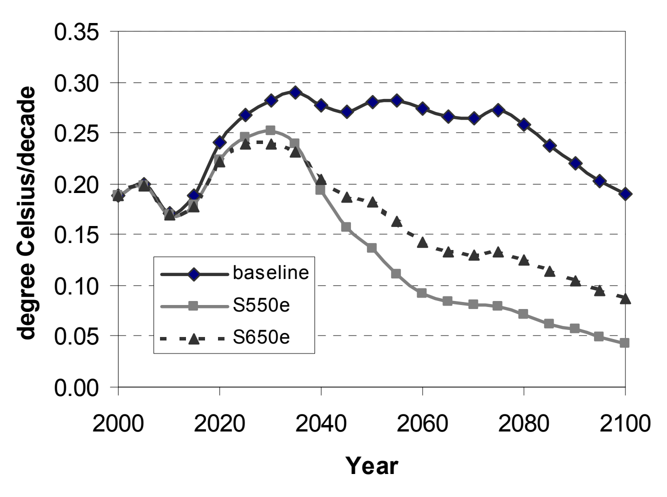


Figure 6.4: Rate of temperature change per decade for the implementation of the IMAGE S550e and IMAGE S650e scenarios. Source: IMAGE 2.2

6.2 Co-benefits of climate policies for regional air pollution control

There is an increasing awareness of the importance to account for the linkages between the traditional air pollutants and greenhouse gases. 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 on local, regional and global scales (see Box 6.2). Thus, emission control strategies that simultaneously address air pollutants and greenhouse gases may lead to a more efficient use of resources on all scales. Current studies indicate that in regions currently considering climate policies, potential co-benefits could be substantial, with financial savings in the order of 20%-50% of total climate control costs (Van Vuuren et al., 2003).

In low-income countries, taking care of the potential synergies of climate change policies, and air pollution policies, could be even more important than in high-income countries. At the moment, both climate change policies and air quality control are, in most cases, still relatively marginal issues in these countries compared to issues such as poverty eradication, food supply, provision of energy services, employment and transportation. To curb the potential risks of rapidly growing emissions of both air pollutants and greenhouse gases in these countries, use could be made of the synergy between sustainable development, issues of national interest (energy, food) and climate change. Accelerated (sustainable) development could in this way be of mutual interest for both local and global communities.

In this study, we quantified some of the possible linkages between climate change and air pollutants world-wide. Not all existing linkages can be quantified on the global scale yet. We have focused our analysis on the consequences of climate policies on SO_2 and NO_x emissions and related environmental problems, looking in more detail at the Asia region.

Box 6.2: Linkages between climate change and regional air pollution

Several linkages exist between climate change and regional air pollution. First, some of the gasses influencing climate change also impact regional air pollution, for instance, methane, sulphur, nitrogen oxide emissions. Second, the emissions introducing both these problems originate to a large degree from the same activity, i.e. fossil fuel consumption. Third, technologies for abatement of one pollutant may also affect emissions of other pollutants, either beneficially or adversely (e.g. the use of catalytic converters increases the emission of the greenhouse gas, N_2O). Fourth, environmental effects may influence each other. Climate change, for instance, changes the weather patterns and thus the transport of pollutants and the buffering capacity of soils (Posch, 2002). It should be noted that linkages work in two directions: there can be synergies and trade-offs. In general terms, policies to reduce air pollutant emissions, such as switching from high-sulphur coal to low-sulphur natural gas, will also reduce the emissions of some greenhouse gases (Mayerhofer et al., 2001). However, a well-known example of a trade-off is the reduction of sulphur dioxide emissions and subsequently concentrations in the atmosphere, which will lead to less sulphur aerosols, thus limiting the cooling effect of sulphur aerosols (e.g., (Charlson et al., 1992)).

On the other hand, legislation in the climate change policy field may have unforeseen consequences for air pollution abatement strategies. For example CO_2 trading will change the spatial distribution of air pollutant emissions and will have effects on regional air pollution in different areas of Europe (Pearce, 2000),(Van Vuuren et al., 2003). The environmental issues of which linkages are known to exist between Climate Change and Air Pollution are acidification, eutrophication, tropospheric ozone formation and urban air pollution; see (Tuinstra et al., 2003) .

Table 6.1 illustrates how the linkages between air pollution and climate change can be seen as a multi-pollutant/multi-effect problem.

Table 6.1: Illustration of linkages between air pollution and climate change

	SO_2	NO_x	NH_3	VOC	CO	Primary PM+BC	CH	CO + GHGs
Ecosystems								
- Acidification	X	X	X					
- Eutrophication		X	X					
- Ground-level ozone		X		X	X		X	
Health impacts								
- direct	X			X	X	X		
- indirect by sec. aerosols & ozone	X	X	X	X	X		X	
Radiative forcing		X					X	X
- via aerosols	X	X	X	X		X		
- via OH		X		X	X		X	

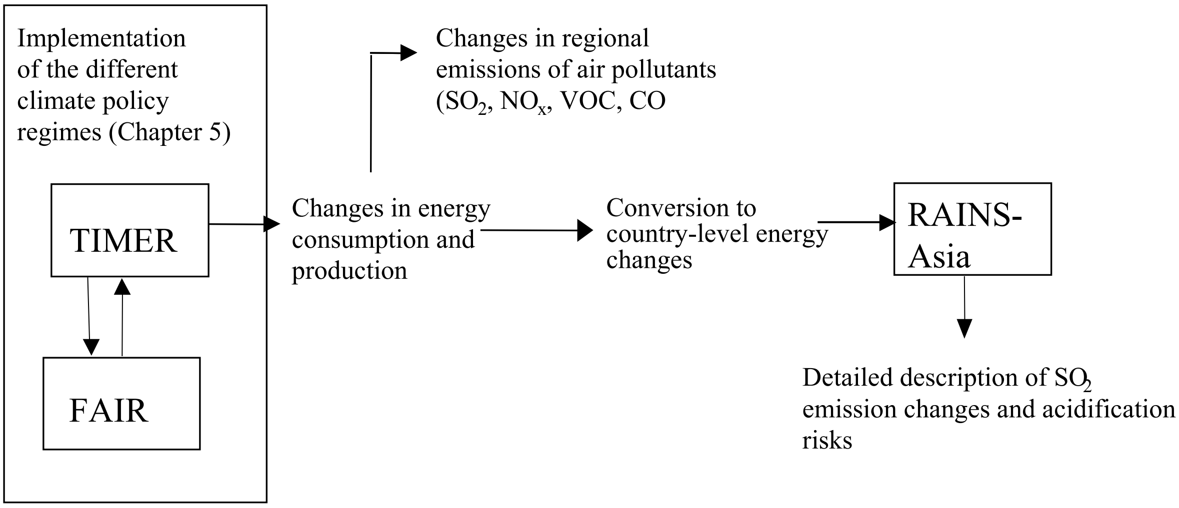


Figure 6.5: Overview of models used for the co-benefit study.

The methodology consists of two separate steps. First of all, the changes in the energy system under the S550e and S650e scenarios (as described in Chapter 5) are used to determine changes in the emissions of air pollutants (see Figure 6.5). These changes result from the changes in consumption of fossil fuels and biomass only, as we have assumed no changes in the emission factors of regional air pollutants compared to baseline. The regional air pollutants that we focus on for our global analysis are sulphur dioxide (SO_2) and nitrogen oxides (NO_x). This methodology was developed earlier as a link between TIMER and the European RAINS model – and has been described in detail in (Van Vuuren et al., 2003). In this report special attention is paid to the Asian regions. For this, the regional energy production and consumption patterns of TIMER are converted to the country level of the RAINS-Asia model (IIASA, 2000).

6.3 Potential co-benefits of the IMAGE S550e and IMAGE S650e mitigation scenarios

Changes in emissions of sulphur and nitrogen oxide

Figure 6.6 shows the changes in global sulphur and nitrogen oxide emissions under the baseline, S550e and S650e. The changes in the energy system result in considerable co-benefits. Sulphur and NO_x emissions are reduced significantly as a co-benefit of climate policies. The S650e leads to world-wide reductions in sulphur and nitrogen oxide emissions of 50% and 35%, respectively, compared to baseline The S550e scenario leads to even sharper reductions, i.e. 70% and 50%.

These results can also be viewed in more detail at the regional level (Figure 6.7 shows that co-benefits occur in all regions. However, as emissions of both sulphur and nitrogen oxide are typically largest in the Asian regions, Latin America and Africa as a result of less strict air pollution control policies, but also because their large populations, in absolute terms co-benefits, are the largest in these regions.

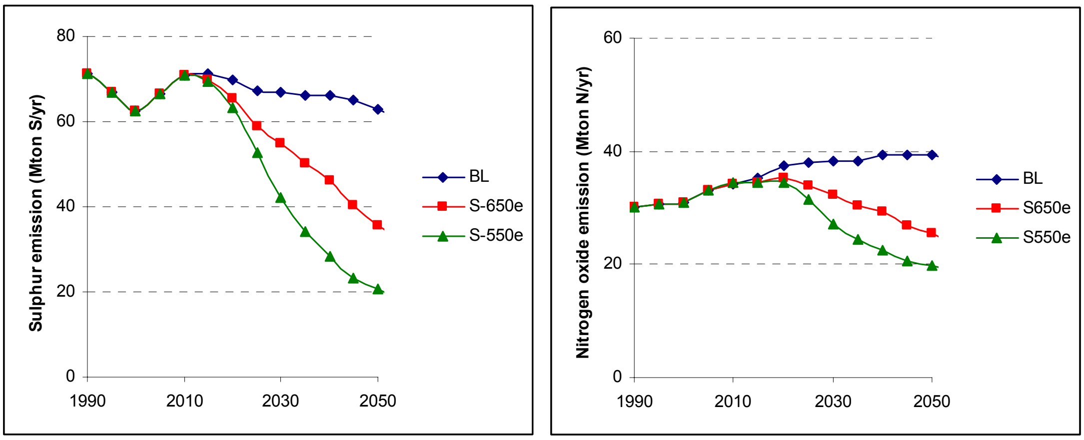


Figure 6.6: Global sulphur (left) and nitrogen oxide (right) emissions under baseline and S550e and 650e profiles. Source: IMAGE 2.2/TIMER 1.0

