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Exploring climate regimes for differentiation of commitments to achieve the EU climate target

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Abstract

This report explores the implications of various international climate regimes for differentiating post-Kyoto (after 2012) commitments under a global emission profile compatible with the EU long-term climate objective to limit global-mean temperature increase to less than 2°C over pre-industrial levels. Five climate regimes are explored: (1) the Brazilian Proposal, with differentiation of emission reductions based on countries' relative contribution to the global temperature increase realised. (2) Multi-Stage approach, with a gradual increase in the number of Parties involved and their level of commitment according to participation and differentiation rules. (3) Per Capita Convergence approach, with universal participation and a convergence of per capita emissions. (4) Preference Score approach, an allocation derived from a population weighted preference score voting for either grandfathering or per capita allocation. (5) Jacoby Rule approach with both participation thresholds and burden allocation-based on per capita income. The quantitative analysis shows that under a emission profile for stabilising CO_2 concentrations at 450 ppmv (consistent with the EU-target), all approaches result into reductions of emission allowances of Annex I regions of at least 20-60% compared to their 1990 emission levels in 2025. For Europe the reductions are 40-60% in 2025. At the same time, major non-Annex I regions (East Asia and South Asia) need to reduce their emissions before the middle of this century, irrespective of the emission allocation approach and type of threshold chosen. In addition to the quantitative analysis, the strengths and weaknesses of the various regimes were also explored qualitatively on the basis of a multi-criteria evaluation. Different types of criteria (environmental, political, economic, technical, institutional and general-policy) were identified Overall, the Multi-Stage approach seems, in principle, to best satisfy the various types of criteria. However, the performance of other approaches could be improved by making adjustments in their design.

Summary

The long-term objective of the European Union climate policy is to prevent global mean temperature increasing by more than 2°C over pre-industrial levels. This study aims at exploring the implications of some proposed international climate regimes for differentiating post-Kyoto (after 2012) commitments under a global emission constraint compatible with the EU climate target. This has been done for two greenhouse gas emission profiles (S550e and S650e), resulting in a stabilisation of the total greenhouse gas concentration at 550 and 650 ppmv in CO_2-equivalent, for the set of six greenhouse gases covered by the Kyoto Protocol. The corresponding CO_2 emission profiles (S450c and S550c) show a stabilisation of CO_2 concentration at 450 and 550 ppmv, respectively. The range in the temperature increase associated with these two profiles will depend on the uncertainty attached to the 'climate sensitivity' parameter. The S550e profile may result in a maximum global mean temperature increase of less than 2°C, with a low to medium level of climate sensitivity. The S650e profile only remains below this level if the climate sensitivity level is low.

For the short term the profiles include the Annex I Kyoto Protocol (KP) targets, optimal banking of surplus emissions and implementation of US intensity targets. Our study explored the following five climate regimes for differentiation of future commitments on a global scale: (1) the Brazilian Proposal, with differentiation of emissions reductions based on countries' relative contribution to the global temperature increase realised and an income threshold for participation; (2) the Multi-Stage approach, with a gradual increase in the number of Parties involved and their level of commitment with respect to participation and differentiation rules; (3) the Per Capita Convergence approach (PCC), with universal participation and a convergence of per capita emissions over time; (4) the Preference Score (PS) approach, an allocation derived from a population-weighted preference score voting for either grandfathering or per capita allocation and (5) the Jacoby Rule (JR) approach, with both participation thresholds and burden allocation on the basis of per capita income. The FAIR 2.0 model was used to calculate the future allocation of emission allowances resulting from these regimes under the two CO_2 emission profiles and using the common POLES-IMAGE baseline. The calculations focus on CO_2 emissions only.

The quantitative analysis showed that all approaches explored for S450c result in reductions in emission allowances for all Annex-I regions of at least 20-60% compared to the 1990 levels in 2025. In 2050 the reductions are 70-90% (S450c), except for the Brazilian Proposal. For Europe the reductions are 40-60% in 2025 and 80-90% in 2050. In the BP case some Annex I regions, notably Europe, experience emission reductions of more than 100% on the long-term, i.e. negative emission allowances. For Europe the reductions are 40-60% in 2025 and 80-90% in 2050. At the same time, major non-Annex I regions (East and South Asia) need to start reducing their emissions before the middle of this century, irrespective of the emission allocation approach and type of threshold chosen. This implies that non-Annex I regions will have to start participating in global emissions reductions at significant lower per capita income and emission levels than Annex I regions under the KP. Under the S550c profile, the change in emission levels for Annex I are much smaller than for the S450c profile, but show a wider range: in 2025 they range from an increase of 30% to a reduction of 50% compared to 1990 levels. For 2050, reductions range from 15 to 70%.). The wider ranges also point at a larger sensitivity for the choice of the burden-sharing keys for the higher stabilisation profile. Non-Annex I countries can start controlling their emissions later, and their emission constraint can be smaller. The low-income non-Annex I regions experience much lower emission constraints in all cases, while

the other middle- and high-income non-Annex I regions take an intermediate position, between low-income non-Annex I and Annex I regions.