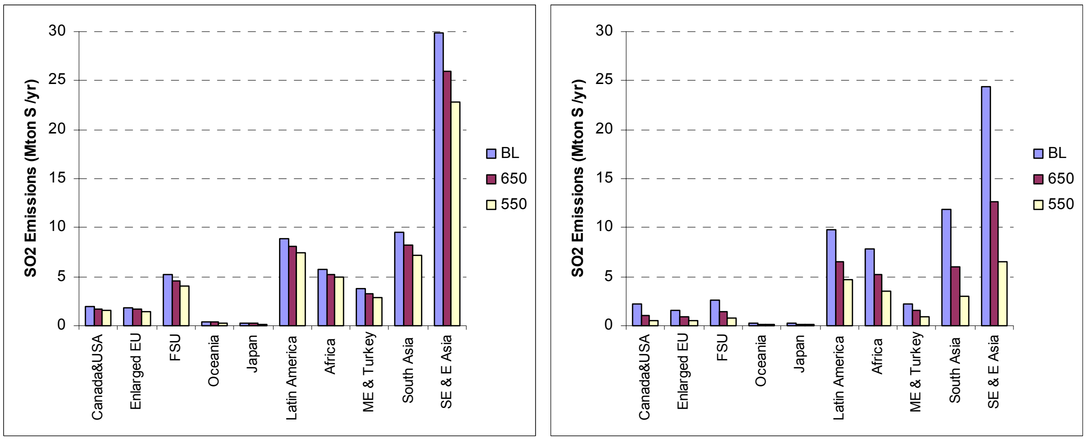


Figure 6.7: Sulphur oxide emissions under baseline, S550e and 650e in 2025 (left) and 2050 (right). Source: IMAGE 2.2/TIMER 1.0

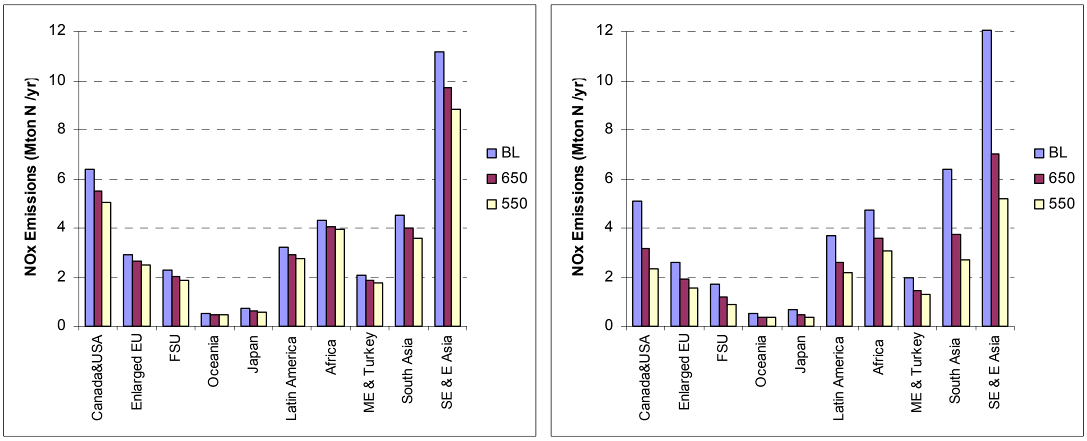


Figure 6.8: Nitrogen oxide emissions for baseline, S550e and 650e in 2025 (left) and 2050 (right). Source: IMAGE 2.2/TIMER 1.0

Potential impacts of emissions to ecosystems

In order to make a first-order assessment of the potential consequences of the projected changes in emissions for acidification risks to ecosystems, we calculated the ratio between regional emissions and the size of each region. This indicator gives a first impression of the potential acidification risks (for more details see Box 6.3 and the proxy indicators used).

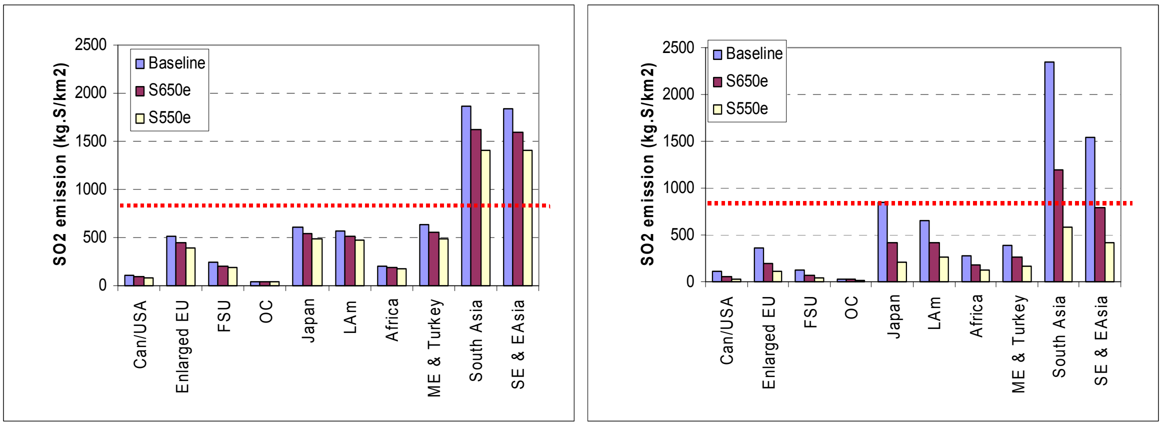


Figure 6.9: Sulphur oxide emissions under baseline, S550e and 650e in 2025 (left) and 2050 (right). Source: IMAGE 2.2/TIMER 1.0

Note : The horizontal line indicates of a level above which risks of to ecosystem damage substantially increase (see also the text box in this session).

Figure 6.9 shows that under the baseline, a substantial number of ecosystems could be confronted with serious acidification risks, in particular, in Asia. For 2025, the S650e and S550e climate policy scenarios reduce the sulphur emissions to some extent but serious acidification risks keep occurring in Asia. The differences between the baseline scenario and the climate policy scenarios become more obvious by 2050 as climate policies tighten. Now under the S550e scenario, the situation is expected to improve considerably and will significantly decrease the acidification risks in Asia. Under the S650e scenario, the situation improves but not enough to avoid serious acidification risks.

NO_x emissions are also important for acidification and eutrophication risks. The highest average emissions per square kilometre in 2025 and 2050 under the baseline scenario occur in Japan (Figure 6.10). In 2025, NO_x emissions are likely to exceed critical loads for all three scenarios in (South)-East Asia and West Europe. By 2050, NO_x emissions under the baseline assumption are still high, somewhat improved in the 650e scenario and considerably improved under the 550e scenario (Figure 6.10).

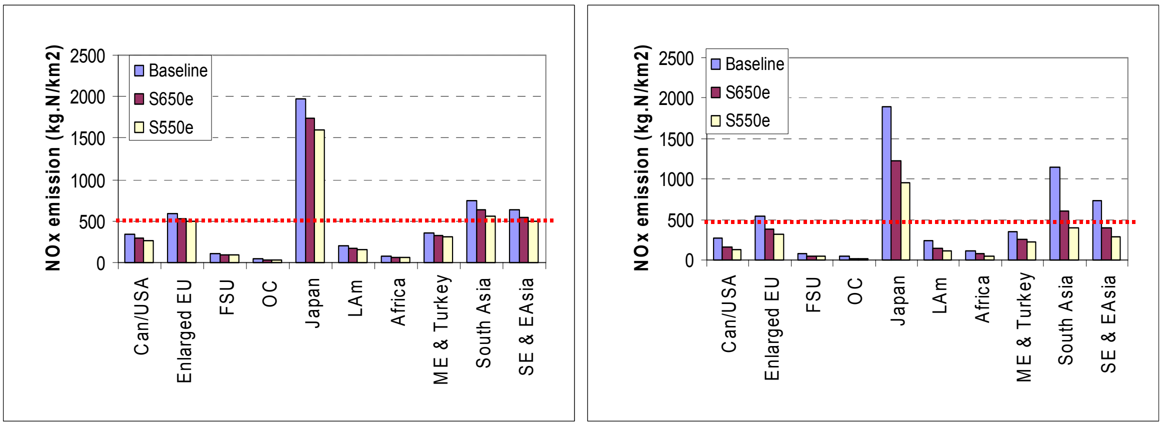


Figure 6.10: Nitrogen oxide emissions (kg.N/km^2) under baseline S550e and 650e in 2025 (left) and 2050 (right). Source: IMAGE 2.2/TIMER 1.0

Note : The horizontal line indicates of a level above which risks of to ecosystem damage substantially increase (see also the text box in this session).

Potential benefits for human health impacts

The largest benefits of climate policies for human health can be expected from the expected reduction of ozone and particles concentrations. As climate policies in general lower fossil fuel use, they also reduce related emissions of particulates. Reduced exposure to these particulates can extend life expectation by 2-3 years (Kovats et al., 1999; Mechler et al., 2002).

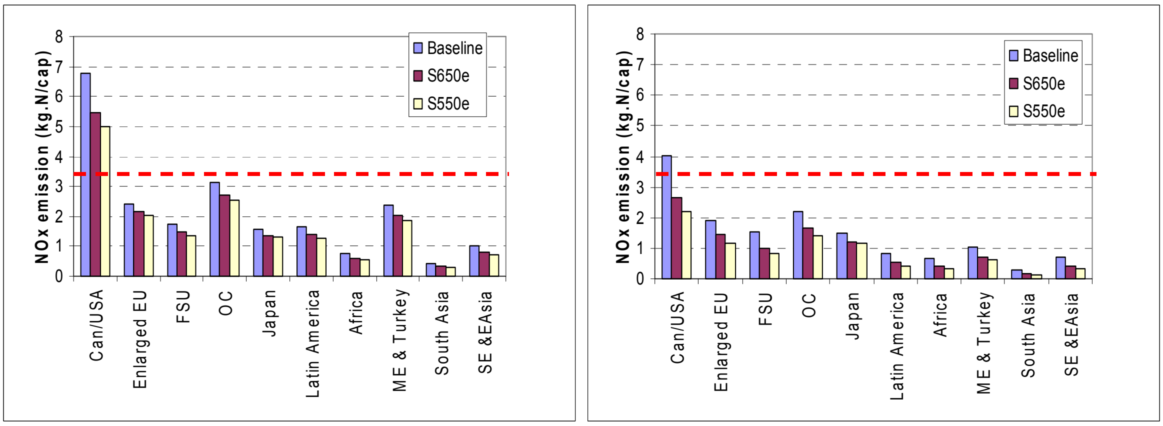


Figure 6.11: Urban nitrogen oxide emissions (sum of transport, services and household emissions) under the baseline, S550e and 650e in 2025 (left) and 2050 (right).

Note : The horizontal line indicates of a level above which risks to human health substantially increase (see also the text box in this session).

Source: IMAGE 2.2/TIMER 1.0

Additional health benefits can be gained by reducing urban concentrations of NO_2 and SO_2. In Figure 6.11 the urban emissions (assumed to be the sum of sectors for transport, services and households) are given as kg/capita. In principle, this can serve as an indicator of health risks in cities assuming equal population density and vulnerability (e.g. meteorological conditions) (see Box 6.2). It should be noted that, in general, the population density in Europe and Asia are higher than, for instance, the United States. Figure 6.11 shows some health risks in cities under the baseline still exists in 2025 and 2050, despite the fact that the situation slowly improves as a result of an increased tightening of air pollution standards in different parts of the world (with increasing income). The figure also shows some improvement going from the baseline scenario to the climate change policy scenarios. It can be concluded that the likelihood of exceeding NO_2 standards will be reduced by 2025 and continue to do so towards 2050.

Urban air quality standards for SO_2 are still likely to be exceeded by 2025 for the Middle East & Turkey, FSU and East-Asia regions (Figure 6.12). In 2050, exceedances are still likely to occur in East Asia under the baseline assumptions; this occurrence becomes less under both mitigation scenarios.

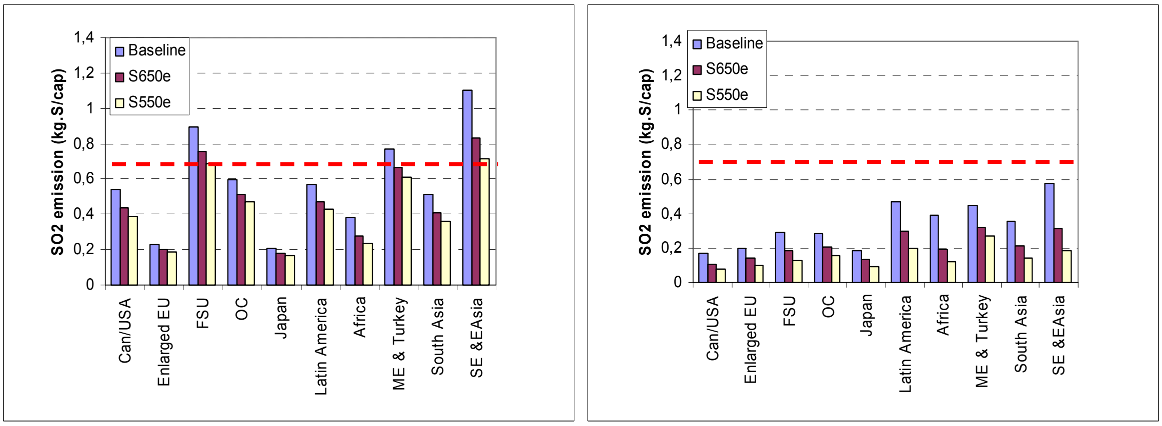


Figure 6.12: Urban sulphur oxide emissions (sum of transport, services and household emissions) under baseline, S550e and 650e in 2025 (left) and 2050 (right). Source: IMAGE 2.2/TIMER 1.0

Note : The horizontal line indicates of a level above which risks to human health substantially increase (see also the text box in this session).

The expected improvement in public health due to a decrease of air pollution emissions can also be expressed in monetary terms. Damage valuation of health effects, certainly on the global scale, still lacks a widely recognised methodology, although some preliminary work is being done in this field. Crucial questions include how to deal with differences in terms of income, population age and health status and level of pollution in a valuation (Criqui et al., 2003). Using the GEM-E3 world model, some attempts on monetarising the co-benefits have been made on the basis of the same policy cases as discussed in this report using the IMAGE model's emission coefficients as starting point. This preliminary analysis shows the impacts of co-benefits on welfare to have been assessed world-wide as 0.3-1.2% and 0.7-2.3% of GDP for S650e and S550e, respectively (compared to GDP losses of 0.4% and 2.2%). This means that the benefits of reducing local pollutant emissions could be substantial for different greenhouse gas emission-reduction targets. Looking at different regions, this becomes even more apparent for the Asia. In particular, positive results for welfare were found in densely populated countries with high emissions of regional air pollutants such as India or China. Here welfare benefits might be in the order of 2-10% (S650e) to 3-17% (S550e) of GDP.

Box 6.3: Proxy indicators for air pollution effects

In this study, two indicators have been used as a proxy for potential air pollution effects on ecosystems and humans. A short description of the assumptions underlying these indicators is given below.

An indicator for potential air pollution effects on ecosystems

Acidification and Eutrophication have been recognised as a major environmental problems since the early 1970s. The main compounds responsible are sulphur dioxide (SO_2, acidification only), nitrogen oxides (NO_x) and ammonia (NH_3). Studies that estimate risks of acidification and eutrophication often do so on the basis of a critical load approach. Such a critical load is the maximum level of deposition of acidifying or eutrophying components on ecosystems that can be tolerated by the ecosystem without damaging effects. The critical load is dependent on the soil type, the ecosystem involved and the climate. If deposition of air pollutants is higher than the critical load values, there is a high risk of the ecosystem deteriorating. If one calculated the average critical loads value for the European data, one would find on average a threshold of 250 mol S/ha for sulphur (500 mol/ha in equivalent H, equivalent to 800 kg S/km^2) and a threshold of 400 mol N/ha (equivalent: 560 kg N/km^2) for NO_x. For this study, it was not possible to estimate the potential exceedance of critical load values on a global basis. Instead, we used the average critical load values and compared these with the average regional emission per square kilometer. If the average regional emissions are near the critical load value, a serious risk of exceedances within that region can be assumed.

An indicator for potential effects of air pollutants on human health

NO_x, benzene, PAHs, SO_2, tropospheric ozone and particulate matter all contribute to 'urban air pollution' Especially ozone and *particulate matter* (PM, also called aerosols) have shown adverse effects on human health and are highly related to the other air pollution problems (Lükewille et al., 2001). Recent epidemiological studies (Andreae, 1995; Katsouyanni et al., 2001; Roemer et al., 2000) have shown quantitative assessment of urban air pollution effects on human health to be possible. It is also known that the levels of urban air pollution are determined by: the emission per square kilometre, the size and shape of the city, the location of the city (river basin versus valley), the meteorological conditions, the height and heat content of the emission source and the seasonal distribution of the emissions.

In this study, however, a much simpler approach was used. First, average threshold emissions per square kilometre were derived from the European data set of critical level values for human health. Assuming an average urban population density of 10,000 inhabitants per km^2, we converted this value to an emission per capita threshold. Next, we assumed that the urban emission could be represented by the sum of the sectoral emission contribution of households, transport and services, as calculated by the TIMER model. For SO_2 and NO_x (proxy for NO_2) the following values were derived on the basis of an increased likelihood of exceedances occurring in at least 25% of the city surface:

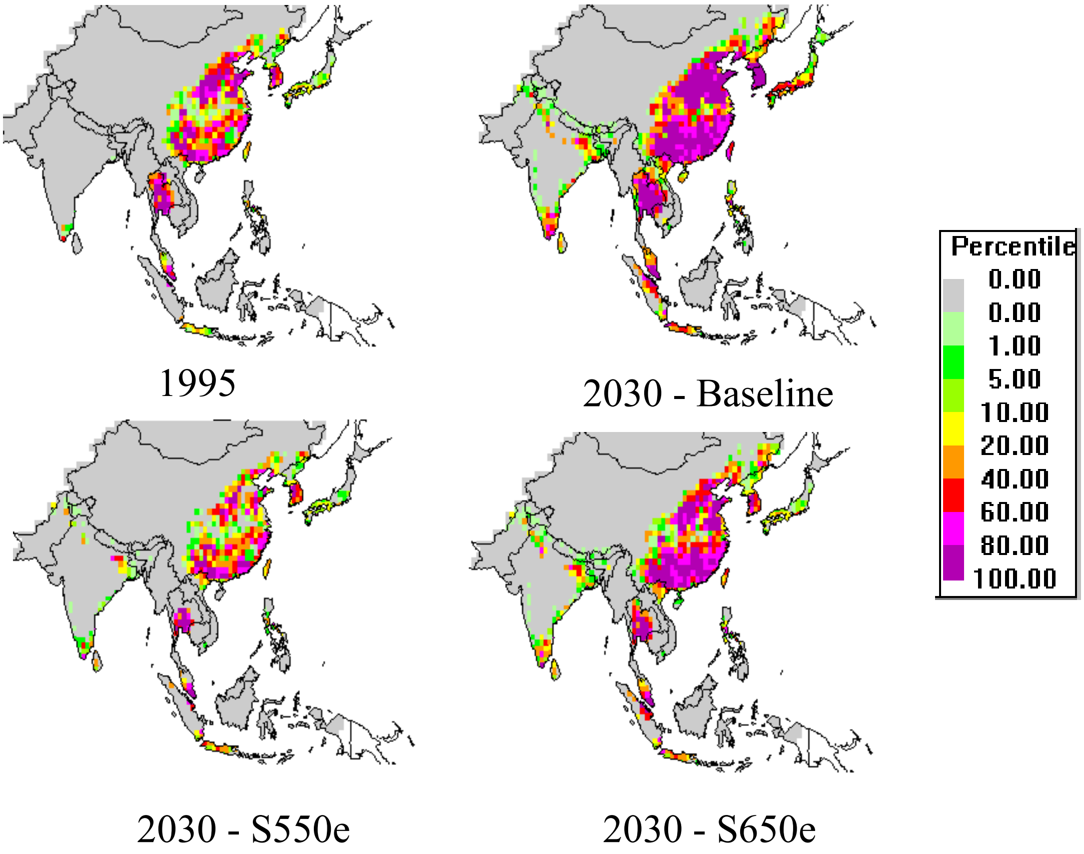
0.7 kg S per capita (assuming a 75% contribution from regional sources);
3.5 kg N per capita (assuming a 25% contribution from regional sources).

6.4 Looking more detailed into changes in Asia

In the previous section we observed that for ecosystems, the sulphur-related acidification risks in 2025 and 2050 could be counted as the worst in the Asian region. A link between TIMER and the RAINS-Asia model has therefore been developed to allow a detailed exploration of the potential co-benefits in Asia (see also 6.1).