For all Annex I regions, the PS regime leads to the highest emissions reductions in the short term, while the Brazilian Proposal (BP) approach leads to the highest reductions in the long term. BP is particularly unattractive for OECD-Europe and Japan due to their large contributions to temperature increase. Apart from the BP approach, the differences in Annex I reductions due to different approaches are relatively small, particularly on the long-term. For the middle- and high-income non-Annex I regions (Latin America, ME & Turkey and SE & East Asia) the Multi-Stage approach is more attractive than PCC and PS in the short term, since the per capita emissions are higher than those of the low-income non-Annex I regions and closer to the world average. In the long term, the differences between the three approaches (PS, BP & PCC) will be small. The BP will then become more favourable, while JR (burden-sharing based on PPP$ income) will turn out to be less favourable. For the least developed non-Annex I countries, early participation is more attractive than late participation when their allowable emission levels are higher than their baseline emissions, as in the case of the PS and PCC approaches. However, while in the short term both approaches are more attractive for these regions than a Multi-Stage approach, in the long term, this situation reverses. Generally, it should be acknowledged that the attractiveness of approaches is dependent on the policy parameter settings chosen and in some cases also on the stringency of the global emission profile to be met.

In addition to the quantitative analysis, the strengths and weaknesses of the various regimes were also explored qualitatively on the basis of a multi-criteria evaluation. Different types of criteria (environmental, political, economic, technical, institutional and general-policy) were identified. Overall, the MS approach seems, in principle, to best satisfy the various types of criteria. However, the performance of other approaches could be improved by making adjustments in their design.

Concluding, meeting the EU climate target requires a peaking of global GHG emissions within the next two decades. This means that early participation of developing countries in global emission control is needed, even under a significant strengthening of the commitments of Annex I countries under the Kyoto Protocol. As the Multi-Stage approach includes the possibility of including different types and levels of commitments for regions with different levels of wealth and intensities of emissions, it seems a good candidate to form the basis for a long-term international climate architecture for the Post-Kyoto era.

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Contents

Samenvatting

Dit rapport beschrijft een kwantitatieve verkenning van verschillende post-Kyoto regimes voor lastenverdeling in het internationale klimaatbeleid, die in overeenstemming zijn met de EU lange termijn klimaatdoelstelling de wereldwijde gemiddelde temperatuurstijging te beperken tot beneden de 2 °C niveau boven het preïndustriële niveau. Dit uitgangspunt is gebruikt voor de constructie van twee mondiale emissieprofielen voor broeikasgassen die resulteren in een stabilisatie van de CO_2 equivalente concentratie op een niveau van respectievelijk ongeveer 550 en 650 ppmv (S550e en S650e profielen), en een stabilisatie van de CO_2 concentratie op een niveau van ongeveer 450 en 550 ppmv (S450c en S550c profielen). De bij deze twee profielen verwachte mondiaal gemiddelde temperatuurstijging hangt af van de veronderstelde de klimaatgevoeligheid, dat wil zeggen de wereld gemiddelde evenwichtstemperatuurstijging als gevolg van een verdubbeling van de CO_2 concentratie. Deze wordt door het IPCC geschat op 1,5 – 4,5ºC, met als centrale schatting 2,5 ºC. Het S550e profiel resulteert in een maximale temperatuurstijging van onder de 2 ºC voor een lage tot centrale schatting van de klimaatgevoeligheid. De temperatuurstijging van het S650e profiel blijft alleen onder dit niveau voor een lage waarde van de klimaatgevoeligheid. Dit betekent dat het onwaarschijnlijk is dat bij dit profiel de EU klimaatdoelstelling wordt gehaald.

Op de korte termijn (tot 2012) veronderstellen de profielen de uitvoering door de Annex I landen van de Kyoto doelstellingen, een optimalisatie (= beperking) van het aanbod van overtollige emissieruimte (‘hot air’) door de voormalige Sovjet Unie en Oost Europa, en uitvoering van de in het Bush Plan voorgestelde emissie-intensiteitsverbetering (-18% tussen 2002 en 2012) in de Verenigde Staten. Voor de post-Kyoto periode zijn vijf verschillende benaderingen voor internationale lastenverdeling geanalyseerd: 1. het Braziliaans voorstel, met een differentiatie van emissiereductiedoelstellingen op basis wat de bijdrage van landen aan de gerealiseerde mondiale temperatuurstijging. 2. ‘Multi-Stage’ (MS) (toenemende participatie), met een geleidelijke toename van het aantal landen en hun inspanningsniveau op basis van regels en criteria voor zowel deelname als bijdrage; 3. Per Capita Convergentie (PCC) of ‘Contraction & Convergence’, met een directe deelname vanalle landen aan een emissierechtenregime, waarbij de toegestane hoofdelijke emissieruimte in de tijd convergeert van het bestaande naar een gelijk niveau; 4. ‘Preference Score’ (PS) (preferentie score), waarbij alle partijen direct deel nemen aan een allocatie van emissieruimte op basis van een naar bevolkingsaantallen gewogen voorkeur voor een verdeling naar aandeel in emissies of wereldbevolking. 5. ‘Jacoby regel’, een benadering waarbij zowel de drempel voor deelname als de lastenverdeling is gebaseerd op inkomensniveaus. Voor de kwantitatieve analyse is gebruik gemaakt van het FAIR 2.0 model (Framework to Assess International Regimes for differentiation of commitments). In de berekeningen wordt uitgegaan van de gemeenschappelijke POLES-IMAGE baseline scenario en de twee CO_2 emissie profielen.