In RAINS, these scenarios are combined with the baseline assumptions for sulphur policy by country. These sulphur policies ('current legislation') are based on earlier IIASA inventories of current and expected policies within each country (IIASA, 2000). For each energy scenario, we assume, in principle, the same sulphur policies. However, the differences between the energy scenarios result in different sulphur emissions within RAINS. The sulphur deposition and the resulting exceedances of critical levels of ecosystems for acidification have been calculated from these emissions (Figures 6.13 and 6.14).

In 1995, 4% of the ecosystems in the total RAINS Asia region experienced deposition of sulphur dioxide above the critical loads. The risks are unevenly distributed across the region and are especially high in East China, with areas where up to 100% of the ecosystems are threatened. Other areas with high exceedances of critical loads include the Korean peninsula, Japan and Thailand. Under the baseline assumptions the number of ecosystems receiving an S-deposition above their critical loads increases substantially (see Figures 6.13 and 6.14). The largest increase occurs in China (from almost 6% to almost 10% of total ecosystem). In 2030 a large share of ecosystems receives deposition above critical loads in Thailand, Malaysia, Indonesia, the Korean peninsula, Japan and India as well. Under the S650e scenario, the areas with exceedances are reduced in most countries by about 10-15% as a result of climate policies. The situation improves much further under the S550e scenario. Here, as a result of climate policies for Asia as a whole, the level of exceedances of critical loads is reduced to near the 1995 value (or about a 50% reduction compared to baseline).


1995

2030 - Baseline

2030 - S550e

2030 - S650e

Figure 6.13: Percentage of ecosystem areas showing exceedance of critical loads. Source: RAINS-Asia model

Note: The percentile value indicates the percentage of each grid cell surface in which the critical level for acid deposition is exceeded.

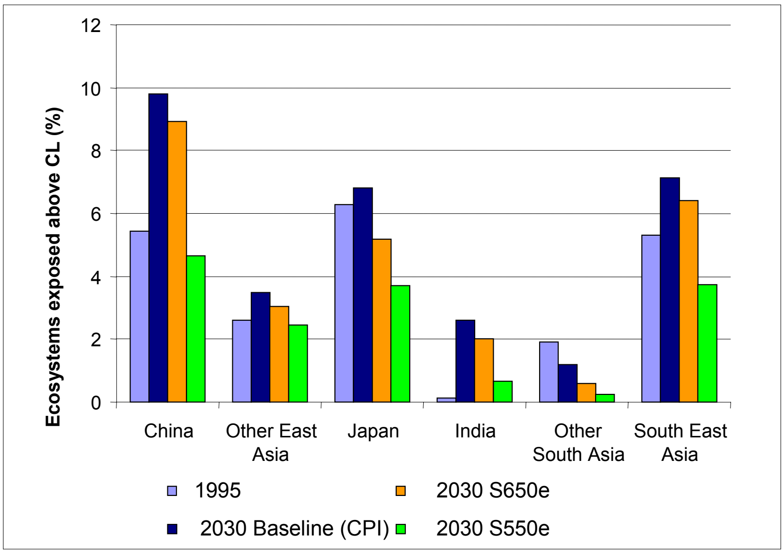


Figure 6.14: Percentage of ecosystem areas showing exceedance of critical loads. Source: RAINS-Asia model

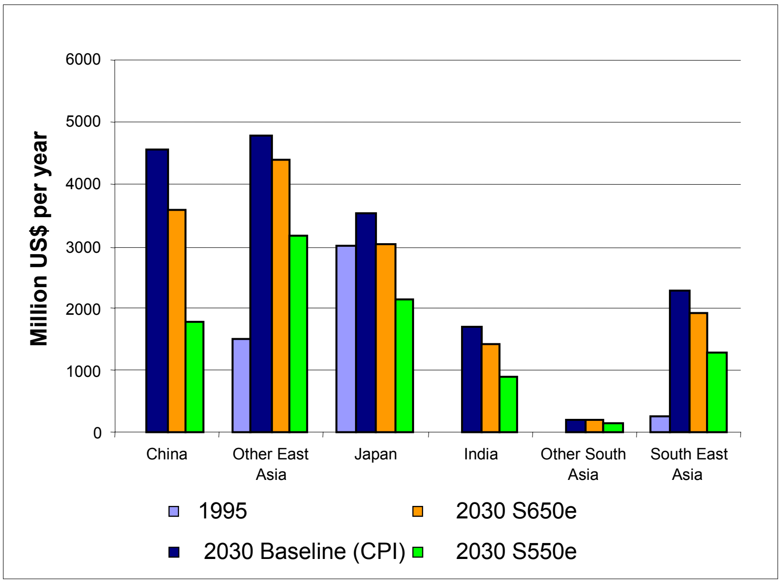


Figure 6.15: Control costs to combat sulphur emissions. Source: RAINS-Asia model

Figure 6.15 shows the changes in air pollution control costs projected by the RAINS model in these scenarios (differences due to lower energy volumes for sulphur control technologies to work on). In most Asian sub-regions, the 2030 control costs of currently formulated policies are expected to be significantly higher than in 1995. In the case of China, for instance, costs increase from zero to more than €4.5 billion per year. The costs under the climate policy scenarios are substantially lower: the 2030 control costs of the S550e scenario are only a third of those for the baseline, while at the same time resulting in about 50% less acidification risk than the baseline. Similar conclusions can be drawn for the other sub-regions, although in the other sub-regions the impacts tend to be smaller (around 30% reduction in control costs). It should be noted that due to different methodologies for determining costs in the different models (in particular, TIMER and RAINS), care should be taken in comparing these gains directly to the costs of the climate regimes explored. However, it is safe to say that the savings of air pollution control costs form a substantial part of the total costs/benefits of this region under the various mitigation scenarios presented here.

6.5 Conclusions

Climate impacts
Assessing the climate impacts of the S550e and S650e scenarios (on the basis of the most cost-efficient implementation as described in Chapter 4) shows that:

- The S550e scenario leads to an increase in global mean temperature of 1.9^{o}C compared to pre-industrial levels in 2100. The S650e scenario leads to an increase of about 2.2 degrees Celsius.
- Both scenarios can ultimately bring back the rate of temperature increase to below 0.1 degrees Celsius per decade (a level above which studies indicate that ecosystem deterioration could occur). This level is reached in 2055 under the IMAGE S550e scenario and in 2090 under the IMAGE S650e scenario.
- In both scenarios considerable impacts from climate change can be expected, in particular, for sensitive ecosystems, and in terms of an increase in the risks from extreme weather events. Such risks are lower in the S550e case than in the S650e case. The IMAGE S550e scenario could keep the risks from future large-scale discontinuities low with a medium climate sensitivity.

Ancillary benefits for air pollution
Many studies have identified important ancillary benefits for air pollution control from climate change policies. Economic studies on ancillary benefits of GHG mitigation suggest that the avoided damages can be used to compensate a sometimes significant number of costs of the measures, sometimes all.

In the context of this study we have highlighted some of the co-benefits on a world-wide scale that can be expected from the S650e and S550e mitigation scenario. The results show that stringent climate policies can also significantly reduce sulphur dioxide and nitrogen oxide emissions. In fact, for sulphur emissions, reductions can be of a similar magnitude to the reduction of carbon dioxide. Both the S550e and the S650e scenarios are much more likely to respect urban air quality standards by 2025 and 2050 than the baseline. Initial estimates of other studies on the benefits of improved public health in economic terms, expressed as percentage of the GDP, shows they can outweigh the cost impact on economic welfare.

For Asia, we have explored these co-benefits in more detail using RAINS-Asia, as calculations show that this region is among those most affected by global air pollution by 2030. The S550e scenario can limit the 2030 exceedance of critical loads in the total region by an average of 50%. The co-benefits of the S65e0e scenario are less. Here, most co-benefits can be expected after 2030. Air pollution emission control costs can be quite expensive (80 billion euro a year in Europe by 2010). In most of Asia air pollution control techniques are not yet very common, therefore most co-benefits are found in the sphere of improvement in the environment and to a lesser extent in saving costs for conventional air pollution control techniques.

7 Conclusions

In the context of the efforts required to stabilise the GHG concentration, the objective of the UNFCCC, the Kyoto Protocol is only a first step. This raises important questions about what future levels of commitments will be needed after the first commitment period of the Kyoto Protocol (focus here was on 2025 and 2050) and about what would constitute a fair differentiation of commitments among countries. In an earlier study, we looked into the regional emission allowances resulting from five different proposals for regimes for differentiation of future commitments (den Elzen et al., 2003b). Two of these, known as the *Per Capita Convergence* and *Multi-stage* approaches, were selected for in-depth analysis of their technical, economic and environmental consequences when applied in combination with an overall objective of stabilising greenhouse gas concentrations at 550 ppmv or 650 ppmv CO_2-equivalent. In the preceding chapters we have endeavoured to present this in-depth analysis, highlighting our observations. This chapter will be largely devoted to our conclusions and recommendations.

7.1 Overall global target and need for international mitigation commitments

- **Sharp GHG emission reductions are required to limit global mean temperature increase to 2 degrees Celsius over pre-industrial levels. In fact, assuming a median climate sensitivity, global greenhouse gas emissions need to peak before 2020 and return to 1990 levels around 2030.**

  A continuation of non-constrained greenhouse gas emissions is projected to result in a global temperature increase of more than 3 degrees Celsius by 2100 (for a median climate sensitivity) and further increases thereafter. In this study, two different constrained emission profiles were evaluated, the first one stabilising the concentration of greenhouse gases at 550 CO_2 ppmv equivalent (S550e) and the second at 650 CO_2 ppmv equivalent (S650e). The S550e profile limits the global temperature increase in 2100 to less than 2 degrees Celsius for median to low climate sensitivity values, while the S650e profile only stays below this level if the climate sensitivity is at the low end of the uncertainty range of IPCC making it unlikely that this profile meets the 2 degrees Celsius target. In the case of high climate sensitivity, the target will not be met under both profiles.

  The emission reductions required for reaching the S550e profile are much more stringent than for the S650e profile. For the S550e profile, global emissions would have to peak before 2020 and return to 1990 levels around 2030. For the S650e profile, global emissions would have to peak around 2030, and return to 1990 levels only around 2070. It should be noted that for stabilising at 650 ppmv CO_2-equivalent, other pathways, which allow emissions to peak later, are possible. For 550 ppmv equivalent a further delay would result in large reductions after 2025 and/or a (temporary) overshooting of the 550 ppmv level. The S550e profile requires a reduction of global greenhouse gases in 2025 of 30% compared to baseline, while the S650e profile requires a reduction of 15%.