De kwantitatieve analyse laat zien dat op de korte termijn (2025) stabilisatie van de CO_2 concentratie op 450 ppmv betekent dat de emissieruimte van de industrielanden (Annex I) ten opzicht van 1990 met 20-60% afneemt, afhankelijk van het gekozen lastenverdelingsregime. Voor Europa zijn de reducties 40-60%. In 2050, liggen de reducties voor de Annex I regio’s in de orde van 70-100%, met uitzondering van het Braziliaanse voorstel. Het Braziliaanse voorstel leidt voor de meeste Annex I regio’s tot reducties van meer dan 100%. Tegelijkertijd is snelle deelname (binnen 20-40 jaar) van met name grote niet Annex I landen, zoals China en India aan wereldwijde beheersing van broeikasgassen noodzakelijk. Dit impliceert dat niet-Annex I landen al zullen moeten

deelnemen bij een veel lager hoofdelijk inkomen dan de Annex I landen (minder dan 50% van het gemiddelde Annex I inkomen). Stabilisatie van de CO_2 concentraties op 550 ppmv vereist veel minder vergaande emissiereducties voor Annex I en een latere deelname van de niet-Annex I landen dan stabilisatie op 450 ppmv. Daarnaast is de range van emissie reducties aanzienlijk groter, variërend van een groei van 30% tot een reductie van 50% t.o.v. de 1990-nviveau's in 2025, en 15-70% reductie in 2050. De emissiereducties worden derhalve ook gevoeliger voor de keuze van de lastenverdelingsregel. Voor dit S550c profiel kunnen de niet-Annex I regio's ook later meedoen aan de emissiereducties, en hun reducties zijn aanzienlijk minder. Voor de minst ontwikkelde niet-Annex I landen gelden slechts geringe reductie-inspanningen, terwijl de rijkere niet-Annex I landen aanzienlijk moeten bijdragen in de emissiereducties. Hun inspanningen nemen een gemiddelde positie in tussen die van de minst ontwikkelde ontwikkelingslanden en de Annex I landen.

Voor benaderingen die een inkomen-gerelateerde deelnamedrempel hanteren, geldt dat het gekozen verdelingscriterium voor emissiereducties (bv. evenredig met hoofdelijke emissies) op de korte termijn (2025) alleen maar de inspanningen van de Annex I beïnvloedt, omdat de meeste niet-Annex I landen (nog) niet deelnemen. De emissiereducties voor de regio's Oost-Europa en de voormalige Sovjet-Unie zijn sterk afhankelijk van de gekozen lastenverdelingsregel door hun hoge emissie-intensiteiten en emissies per hoofd. Voor alle Annex I regio's geldt dat op de korte termijn het Preference Score regime het minst aantrekkelijk is. Op de lange termijn verschuift dit naar het Braziliaans voorstel, omdat dit zelfs tot negatieve emissieruimte voor de Annex I regio's leidt, met name voor Europa en Japan. Voor de meer ontwikkelde niet-Annex I regio's geldt dat de PCC en PS regimes minder aantrekkelijk zijn dan het Multi-Stage regime met een inkomensdrempel voor deelname. Op de lange termijn worden de verschillen tussen de benaderingen klein. Voor de minst ontwikkelde regio's lijkt op de korte termijn deelname in een PS en PCC regime aantrekkelijker dan een regime van toenemende participatie, omdat deze regio's dan meer emissieruimte zouden krijgen dan in de baseline emissies. Daarentegen geldt op de lange termijn voor het meer stringente profiel S450c de omgekeerde situatie. De relatieve aantrekkelijkheid van een regime voor verschillende regio's kan derhalve veranderen in de tijd, en hangt af van de gekozen deelname- en lastenverdelingsregel, alsmede de concentratiedoelstelling.

Naast de kwantitatieve analyse is op basis van een multi-criteria analyse ook een kwalitatieve beoordeling gemaakt van de sterke en zwakke kanten van de verschillende regime benaderingen. Hierbij wordt een onderscheid gemaakt tussen verschillende soorten criteria: milieu criteria, politieke criteria, economische criteria, institutioneel-technische criteria en algemene beleidscriteria. Uit deze evaluatie komt naar voren dat de Multi-Stage benadering het beste voldoet aan de verschillende soorten criteria. Echter, er zijn ook mogelijkheden om de score van de andere benaderingen te verbeteren door middel van aanpassingen in het ontwerp.

1 Introduction

1.1 Background

In 1997, the Kyoto Protocol (KP) to the United Nations Framework Convention on Climate Change (UNFCCC) was agreed in Kyoto, Japan (UNFCCC, 1997a). It constituted the first international treaty with legally binding quantified commitments to limit greenhouse gas emissions. Upon entry into force of the Kyoto Protocol, the Industrialised Countries, included in Annex I, committed themselves to reducing their collective emissions of six key greenhouse gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)) by at least 5.2% with respect to their base-year levels (1990) in the first Commitment Period (CP) (2008 to 2012).

Although the KP is an important milestone in international climate policy making, it represents only a minor first step in controlling global emissions of greenhouse gases. Implementation of the KP will only result in a slowdown of the global increase in greenhouse gas emissions. This reality became even clearer after the United States withdrew from the KP in early 2001, later followed by Australia.

A stabilisation of the concentrations of greenhouse gases (GHGs) in the atmosphere, the objective of the UNFCCC (UNFCCC, 1992), will require substantial reductions of global GHG emissions in the order of over 60% of 1990 levels (IPCC, 2001c). Such emissions reductions are not possible without the participation of developing countries in future GHG emission control. The share of developing countries in global greenhouse gas emissions was about 30% in 1990, but this is projected to exceed that of the industrialised countries in the coming decades (Nakicenovic et al., 2000). The timing and level of the emission control needed by developing countries will depend on the targeted level of stabilisation of GHG concentrations. In the case of stabilisation levels below a doubling of pre-industrial CO_2 concentrations (approximately 550 ppmv), it is crucial for developing countries (non-Annex I Parties) to be already be involved in limiting global greenhouse gas emissions in the next few decades after to the first commitment period under the KP. This has raised important questions on what future levels of commitment from both Annex I and non-Annex I countries would be needed and what would constitute a fair differentiation of commitments among countries. According to the KP, the review of future commitments for Annex I Parties is be initiated by 2005 (UNFCCC, 1997a).

1.2 The EU project on 'Greenhouse Gas Reduction Pathways in the UNFCCC Post-Kyoto process up to 2025'

This report presents the results of the RIVM contribution of the EU project, 'Greenhouse Gas Reduction Pathways in the UNFCCC Post-Kyoto process up to 2025'[1]. This project was set up to explore the implications of options for a global differentiation of future climate commitments with a view to meeting the EU climate target of limiting global average temperature change to less than 2 °C compared to pre-industrial levels. This should help in defining global and regional greenhouse gas emission targets in the UNFCCC post-Kyoto process up to 2025. The project was directed by CNRS-IEPE (Institute de l'Economie et de

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Politique de l'Energie, University of Grenoble, France)[2], with contributions from ICCS-NTUA (Greece), CES-KUL (Belgium), and RIVM (The Netherlands). The first phase of the project explored a set of proposals for differentiating future climate change mitigation efforts. In the second phase of the project a more confined set of options was subjected to a comprehensive analysis of their technical and economic implications.

This report is based on RIVM's contribution to the first phase of this project (February 2002-July 2002), extended with additional information on criteria for evaluating options for future climate regimes. In co-operation with the IEPE the RIVM explored a set of international climate regimes for the differentiation of future commitments (as described in section 1.4). This was done using a common baseline emission scenario, Common POLES-IMAGE (CPI), named after the models used, and global emission profiles for the stabilisation of atmospheric GHG concentrations. The CPI baseline scenario was developed with two global energy models: the POLES model (IEPE) and the IMAGE/TIMER model (RIVM)). The global GHG emission profiles were developed with the IMAGE model (RIVM). Finally, IEPE and RIVM both used dedicated modelling tools, i.e. the ASPEN model (Criqui et al., 1999) and FAIR 2.0 model (den Elzen, 2002) to explore the implications of the various proposals for the differentiation of future commitments. This report presents the results of the analysis using the FAIR 2.0 model as part of the common exercise.

1.3 Global emission constraints and reference scenario assumptions

In 1996 the EU Council adopted as its long-term objective of the European Union climate policy to prevent global mean temperature increasing by more than 2°C over pre-industrial levels. In order to explore the implications of this EU long-term climate target, RIVM developed two alternative greenhouse gas emission profiles (Eickhout et al., 2003). These emission profiles result in a stabilisation of CO_2 equivalent concentration at 550 and 650 ppmv, respectively, with corresponding levels of stabilisation of atmospheric CO_2 concentrations of 450 and 550 ppmv. For the short term (up to 2010) the profiles take account of the Annex I Kyoto Protocol targets, implementation of the proposed greenhouse gas intensity target for the USA, and an optimal level of banking of surplus emission allowances (hot air) by the Former Soviet Union and Eastern Europe. These assumptions are important in defining the initial situation for the analysis (i.e. the regional emission levels by 2010) and the same for all cases analysed. The analysis itself focuses on the emission allowances for the post-Kyoto period (after the middle of the first commitment period 2010) up to 2050. A similar baseline scenario was assumed for this period. The main features of this scenario are provided in Chapter 3.

1.4 Approaches for differentiation of commitments explored

In our study we have evaluated the following five proposals for differentiation of commitments:

1. Brazilian Proposal (BP)
During the negotiations on the Kyoto Protocol, Brazil made a proposal to allocate the emissions reductions of Annex I Parties based on the relative effect of a country's historical

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2 Since January 2003, IEPE has moved to the department of Energy and Environmental Policy (Département Energie et Politiques de l'Environnement, EPE) as part of the new laboratory of Production Economy and International Integration (Laboratoire d'Economie de la Production et de l'Intégration Internationale (LEPII) of the University of Grenoble.

emissions on global temperature increase (UNFCCC, 1997b). The scientific and methodological aspects of the Brazilian Proposal are still under review by the Subsidiary Body for Scientific and Technical Advise (SBSTA) of the UNFCCC. Lately it has also been subject of the UNFCCC project 'Assessment of Contributions to Climate Change' (ACCC) (UNFCCC, 2002a). In our study, the BP approach is applied on a global level, combined with a threshold for participation for the non-Annex I regions (den Elzen et al., 1999).

2. Multi-Stage approach (MS)
The Multi-Stage approach consists of a system to divide countries into groups with different levels of responsibility or types of commitments (stages). The approach results over time in a gradual increase in the number of countries involved and their level of commitment according to participation and differentiation rules on the basis of criteria such as per capita income or per capita emission. The approach was first developed by Gupta (1998; 2001) and later elaborated into a quantitative scheme by den Elzen et al. (1999) and Berk and den Elzen (2001).

3. Per Capita Convergence (PCC)
The Per Capita Convergence (PCC) or 'Contraction & Convergence' approach defines emission permits on the basis of a 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 equal per capita levels over time (Meyer, 2000).