- **Halting global emission growth within 2 – 3 decades will require early participation of developing countries in climate policies at a lower income level than Annex I countries under the Kyoto Protocol. It will also require considerable strengthening of the reduction targets of Annex I countries.**

  Our results show that even under a significant strengthening of the commitments taken on by the Annex I countries under the Kyoto Protocol, early participation of developing countries is required to reach the global emission reductions needed for stabilising GHG concentrations under the two emission profiles. The challenge is therefore to develop an international commitment regime that is both effective in controlling emissions and sufficiently fair to be acceptable to various parties throughout the world. Results indicate that approaches based on binding quantified emission targets, combined with mechanisms for flexible implementation of these targets, could provide a sufficiently effective and efficient incentive structure for achieving such quick change in global greenhouse gas emission trends. Within such an approach, use of flexible instruments (emission trading, JI/CDM) could ensure an effective means to limit global control costs and provide incentives for participation of developing countries (see also below).

7.2 Implications of 2 climate change regimes: Per Capita Convergence and Multi-stage

- **Under the Per Capita Convergence and Multi-stage approaches analysed, the future abatement efforts for Annex I regions are determined more by the stabilisation level than by climate regimes. The abatement efforts (allocations) for Annex I regions for S550e generally range from 25%-50% below 1990 levels in 2025 (across regions and regimes) and 70-85% in 2050. For S650e, these efforts range from 10% increase to 25% reduction in 2025 and 40-60% reduction in 2050. The 2100 Per Capita Convergence regime forms an exception, leads to lower targets for Annex I regions.**
- **Most non-Annex I regions will need to reduce their emissions by 2025 compared to baseline levels, but emissions can increase compared to 1990 under any of the regimes analysed. For non-Annex I regions, the results for the various commitment schemes, stabilisation targets and time horizons (2025 versus 2050) differ more sharply than for Annex I regions. Regions also display the lowest reduction targets under different regimes. In general, low income-regions (Africa, South Asia) display lower abatement efforts from baseline than middle-income countries (Latin America, the Middle East and Turkey, East and South-East Asia).**

  In the preceding chapters we looked into the consequences of different variants of the Per Capita Convergence and Multi-stage approaches to act as effective schemes to systematically derive emission targets on the basis of different principles of a fair distribution of emission reduction obligations[37].

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[37] For the Multi-stage schemes, the different rules determining the entry of parties into the full participation stage were analysed. However, in all variants, parameters were chosen to ensure a smooth entry of various groups of non-Annex I countries; the differences between the variants are not very large for the group of Annex I and non-Annex I countries as a whole.

For the Annex I regions, the differences between the total group of regimes analysed are relatively small (varying from 25 to 50% below 1990 levels, or from 40 to 60% below baseline in 2025 under S550e). Only the 2100 convergence regime forms an exception, and leads to the lowest reduction efforts for the Annex I regions (5-35% compared to 1990; 25-45% from baseline) but to the highest reduction for non-Annex I regions. In general, schemes showing late entry of the middle- and high-income non-Annex I regions (such as the Multi-stage variant with a prescribed transition period and the 2050 convergence variant) lead to relatively high targets for Annex I regions. For the S650e profile, the required reductions are obviously lower, ranging from a 10% increase to a 30% decrease (15-40% from baseline). In 2050, the reductions are in the order of 70%-85% (S550e) and 45-75% (S650e) compared to 1990.

Box 7.1: Detailed findings for the Per Capita Convergence and Multi-stage variants

Per capita convergence:
The following conclusions can be drawn from the analysis of the per capita convergence variants :

- The major strength of the per capita convergence approach is that it provides a relatively simple scheme. Within this scheme, the convergence year has a strong impact on the distribution of emission allowances. An early convergence year (2050) is favourable for low-income regions, but less favourable for Annex I regions (strong reductions). In contrast, a late convergence year (2100) results in the lowest reduction obligations of all variants analysed for the Annex I regions but, by far, in the highest reductions for low-income regions.
- The 2050 Per Capita Convergence scheme results in a distribution of reduction efforts comparable to those of the Multi-stage variants. A distinctive feature of this case, however, is that it can result in considerable surplus emission allowances for Africa and South Asia for the S650e regimes. This increases the number of traded allowances (and thus the capital flows). For a balanced distribution of emission reductions, avoiding excess emissions, there needs to be a match between the convergence year and stabilisation profile.

Multi-stage approach:

- The strength of the Multi-stage approach is that it opens the way for an incremental, but rule-based, approach to the definition of emission allowances, taking into account the specific situations and constraints applying to individual parties.
- The results for the Multi-stage variants are found between early and late per capita convergence variants.
- The new CR index used in all MS variants, which combines per capita emissions (responsibility) and income (capability) (CR-index), results in earlier participation of low-income countries, with relatively high per capita emission levels, than income threshold only.
- The MS variants were found to have strengths and weaknesses. The simulations indicate that a threshold based on a percentage of world average per capita emissions (responsibility-oriented; MS1 variant) results in timely participation of non-Annex I countries, but also in relatively large emission reduction burdens for regions with high emissions but low per capita income (e.g. the Middle East & Turkey). An approach that also takes per capita income into account using a second CR index (MS2) reduces this effect. On the other hand, the percentage of world average per capita emission threshold may still be considered interesting. This is because it provides an incentive for non-Annex I countries to stay below this threshold and is easier to adjust. A prescribed transition period for bending emission trends (MS3) is also possible but carries risks if countries experience sudden changes in their baseline emissions.

For non-Annex I regions, the regimes differ more sharply for different commitment schemes, stabilisation targets, the time horizon (2025 versus 2050) and among regions than for Annex I regions. In general, the reduction obligations found for Latin America, Turkey, the Middle East and East and South-East Asia (40-140% increase from 1990 levels, but a 20-50% reduction from baseline for S550e) are greater than those for Africa and South Asia (90-300% increase from 1990 levels, or a 10% increase to 25% decrease from baseline for S550e in 2025). For the more developed non-Annex I regions, the convergence approaches tend to lead to higher reductions. The 2050 Convergence approach leads in 2025 to surplus emission allowances (above baseline) for Africa and South Asia under both the S550e and S650e profile.

More detailed findings for each of the two approaches analysed are indicated in Box 7.1.

7.3 The costs and benefits of the climate regimes

- **Restricting global GHG emissions to the S550e profile will require larger abatement costs than the S650e profile (equivalent to 1.0% versus 0.2% of world GDP in 2050)[38]. Obviously, these costs are subject to considerable uncertainty. For the S550e profile, uncertainty analysis showed different assumptions of marginal abatement costs to result in a cost range of 1.0-1.5%.**
- **There are considerable differences among the various regions in terms of costs. Under the S550e profile, these range from net gains from Africa and South Asia in some regimes to abatement costs up to 3-4% of GDP for the Middle East &Turkey and 2% for CIS.**
- **The gains of global emission trading can provide an incentive for non-Annex I countries to take on quantified emission limitation commitments, while alleviating the costs of GHG emission policies at global level at the same time.**

For the S550e profile the direct annual abatement costs as percentage of GDP increase after 2020 towards the middle of the century to a maximum level of approximately 1.0% of the world GDP, after which they gradually decrease. For the S650e profile, the costs increase more gradually to 0.2% of GDP by 2050 and stabilise in the last quarter of the century. The corresponding 2050 international permit prices are €120-130 and €30-40 per tCO_2-eq, respectively. The international permit price and global costs are only dependent on the number of participants in the future commitment regime and stabilisation level. The regional costs, however, are also dependent on emission allocation and can differ largely between regions.

Obviously, these cost calculations are subject to considerable uncertainty (as shown in Chapter 5) and should be regarded as lower boundary costs, since we have assumed fully effective emission trading and removal of implementation barriers. These abatement costs constitute one measure of the costs of climate policy, but do not take into account the impact on fuel trade or macro-economic impacts (including sectoral changes or trade impacts). These costs can be compared to the total costs of the energy sector (world-wide around 7.5% of GDP today and under our baseline expected to remain nearly

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[38] These abatement costs are equal to the sum of domestic abatement costs and the amount of allowances traded, multiplied by the international permit price.

constant) or to the costs of environmental policy (in the EU around 2.0-2.8%, mostly for waste and wastewater management).

For the abatement costs as per cent of GDP, four groups with similar effort rates can be identified, i.e.: 1) regions with high per capita emissions and a high income (Annex I regions excluding the FSU) are confronted average costs when compared to other regions (0.5-1.0% of GDP in 2025); 2) regions with medium to high per capita emissions, but a medium to low income (FSU, the Middle East & Turkey, and to a lesser extent, Latin America) are confronted with average to high costs (1.0-2.0% of GDP in 2025 and lower for Latin America); 3) regions with low to medium income levels and per capita emissions (South-East & East Asia) show low to medium cost levels (0-0.3% of GDP in 2025); and 4) regions with low per capita emissions and a low-medium income (Africa and South-Asia) show low costs or net gains from emissions trading.

Differences among future commitment regimes
The differences in regional costs reflect, in general, the differences in reduction targets. While most regimes explored show fairly similar regional economic impacts, the Multi-stage variant, based on a fixed transition pathway (MS3) and the convergence 2100 approach, differ the most in terms of emission allowances and thus total abatement costs. For the MS3 variant, this is a result of the longer and less stringent transition period for the middle-income non-Annex I regions. For the convergence in 2100 approach, reduction targets for Annex I countries are relatively modest, resulting in some Annex I regions becoming sellers of emission permits to non-Annex I regions.

The financial flows involved in emission trading in some regimes can be large. For the S550e, these can amount to € 200 billion in 2025 and more than €500 billion in 2050. For the S650e profile, these numbers vary between €10-50 billion in 2025 and €150-300 billion in 2050. On the one hand, the flows might create a strong incentive for non-Annex I countries, with low per capita emissions entering the regime, while on the other hand, they will pose serious challenges in finding practical options to implement such a regime.