4. Preference Score approach (PS)
This approach is based on a voting procedure that combines preferences for a distribution of emission rights according to emission levels (grandfathering) or population levels (a per capita allocation). A 'Preference Score Share' is calculated for each country by adding up the relative emission shares of either options weighted by the share of world population preferring either the first or second approach (basically Annex I countries versus non-Annex I countries) (Müller, 1999).

5. Jacoby Rule approach (JR)
The Jacoby rule approach consists of a system for: (1) progressively integrating non-Annex I countries into a system of global emissions reduction and (2) defining subsequent levels of reduction commitments for meeting long-term climate targets, which will basically depend on the GDP per capita levels of countries (Jacoby et al., 1999).

1.5 Organisation of the report

The report is organised into 11 chapters. Chapter 2 aims at positioning the various emission allocation proposals explored by providing an overview of equity principles and other dimensions of possible regimes for the differentiation of future commitments. Chapter 3 describes the baseline emission scenario and two greenhouse gas emission profiles resulting in a stabilisation of CO_2 equivalent concentration at 550 and 650 ppmv, as well as the corresponding CO_2 emission profiles resulting in a stabilisation of CO_2 concentration at 450 and 550 ppmv. In Chapter 4 to 8 the CO_2 emission profiles are used as global emission constraints in the analysing the implications of the various approaches for differentiating future commitments, respectively the Brazilian Proposal (Chapter 4), the Multi-Stage approach (Chapter 6), the Per Capita Convergence Approach (Chapter 6), the Preference Score approach (Chapter 7), and the Jacoby Rule approach (Chapter 8). The decision-support model, FAIR 2.0 (Framework to Assess International Regimes for differentiation of future commitments) (den Elzen and Lucas, 2003), is used as framework for the emission allocation analysis. The analyses are limited to energy- and industry-related CO_2 emissions only. In future analyses, we envisage basing the analysis on a multi-gas approach and assessing mitigation costs using a so-called marginal abatement cost curves (MACs) approach. Chapter 9 compares the results of the various approaches, as well as the outcomes for the two different levels of CO_2 concentration stabilisation, 450 and 550 ppmv. After this quantitative assessment, we will turn to a more qualitative evaluation of the approaches in Chapter 10 on the basis of a set of various criteria, e.g. environmental, economic and political. Finally, we will combine the results from the model-based analysis with those of the multi-criteria analysis to discuss the major strengths and weakness of the various approaches. The main conclusions of the study are summarised in Chapter 11.

Box 1. The FAIR 2.0 model

The FAIR 2.0 model (Framework to Assess International Regimes for differentiation of future commitments) is a model-based decision support tool designed to quantitatively explore a range of alternative climate regimes for international differentiation of post-Kyoto commitments and to link these to targets for global climate protection (den Elzen, 2002; den Elzen et al., 2001; den Elzen and Lucas, 2003). The FAIR 2.0 model aims at (i) evaluation of the environmental effectiveness and economic costs of the Kyoto Protocol and post-Kyoto climate regimes of differentiating future commitments and (ii) support of the dialogue between scientists, NGOs and policy-makers. The FAIR 2.0 is an interactive simulation tool with a graphic interface allowing for interactive viewing and changing model input and output.

Model structure of FAIR 2.0
The FAIR 2.0 model now represents an integration of the following three models:
1. Climate model for constructing and evaluating the climate impacts of global emission profiles and calculating the regional contributions to climate change.
2. Emissions-allocation model for exploring and evaluating emission allowances for climate regimes for differentiation of future commitments.
3. Mitigation costs & emissions trade model for calculating mitigation costs, permit price and emissions reductions after emission trading; calculating buyers and sellers on the market and distributing the emissions reduction over different regions, sectors and gases following a least-cost approach.

Policy applications of FAIR 2.0
FAIR 2.0 has been used in several policy-supporting exercises such as the evaluation of the Brazilian Proposal as well as other climate regimes for future commitments for the Dutch Ministry of the Environment (e.g. den Elzen et al. (1999); den Elzen and Schaeffer (2002)) and in the framework of the UNFCCC project entitled, ‘Assessment of Contributions to Climate Change’ (ACCC) (UNFCCC, 2002a), as described in den Elzen et al. (2002)). It has also been applied to the evaluation of the Kyoto Protocol under the Bonn and Marrakech agreements for the Dutch Ministry of the Environment, as described in den Elzen and de Moor (2001a; 2001b; 2002a; 2002b), and recently updated by also incorporating the non-CO_2 GHG in the cost calculations (Lucas, 2003). It is used interactively in the context of the COOL project, an international science-policy dialogue between international scientists, policy-makers and NGOs on the implications of long-term climate targets for short to medium-term climate policy making (Berk et al., 2002).

A more detailed description of the FAIR 2.0 model is given in Appendix I.

2 Options for differentiation of future commitments

2.1 Introduction

This aim of this chapter is to provide an analytical framework for understanding the principle differences between the various regime approaches presented in Chapter 1. A key element of any proposal for differentiation of future commitments will be equity or fairness. However, there are also other relevant dimensions of regime that need proper attention in the discussion on possible regimes for differentiation of future commitments.

While this report focuses on equity aspects of emission mitigation, it should be noted that equity also concerns the distribution of costs for adaptation to and impacts of climate change. IPCC (2001a) has indicated that particularly developing countries will be damaged by climate change because they are more vulnerable. Climate impacts and adaptation costs will play a major role in discussions on the ‘adequacy of commitments’ and thus on the (overall) stringency of reduction targets, as well as on a fair differentiation of mitigation efforts. In developing our analytical framework we will start by overviewing equity principles found in the literature and the UNFCCC that are related to the distribution of greenhouse gas emissions reductions. Next, we will discuss a number of other regime dimensions and will end with an evaluation of the regime approaches along the various dimensions.