- **Stabilising GHG concentrations at 550 ppmv and 650 ppmv was found to be technically and economically feasible – but implementation will result in major changes in the energy system, and related to this, in energy trade. The financial consequences of changes in fuel trade could, for some regions (the Middle East, North and West Africa, Oceania and possibly CIS and Latin America), be of the same order of magnitude as direct costs of implementing climate policies. The production and export of biofuels could partially compensate the oil export losses of Latin America and the CIS.**

  Realising the S550e profile will require the contribution of several reduction options, including improved energy efficiency, a strong move away from coal use, fossil CO_2 capture and storage, the use of renewables and biofuels, reduction in non-CO_2 gases (including gases from land use) and the use of sinks.

  These changes are likely to have a considerable impact on energy trade. In several regions (OECD regions and Asia) the reduced energy imports could compensate some of the direct abatement costs of climate policies. However, other regions will suffer from reduced export, which can be substantial. The lost oil revenues may, in fact, be of similar magnitude as the direct costs of climate policies (for the Middle East, CIS, North and West Africa, Latin America these range from 3.5 to 0.5% of GDP; in absolute numbers the costs reach amounts of up to € 200 billion; or 50% of baseline exports). Lost coal trade revenues are lower as the total financial flows are smaller but can still be high for Oceania (about 1% of GDP). The production and export of biofuels could partially compensate the oil export losses of Latin America and the CIS.

- **Climate policies can have significant co-benefits, both in terms of reduced emissions of regional air pollutants such as SO_2/NO_x and of avoided costs for controlling these gases. For developing countries, co-benefits could be important in supporting sustainable development strategies.**

  Climate policies can have significant co-benefits. In particular, reduction of coal use can lead to reductions in emissions of air pollutants. Implementing the S550e profile was found to reduce global SO_2 and NO_x emissions in 2050 by 70% and 50% from baseline, respectively. For the S650 profile these numbers are 50% and 35%. This will lead to both improved air quality within urban areas and lower acidification risks for ecosystems. For acidification in Asia, implementing the S550e profile can, in fact, limit the areas exposed to high risks by an average of 50% compared to baseline. Due to the importance of the co-benefits of GHG mitigation, this implementation would also provide a powerful support for sustainable development strategies in the developing world.

- **The Multi-Stage and Per Capita convergence regime approaches each have strengths and weaknesses.**
  In addition to the quantitative analysis we also evaluated the strengths and weaknesses of the specific Multi-stage and Per Capita Convergence variants, and of the two approaches in general. From this analysis we can conclude that the PCC and MS approaches both have their strengths and weaknesses. Overall, the MS approach better fits in with the current approach taken under the international climate policy framework (in particular in differentiating commitments for different groups of countries). The MS approach seems to provide a more flexible, institutionally feasible and politically acceptable approach for differentiating future commitments than the PCC approach. To enhance flexibility, even more stages could be identified than the variants analysed here – but often at the cost of transparency. In contrast, the PCC approach has a high level of transparency but limited flexibility (only one variable to adjust the results). An advantage of the PCC approach is that it provides more certainty about early developing country participation that is needed to meet stringent climate policy goals. Full participation in the PCC approach, in principle, also allows for the lowest global abatement costs. However, this is only possible if low-income countries comply to conditions required for proper functioning of emission trading. Building up the capacity to fulfil these conditions in time poses a major challenge. The gradual participation of different groups of countries and the limitations to emission trading in different stages in the MS approach leads to somewhat higher overall costs and could result in carbon leakage. In both approaches, there are options for remedying some of the problems identified.

7.4 General insights gained

- **Financial gains from emission trading and co-benefits of climate policies may allow non-Annex I countries to take on quantified emission limitation commitments (if not too strict) at net gains or low costs while alleviating the costs of GHG emission policies at the world level at the same time. This, however, requires a fully effective functioning of emission trading instruments.**

  Meeting the objective of limiting the global average temperature increase to 2°C will require early participation of developing countries, even with significant strengthening of the commitments of Annex I countries. The regimes explored all provide a way of ensuring such participation (resulting in different results for different regions). The results indicate that in many cases the financial gains from emission trading under these regimes can provide an incentive for non-Annex I countries to take on quantified emission limitation commitments (if not too strict), while, at the same time, alleviating the costs of GHG emission policies at global level. All Multi-Stage variants and the 2050 convergence approach provide schemes that can meet this condition. In addition, the gains from reduced air pollution damage can also make early participation of developing countries in global GHG emission control attractive.

  The conclusions above can only be drawn with a fully effective participation of low-income countries in emission trading. This is only possible if these countries comply to conditions required for the functioning of emission trading instruments. An example here could be the functioning of an emission registration system and sufficient liability/credibility in selling emission rights. Capacity-building will be required to ensure that low-income developing countries can meet these conditions.

- **In evaluating the fairness and political acceptability of the various regimes, it is not sufficient to only evaluate the allocation of the emissions compared to baseline. It will also require an assessment of the distribution of abatement costs, impacts from emission trading and the impacts resulting from a change in energy trade.**

  The regimes explored in this report result, in general, in slightly above average cost levels for Annex I regions compared to other regions world-wide. Several low-income regions have, certainly in first few decades, much lower costs or even net gains. However, other regions, in particular those with low to medium income, but relatively high per capita emissions (such as the Middle East or FSU) could face relatively high abatement costs. At the same time, these regions can also be exposed to higher costs due to lost energy trade revenues. This implies that in evaluating the actual implications of the various regimes, it is not sufficient to evaluate only the allocation of the emissions compared to baseline; also required is an assessment of the impacts from emission trading and the impacts resulting from a change in energy trade. Ignoring this can result in allocations that would constitute a ‘disproportional or abnormal burden’ (UNFCCC, Art. 3). This illustrates the need for dealing with national circumstances in future regimes.

- **Further research is needed on future levels of commitments among regions.**

  The climate regimes selected in this report have been analysed primarily from a quantitative point of view and with emphasis on technical and cost aspects. On the basis of these results, several areas can be defined for further research.
  - The study did not go into a full macro-economic evaluation of these regimes. While others have performed preliminary work in this area, we feel a need for further research here.
  - The study did not go into an evaluation of all kinds of implementation issues that might identify limitations for putting these (theoretical) approaches into practice. As a next step therefore, promising approaches need to be analysed on a more detailed and refined scale, including issues of practical feasibility such as data needs compared to availability or conditions of implementation and control.
  - Finally, it would be useful to include other regimes in such an analysis, as results for different regions showed each of the regimes studied to have both strengths and weaknesses. The large differences in regional cost levels indicates that national circumstance may need to be better accounted in the design of future regimes.

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Annex 1: Description of the models used

The FAIR 2.0 model

The FAIR model is developed with the major objective of assisting policy-makers in exploring and evaluating different international climate regimes for differentiation of future commitments under the Climate Change Convention (post-Kyoto) in the context of stabilising GHG concentrations (Article 2 UNFCCC). Other objectives are the evaluation of Kyoto Protocol in terms of environmental effectiveness and economic costs and supporting the dialogue between scientists and policy-makers. Therefore, the FAIR model is an interactive - scanner-type - simulation tool with a graphic interface allowing for changing and viewing model input and output in an interactive way. For this analysis we use the new version 2.0 of the FAIR model (den Elzen, 2002; den Elzen and Lucas, 2003). The FAIR 1.0 (den Elzen et al., 2001) can be downloaded from our website: www.rivm.nl\fair.

Model structure of FAIR 2.0
The FAIR 2.0 model consists of an integration of three models: a simple integrated climate model, an emissions allocation model and a mitigation costs & emission trade model (Figure I.1). More specifically:

1. *The climate model*: the stand-alone version of AOS (IMAGE-team, 2001) is used to calculate the CO_2-equivalent greenhouse gas concentration, global temperature increase, rate of temperature increase and the sea-level rise for the global emission scenarios and profiles. Alternatively, the UNFCCC-ACCC climate model (see Terms of Reference (UNFCCC, 2002) (ACCC-TOR)), or the IRF functions based on simulation experiments with various Atmosphere-Ocean General Circulation Models can be used (AOGCMs). A special attribution model calculates the regional contribution to the different climate indicators.
2. *The emission allocation model*: this model calculates regional emission allowances or permits on the basis of five different families of commitment future regimes:
    a. Multi-Stage approach: a gradual increase in the number of Parties involved and their level of commitment according to participation and differentiation rules, such as per capita income and per capita emissions (Berk and den Elzen, 2001).
    b. Brazilian Proposal: a gradual increase in the number of Parties involved according to certain participation rules, such as per capita income or per capita emissions, and differentiation of their level of commitments by their contribution to global warming (den Elzen et al., 2002).
    c. Per capita convergence approach: all Parties participate in the climate regime, with emission allowances converging to equal per capita levels over time. Three types of convergence regimes are included: (i) ‘Contraction & Convergence’, convergence towards equal per capita emission allowances (Meyer, 2000); (ii) Contraction & convergence approach with basic sustainable emission rights as suggested by the Centre of Science and Environment (CSE) (CSE, 1998); (iii) Preference Score regime of Müller (1999), which is a combination of grandfathering entitlement method and a Per Capita Convergence approach.
    d. Emissions intensity system: the emission intensity is the emissions per unit of economic activity expressed in GDP or PPP-terms. Three types of emission intensity systems are included: (i) emission intensity convergence: a top-down approach with convergence of emission intensities of the economy; (ii) Emission intensity forever: a bottom-up approach in which all Parties adopt GHG intensity targets straight after

Kyoto when achieving an income threshold (den Elzen and Berk, 2003). (iii) Jacoby Rule: a bottom-up approach in which both participation and emissions reductions are depending on the per capita income (Jacoby et al., 1999). This approach can also be applied top-down by scaling towards the emission profile.

e. Triptych approach, a sector and technology-oriented approach in which overall emission allowances are determined by different differentiation rules applying to different sectors (e.g. convergence of per capita emissions in the domestic sector, efficiency and de-carbonisation targets for the industrial and the power generation sector).

3. *The mitigation costs & emission trade model*: The model calculates the tradable emission permits, the international permit price and the total abatement costs up to 2030, with or without emission trading, according to the calculated regional emission allowances of a selected climate regime. The model makes use Marginal Abatement Curves (MACs), used to derive permit supply and demand curves, under different regulation schemes in any emission trading market using the same methodology as Ellerman and Decaux (Agarwal et al., 1999; Berk and den Elzen, 2001; Ellerman and Decaux, 1998). These schemes could include constraints on imports and exports of emission permits, non-competitive behaviour, transaction costs associated with the use of emission trading and less than fully efficient supply (related to the operational availability of viable CDM projects).