2.2 Principles of distributive fairness

There is no common accepted definition of equity. Equity principles refer to more general notions or concepts of distributive justice or fairness. Many different categorisations of equity principles can be found in the literature (Banuri et al., 1996; Rose, 1998; Ringius et al., 1998). Often quoted equity principles in the climate change context are:

- *egalitarian:* all individuals have equal rights in their use of the atmosphere;
- *sovereignty / acquired rights:* all countries have equal rights in the use of the atmosphere; current emissions constitute a status quo right;
- *horizontal:* countries with similar (economic) conditions should have similar emissions reduction commitments / costs;
- *vertical/capability:* the greater the capacity to act or ability to pay, the greater the share in the mitigation / economic burden;
- *responsibility/polluter pays:* the greater the contribution to the problem, the greater the share in the mitigation / economic burden;
- *basic needs:* individuals have equal rights in fulfilling basic (development) needs; basic needs take priority (related principles: priority and no-harm);
- *Rawlsian:* the ‘disadvantaged’ should benefit from the distribution of costs or benefits.

These general equity principles need to be distinguished from specific rules or formulas for burden-sharing or emission allocation, and from equity criteria or indicators (Ringius et al., 1998; Ringius et al., 2002; Rose, 1992). Rules for burden-sharing or emissions allocation specify how the equity principle can be interpreted and applied in the context of greenhouse gas emission control. Equity criteria or indicators further specify how rules for burden-sharing or emissions allocation are to be operationalised (e.g. what data is to be used). Ringius et al. (1998) note that, in practice, proposals for differentiation of commitments often use formulas that relate to different equity principles and multiple criteria relating to both economic and environmental dimensions of climate change regimes. Moreover, the selection of indicators can have a large influence on the actual implications of the application of an equity principle (as illustrated below in Chapter 4 in the case of responsibility).

Rose (1992) and Rose et al. (1998) have indicated a distinction between three types of alternative equity rules for climate regimes:

- *Allocation-based criteria,* defining equitable differentiation of commitments in terms of criteria for the distribution of emission allowances or the allocation of emission burdens.
- *Outcome-based criteria,* defining equitable differentiation of commitments in terms of outcomes, in particular, the distribution of economic effects, and
- *Process-based criteria,* defining equitable differentiation of commitments in terms of the process leading to distribution of emission burdens.

This distinction is important because some equity principles – notably capacity - can be interpreted in both an allocation-based and an outcome-based way, which may result in quite different results. Moreover, the distinction is important, as almost all approaches explored here are allocation-based. A disadvantage of outcome-based approaches is that they are dependent on complex economic models, the outcomes of which are usually not transparent to policy-makers. On the other hand, the (perceived) costs and economic impacts of options for differentiation of future commitments will have an important impact on the evaluation of policy options. Process-based criteria are generally less suitable for ex ante evaluation because their outcomes are less predictable. One of the proposals evaluated here, the Preference Score approach, is, in fact, process-based. However, this proposal has here been transformed into an allocation-based approach by assuming rational behaviour.

2.3 The UNFCCC and equitable emissions reduction efforts

The most explicit statement in the UNFCCC about burden differentiation can be found in Article 3.1 below:

'The Parties should protect the climate system for the benefit of present and future generations, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities,…' (Article 3.1) (UNFCCC, 1992).

This article confirms the relevance of the principles of responsibility and capability, and of intergenerational equity, but leaves open what needs to be considered equitable. The UNFCCC includes other articles that contain important elements for further defining conditions for an equitable burden differentiation. These conditions relate to the outcomes of any differentiation of mitigation efforts, and are thus outcome-based in nature. Article 3.2 states that:

'The specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration'. (Article 3.2) (UNFCCC, 1992).

This article seems to imply that whatever the (principles for) distribution of the burden in mitigating climate change, the outcome should meet the condition of proportionality.

Another important condition for the differentiation of commitments can be found in Article 2 on the objective of the Convention. This states that the level of stabilisation of the GHG concentrations in the atmosphere should (to avoid dangerous interference with the climate system) '(…) enable economic development to proceed in a sustainable manner (…)'. This article relates to both the acceptable levels of impacts resulting from the disturbance of the climate system and to the costs of mitigating climate change. Neither impacts nor mitigation costs should impair sustainable (economic) development. This condition seems to relate particularly to developing countries, as in the UNFCCC preamble, where it is affirmed that:

'(…) responses to climate change should be co-ordinated with social and economic development with a view to avoiding adverse impacts on the latter, taking into full account the legitimate priority needs of developing countries for the achievement of sustained economic growth and eradication of poverty (…)'.

With respect to the differentiation of mitigation efforts, the UNFCCC thus implicitly seems to recognise both the 'basic needs' principle and the 'no-harm' principle: i.e. the distribution of mitigation efforts should not harm the opportunities for socio-economic development for the least developed countries to meet their peoples' basic needs. These principles imply that mitigation regimes should either exclude the least developed countries from participation in the burden-sharing (by introducing some threshold for participation) or allocate emission allowances in such a way that their development opportunities are not affected. One can argue this to be a minimum condition because it does not account for possible negative impacts of climate change that hamper economic development and the fulfilment of basic needs.[3]

Therefore the UNFCCC explicitly supports the principles of responsibility and capability, and implicitly supports the basic need principle. In addition, it is clear that no distribution of commitments or of the measures taken to implement them should result in abnormal and disproportional burdening of some countries.

2.4 Characterisation of the approaches explored

Ringius et al. (1998; 2002) have tried to indicate which of the various equity principles for distributive fairness found in the literature are the most politically salient; in other words, need to be accounted for in proposals for burden differentiation in order to make these widely acceptable in future international climate negotiations. On the basis of both literature and the practice of international environmental negotiations, Ringius et al. conclude that the three principles below stand out as being the most relevant elements for a widely accepted approach to burden differentiation in future international climate negotiations:

- *Responsibility*: mitigation efforts should be distributed in proportion to a country's share of responsibility for causing the problem;
- *Capability*: mitigation efforts should be distributed in proportion to country's ability to pay, as well as to their mitigation opportunities;
- *Need*: all individuals have equal rights to pollution permits, in which securing basic human rights is the minimal requirement; this includes the right to a decent standard of living, i.e. respect for individual (equal) rights to develop.

This simplified typology comes close to what has been said about an equitable distribution of mitigation efforts in the UNFCCC, although one or two important comments need to be made here.

The first comment relates to the rather ambiguous character of the definition of the 'need principle' given by Ringius et al. (2002). This seems not only to refer to the basic needs

[3] The application of the no-harm principle on both mitigation and impacts is likely to result in the need for substantial compensation.

equity principle, but also to the egalitarian equity principle. However, these principles are fundamentally different. The egalitarian equity principle is not based on the concept of 'need' but on the concept of 'rights': all humans have equal user rights with respect to the global atmosphere, irrespective of their needs. Such rights are inalienable and independent of actual needs. As indicated by Ringius et al. (2002), the basic need principle is founded on the pillar of basic human rights, including the right to development. This right provide the grounds for exempting countries from sharing in the global GHG emission control (or for providing compensation for negative effects) but not for allocating them emission rights irrespective of their actual needs, as in the case of the egalitarian equity principle. This is not to say that the egalitarian equity principle does not have relevance in the climate negotiations. In fact, it has been referred to in many proposals, such as the Contraction and Convergence approach and includes those of the Parties to the UNFCCC (Depledge, 2000; Ringius et al., 2002). The point here is that the egalitarian equity principle is different from the (basic) need principle and also seems to have a weaker legal claim than the basic need principle, in particular, in consideration of the UNFCCC wording.

The second comment relates to the Ringius et al. (2002) exclusion of the principle of sovereignty and acquired rights. The principle of sovereignty is a basic principle in international relations, stating that all states are equal and have an exclusive right to govern their territory. From this principle it follows that states (1) have equal obligations, and (2) are free to decide about the use of their natural resources. In international environmental negotiations, this principle is often used to claim status quo rights and rights to equal obligations (e.g. flat rate reductions), which seems to be the default option if no agreement on differentiation is reached. The sovereignty principle is explicitly reaffirmed in the preamble of the UNFCCC.

The principle of acquired rights is a broader concept with a much more general foundation in national and common law, and goes beyond international affairs. This acquired rights principle is based on the priority principle: he /she who comes first can claim property rights. This concept has been applied to the occupation of land, exploration of natural resources (e.g. fishery rights) and use of technological inventions (intellectual property rights e.g. patents). It is thus not necessary to resort to the sovereignty principle in international law to legitimate a claim of historical rights or entitlements.

According to Ringius et al. (2002), the sovereignty principle no longer has the same leverage as the three above-mentioned principles of responsibility, capability and need, particularly when the principles are conflicting. They acknowledge that the concept of acquired rights is well established, but note that it is subject to the legitimacy of behaviour. They argue that historical emissions of GHG are unlikely to provide a legitimate ground for claiming the right to continue polluting. It is true that the legitimacy of the sovereignty principle has being eroded, particularly in international environmental law. According to international environmental law, states should prevent transboundary damage resulting from activities on their territory (Ringius et al., 2002). The sovereignty principle, therefore, cannot be used to legitimise unlimited GHG emissions when it is known that these are likely to be harmful to other states.
At the same time, it can be argued that countries previously did not know about the possible negative impacts of large-scale GHG emissions and therefore cannot be held legally responsible for their past behaviour. Moreover, it can be argued that they have become economically and socially dependent on the use of fossil fuels, and that a strong reduction would result in an abnormal and disproportional burden, as referred to in the UNFCCC. The claim of status quo or acquired rights, and related proposals for a flat-rate reduction or the grandfathering of GHG emission permits, thus still seem to carry some weight and cannot be

easily dismissed (Müller, 1999). The relevance of acquired rights is also illustrated by some of the proposals evaluated in this report.

We want to emphasise that, in contrast to Ringius et al. (2002), our aim here is not to identify the most relevant principles for designing burden-sharing approaches, but to develop a analytical framework to aid the understanding of the various approaches explored.[4] For the purpose of characterising the various allocation-based regime proposals, we therefore propose a revision of the scheme developed by Ringius et al. (2002). This scheme includes the egalitarian equity principle instead of the need principle, and also the contrasting (libertarian) acquired rights/sovereignty principles. The basic needs/no-harm principles are included here as a special expression of the capability principle: the Parties least capable should be exempted from the duty to share in the emissions reduction effort to secure their basic needs.