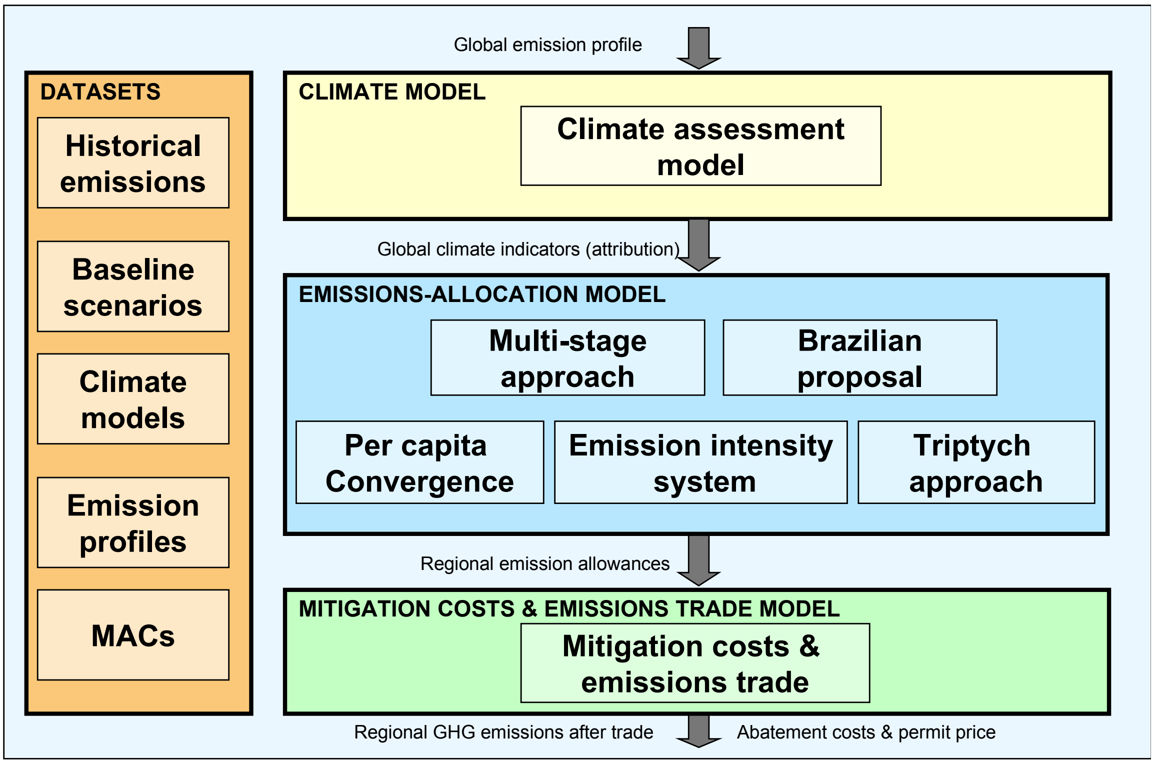

Figure AI.1 Schematic diagram of FAIR 2.0 showing its framework and linkages (den Elzen and Lucas, 2003)

The IMAGE 2.2 Integrated Assessment model

The objective of the IMAGE 2.2 modelling framework (Integrated Model to Assess the Global Environment; IMAGE team, 2001) is to explore the long-term dynamics of global environmental change. The framework consists of several linked and integrated submodels (Figure 2.1) and provides results for 17 socio-economic regions (plus Antarctica and Greenland) and for most environmental parameters also at a 0.5 x 0.5 grid.

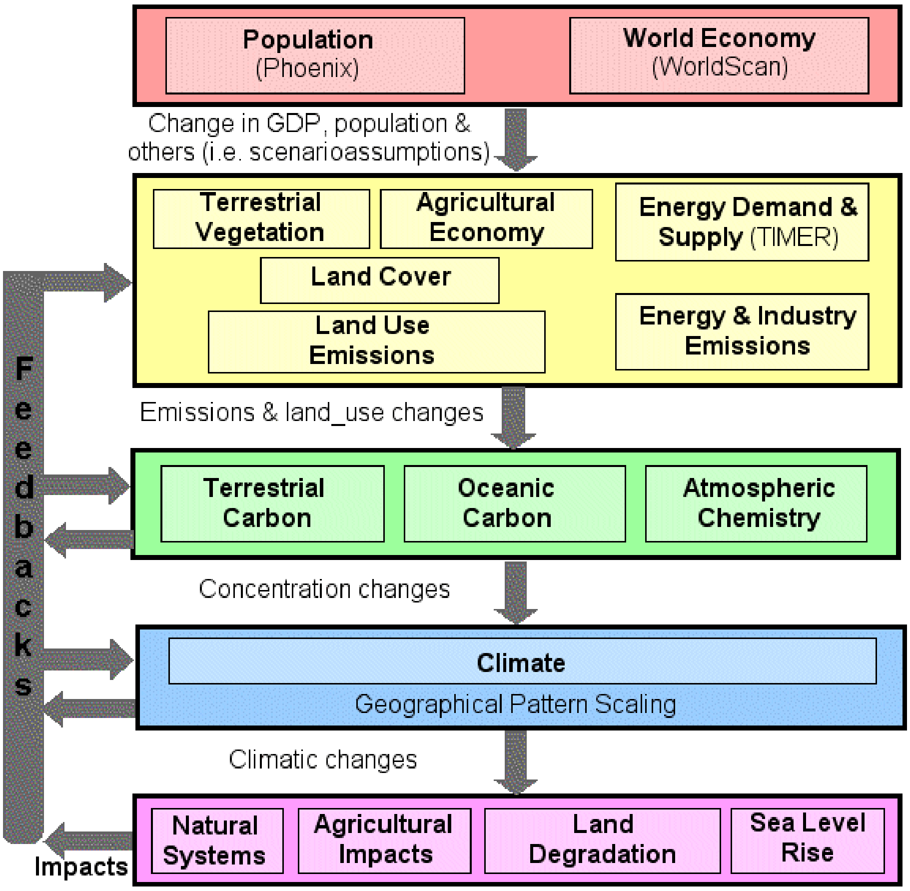

Figure A1.2: The structure of the IMAGE 2.2 framework (IMAGE team, 2001).

The IMAGE model consists of four main components:

- The Energy-Industry models calculate regional energy consumption, energy efficiency improvements, fuel substitution, supply and trade of fossil fuels and renewable energy technologies. On the basis of energy use and industrial production, emissions of GHGs, ozone precursors and sulphur are computed (de Vries et al., 2002).
- The ecosystem, crop and land-use models dynamically compute land use on the basis of regional consumption, production and trading of food, animal feed, fodder, grass and timber, and local climatic and terrain properties. Emissions from land-use change, natural ecosystems and agricultural production systems, and the exchange of CO_2 between terrestrial ecosystems and the atmosphere are computed (Alcamo et al., 1998).
- The atmospheric and ocean models calculate changes in atmospheric composition by employing the emissions and by taking oceanic CO_2 uptake and atmospheric chemistry into consideration. Subsequently, changes in climatic properties are computed by resolving the changes in radiative forcing caused by GHGs, aerosols and oceanic heat transport. The upwelling-diffusion climate model implemented in IMAGE 2.2 is based on the MAGICC model (Hulme et al., 2000).

The impact models involve specific models for sea-level rise and land degradation and make use of specific features of the ecosystem and crop models to depict impacts on vegetation. The ecosystem models include an algorithm that estimates the carbon cycle consequences of different assumptions on the speed of climate-change induced vegetation migration (Van Minnen et al., 2000).

The world energy model TIMER 1.0

The energy system model, TIMER (Targets IMage Energy Regional Model), has been developed to simulate long-term energy baseline and mitigation scenarios and explore the long-term dynamics of the energy system (de Vries et al., 2002). The model describes the investments in, and the use of, different types of energy options influenced by technology development (learning-by-doing) and depletion. Inputs to the model are macro-economic scenarios and assumptions on technology development, preference levels and fuel trade. The output of the model demonstrates how energy intensity, fuel costs and competing non-fossil supply technologies develop over time. The model recognises 17 world regions, 5 different end-use sectors, several different energy-producing sectors and about 10 energy carriers. In terms of final energy use the model recognises the energy carriers coal and solid fuels, light liquid fuels, heavy liquid fuels, gaseous fuels, modern biofuels, gaseous biofuels, electricity and heat. The electricity generation sub-model includes production options based on hydropower, nuclear energy, renewables and different fossil fuels. The use of fossil fuels can be combined with carbon capture and storage, with regional data on storage options and their costs as taken from (Henkdriks and Graus, 2002). The model is linked to an emission module that relates energy use to emissions of various greenhouse gasses. TIMER is incorporated into the IMAGE integrated assessment framework to study global change.

Implementation of CO_2 mitigation is generally modelled on the basis of price signals. A tax on carbon dioxide (carbon tax) is applied to bring down carbon emissions from the energy system. It should be noted that TIMER does not account for any feedback from the energy system to economic drivers. In response to the carbon tax, the model generates several responses:

1. Price-induced investments in energy-efficiency, which, in turn, affect the energy-efficiency supply cost curve as a result of learning-by-doing (economies of scale, innovation).
2. Price-induced fossil fuel substitution.
3. Changes in the trade patterns of (fossil) fuels as a consequence of changing demand patterns and regional fuel prices.
4. Price-induced acceleration of investments in non-fossil options such as wind/solar energy, nuclear energy and biofuels, bringing down their specific investment costs in the process of learning-by-doing.
5. A decrease in the use of fossil fuels (as result of the responses discussed above), leading to slower depletion rates and consequently lower prices but also to a lower rate of innovation in the production of these fuels (slowing down learning-by-doing).
6. Using fossil fuels in the electric power sector in combination with carbon capture and storage technology (leading in the long run to depletion of available storage capacity).

TIMER simulates a variety of technological and economic changes in the energy system in response to the requirement to reduce CO_2 emissions. Costs of (aggregated) energy technologies used by the model are calibrated for the base year using historical data. It should be stressed that total system costs are not directly related to the costs of a single measure because each option induces changes in the costs of other parts of the system. Investing in energy efficiency, for instance, reduces the costs of energy production and also accelerates the learning of energy-efficiency technology. Costs of air pollution control equipment are not included in the energy system costs of TIMER.

Annex 2: regional breakdown

North America	Canada United States
Enlarged EU*	France United Kingdom Italy Germany Austria Belgium Luxembourg Denmark Finland Ireland Netherlands Sweden Spain Greece Portugal Gibraltar Iceland Norway Switzerland Hungary Poland Czech Republic Slovakia Estonia*** Latvia*** Lithuania*** Slovenia* Malta Cyprus Bulgaria Romania Albania Bosnia and Herzegovina Croatia Macedonia, the former Yugoslav Republic of Yugoslavia
CIS & R. Europe	Ukraine Kazakstan Kyrgyzstan Tajikistan Turkmenistan Uzbekistan Belarus Moldova, Republic of Russian Federation Armenia Azerbaijan Georgia
Auatralia	Australia American Samoa Cook Islands Fiji Kiribati New Caledonia Vanuatu Nauru New Zealand US Pacific Islands French Polynesia Solomon Islands Tonga Western Samoa Wake Island
Japan	Japan
Latin America	Mexico Bahamas Belize Bermuda Barbados Costa Rica Cuba Cayman Islands Dominica Dominican Republic Guadeloupe Grenada Guatemala Honduras Haiti Netherlands Antilles Jamaica Saint Kitts and Nevis Saint Lucia Leeward Martinique Nicaragua Panama El Salvador Turks and Caicos Islands Trinidad and Tobago Saint Vincent and the Grenadines Brazil Argentina Bolivia Chile Colombia Ecuador Falklands Islands (Malvinas) French Guiana Suriname Guyana Peru Paraguay Uruguay Venezuela
Africa	Egypt Algeria Libyan Arab Jamahiriya Tunisia Morocco Western Sahara Benin Burkina Faso Cameroon Cape Verde Central African Republic Chad Congo Congo, the Democratic Republic of the Côte d'Ivoire Equatorial Guinea Gabon Ghana Guinea Gambia Guinea-Bissau Liberia Mali Mauritania Niger Nigeria Saint Helena Sao Tome and Principe Sierra Leone Senegal Togo Angola Botswana Lesotho Mozambique Malawi Swaziland Tanzania, United Republic of Zimbabwe Zambia Burundi Comoros Djibouti Eritrea Ethiopia Kenya Madagascar Mauritius Réunion Rwanda Seychelles Sudan Somalia Uganda
Middle East & Turkey	Israel Jordan Lebanon Syrian Arab Republic United Arab Emirates Bahrain Iran, Islamic Republic of Iraq Kuwait Oman Qatar Saudi Arabia Yemen Turkey
South Asia	India Pakistan Afghanistan Bangladesh Bhutan Sri Lanka Maldives Nepal
SE & E Asia	Korea, Republic of Korea, Democratic* ople's Republic of China Hong Kong Macau Mongolia Taiwan, Province of China Brunei Darussalam Myanmar Cambodia Lao People's Democratic Republic Malaysia Philippines Singapore Thailand Viet Nam Indonesia Papua New Guinea

Annex 3: Regional results

1. Regional emission allowances

Regional emission allowances for the MS and PCC variants in the year 2025 and 2050 for the ***S550e*** *profile.*

(a) expressed as reductions compared to baseline emissions

S550e profile	2025					2050				
Regions	MS1	MS2	MS3	PCC50	PCC100	MS1	MS2	MS3	PCC50	PCC100
Canada & USA	55	51	61	44	32	84	85	83	88	65
Enlarged EU	38	36	44	37	29	73	74	71	78	61
CIS + O. Europe	47	44	53	44	34	80	81	78	85	66
Oceania	55	53	61	51	43	83	83	82	85	71
Japan	45	43	50	44	37	74	75	73	78	63
Latin America	35	36	20	32	33	73	77	70	68	70
Africa	6	6	8	6	25	37	18	40	28	55
ME & Turkey	49	48	43	46	44	81	82	78	76	75
South Asia	1	1	6	3	25	29	29	38	33	57
SE & E Asia	21	26	15	31	33	65	69	63	64	66

(b) expressed compared to 1990 emissions (1990 emission are 100)

S550e profile	2025					2050				
Regions	MS1	MS2	MS3	PCC50	PCC100	MS1	MS2	MS3	PCC50	PCC100
Canada & USA	61	66	52	75	92	22	20	23	17	48
Enlarged EU	65	68	59	67	75	29	28	31	24	42
CIS + O. Europe	53	56	47	56	65	21	20	23	16	35
Oceania	68	72	60	74	87	29	28	31	26	49
Japan	68	71	62	70	78	31	29	33	26	44
Latin America	147	144	181	153	151	95	83	108	113	108
Africa	268	268	260	268	213	320	413	302	362	227
ME & Turkey	167	173	187	178	186	97	94	112	123	129
South Asia	308	308	291	300	234	378	379	331	355	228
SE & E Asia	219	207	237	192	187	134	117	141	136	131

Regional emission allowances for the MS and PCC variants in the year 2025 and 2050 for the ***S650e*** *profile.*

(a) expressed as reductions compared to baseline emissions

S650e profile	2025					2050				
Regions	MS1	MS2	MS3	PCC50	PCC100	MS1	MS2	MS3	PCC50	PCC100
Canada & USA	21	25	27	30	14	64	66	60	79	38
Enlarged EU	18	20	20	20	10	50	52	46	62	31
CIS + O. Europe	24	26	27	29	17	60	61	56	73	41
Oceania	34	36	37	39	28	65	66	62	73	49
Japan	27	29	30	29	20	53	54	49	62	35
Latin America	18	18	12	14	15	49	51	53	45	47
Africa	0	0	0	-19	5	11	3	2	-25	22
ME & Turkey	38	20	23	32	29	70	46	62	58	56
South Asia	0	0	0	-22	5	0	0	1	-16	25
SE & E Asia	5	5	4	13	15	27	34	35	38	40
World	14	14	14	14	14	37	37	37	37	37

(b) expressed compared to 1990 emissions (1990 emission are 100)

S650e profile	2025					2050				
Regions	MS1	MS2	MS3	PCC50	PCC100	MS1	MS2	MS3	PCC50	PCC100
Canada & USA	106	101	99	95	116	49	47	55	29	84
Enlarged EU	87	85	84	85	95	54	52	58	41	74
CIS + O. Europe	76	74	73	71	83	42	41	47	28	62
Oceania	101	97	96	94	109	59	57	64	45	86
Japan	90	88	88	88	99	56	55	61	45	77
Latin America	184	184	198	193	191	181	174	167	197	189
Africa	284	284	284	339	269	451	493	494	631	395
ME & Turkey	206	266	253	225	234	156	275	196	215	225
South Asia	311	311	311	379	296	531	531	527	618	397
SE & E Asia	266	266	267	243	236	280	251	248	238	229

2. Regional emission reductions (after emission trading)

*Regional emission reductions after emission trading for the MS and PCC variants in the year 2025 and 2050 for the **S550e** profile: expressed as reductions (a) compared to baseline emissions and (b) compared to 1990 emissions*

(a) expressed as reductions compared to baseline emissions

S550e profile	2025					2050				
Regions	MS1	MS2	MS3	PCC50	PCC100	MS1	MS2	MS3	PCC50	PCC100
Canada & USA	36	36	36	35	34	72	71	71	70	69
Enlarged EU	27	27	28	26	25	64	65	64	63	63
CIS + O. Europe	38	38	38	38	37	73	73	73	71	71
Oceania	32	32	32	31	31	65	65	65	63	64
Japan	30	30	30	30	30	68	67	68	65	65
Latin America	26	28	27	27	27	60	61	61	59	60
Africa	20	20	20	27	27	43	43	43	52	54
ME & Turkey	28	28	28	27	27	55	55	55	54	54
South Asia	30	30	32	31	31	66	66	66	65	65
SE & E Asia	35	35	35	34	33	67	67	65	65	63

(b) expressed compared to 1990 emissions (1990 emission are 100)

S550e profile	2025					2050				
Regions	MS1	MS2	MS3	PCC50	PCC100	MS1	MS2	MS3	PCC50	PCC100
Canada & USA	86	86	86	87	89	39	39	39	41	41
Enlarged EU	78	79	78	79	81	39	39	39	41	41
CIS + O. Europe	61	61	61	62	62	29	29	29	30	30
Oceania	104	104	104	105	104	59	59	59	61	61
Japan	89	90	89	90	90	40	40	40	43	43
Latin America	160	156	158	158	157	136	133	133	141	138
Africa	221	221	221	204	203	280	280	282	236	225
ME & Turkey	236	236	236	238	237	229	230	230	236	236
South Asia	221	221	214	217	216	184	185	184	191	191
SE & E Asia	179	179	179	182	184	125	124	130	131	139

Regional emission reductions after emission trading for the MS and PCC variants in the year 2025 and 2050 for the ***S650e*** *profile: expressed as reductions (a) compared to baseline emissions and (b) compared to 1990 emissions*

(b) expressed as reductions compared to baseline emissions

S650e profile	2025					2050				
Regions	MS1	MS2	MS3	PCC50	PCC100	MS1	MS2	MS3	PCC50	PCC100
Canada & USA	18	18	18	16	14	43	43	42	41	40
Enlarged EU	12	13	13	11	11	36	36	35	34	33
CIS + O. Europe	24	25	25	23	22	46	46	45	44	44
Oceania	18	18	18	17	17	43	43	43	42	42
Japan	16	16	16	14	14	40	40	39	38	37
Latin America	13	13	12	11	10	36	36	36	34	35
Africa	3	3	3	12	10	26	25	24	30	26
ME & Turkey	13	13	13	11	11	29	29	28	27	28
South Asia	4	4	4	12	12	35	35	35	33	38
SE & E Asia	16	16	16	13	14	40	40	39	38	38

(b) expressed compared to 1990 emissions (1990 emission are 100)

S650e profile	2025					2050				
Regions	MS1	MS2	MS3	PCC50	PCC100	MS1	MS2	MS3	PCC50	PCC100
Canada & USA	110	110	110	113	115	77	77	78	80	81
Enlarged EU	95	94	94	96	96	70	70	71	72	73
CIS + O. Europe	75	75	75	77	77	58	58	58	59	60
Oceania	124	124	124	126	126	95	95	96	98	97
Japan	108	108	108	110	110	74	74	75	76	77
Latin America	188	188	190	193	191	219	218	220	228	223
Africa	268	268	268	244	250	367	373	375	346	367
ME & Turkey	282	282	282	288	288	363	363	366	370	369
South Asia	304	304	304	277	277	351	351	355	362	335
SE & E Asia	232	232	232	238	237	226	226	228	234	235