The four principles – responsibility, capability, sovereignty and egalitarian - can thus be used to create a square, embracing principles reflected in the UNFCCC and other salient principles. These four principles can be further ordered as being either rights- or duty-based (Figure 2.1): responsibility and capability resulting in a duty to contribute to mitigation, with the egalitarian and sovereignty principles establishing the right to emit. This scheme may, furthermore, be used to characterise the regime proposals explored here in the report.

The PCC and PS approaches are both *rights-based,* founded on a combination of both the egalitarian and sovereignty principles, while leaving aside the principle of responsibility. Here, the PS approach is generally closer to the egalitarian principle than PCC, since the change in relative weight of emissions (sovereignty) versus population (egalitarian) in the distribution of emission space is normally more rapid under PS than under PCC because of the preference voting based on population numbers[5]. The other approaches are *duty-based*, with the Brazilian Proposal and Jacoby rule being clearly oriented to the responsibility and capability principles, respectively. The Multi-Stage approach is based on a combination of the responsibility and capability principles, but may also include elements related to the egalitarian principle, e.g. by using per capita emissions levels as burden-sharing key.

[4] However, on the basis of Ringius at al. (2002) one could, in fact, derive a *hierarchy of equity principles*. In this hierarchy, the basic need principle would come first, as it exempts one from - not even proportionally - contributing. The capability principle would forego the responsibility principle as one cannot be expected to contribute proportionally to one's responsibility if this constitutes a disproportional or an abnormal burden. Finally, the sovereignty principle comes last as one is not allowed to continue to emit freely if the emission is known to be harmful to others.

[5] In principle, the PCC approach could result in a faster redistribution of emission space towards a per capita distribution than PS if the convergence period chosen were very short e.g. 10 years. However, in most proposals for a PCC approach, the convergence period is usually set at 20-40 years or more.

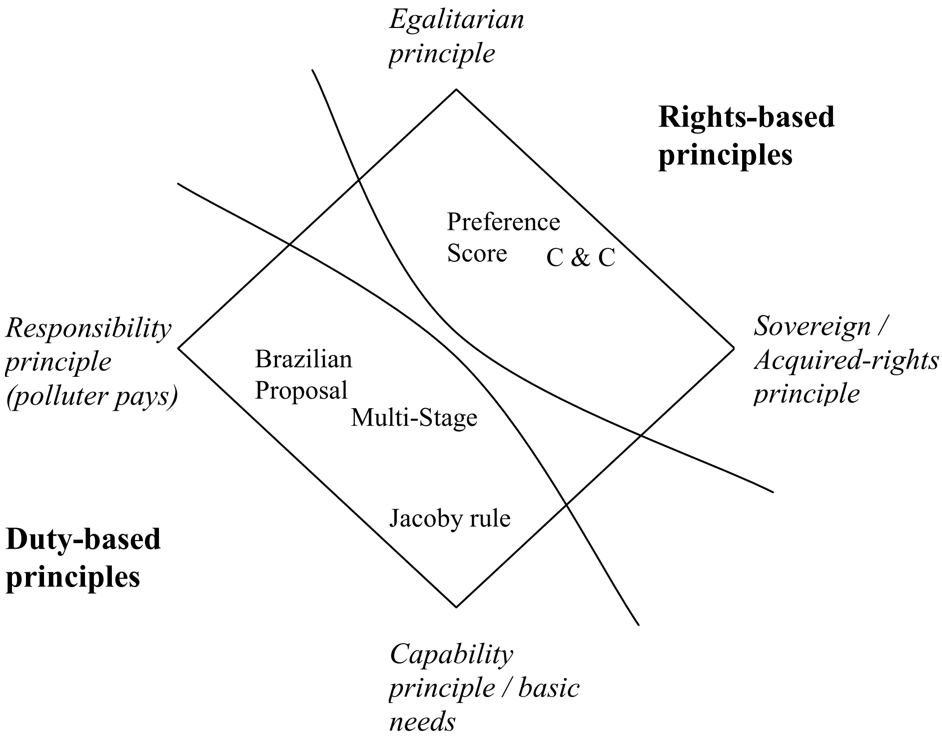


Figure 2.1: Allocation-based equity principles and proposals for differentiation of commitments.

2.5 Other relevant dimensions of regimes for differentiation of commitments

In addition to equity principles, there are a number of other dimensions of possible regimes for the differentiation of future commitments (see also Berk et al., 2002).

Problem definition (burden-sharing or resource-sharing): The climate change problem can be defined either as a pollution problem or as a property-sharing issue. These different approaches have implications for the design of climate regimes. In the first approach, burden-sharing will focus on defining who should reduce or limit their pollution and how much; in the latter approach the focus is on who has what user rights; the reduction of emissions will be in line with the user rights.

Emission limit: One can define the emissions reduction top-down by first defining globally allowed emissions and then applying certain participation and differentiation rules for allocating the overall reduction effort needed, or instead, bottom-up, by allocating emission control efforts among Parties without a predefined overall emissions reduction effort. In the top-down approach, the question of adequacy of commitments is separated from the issue of burden differentiation. In the bottom-up approach, the two are dealt with at the same time.

Participation (thresholds/timing): Another dimension is the degree of participation: who should participate in sharing the burden and when? This issue concerns discussions on both the types of thresholds for participation and the threshold level or the timing. At the same time, there is no need for all Parties to participate in the same way.

Type of commitment: The approaches for differentiation of commitments can either pre-define the allocations of emissions over time or make the allocation dependent on actual developments in levels of economic activity, population or emissions. In ex ante analysis this results in baseline-dependent allowance schemes. The level of dependency on actual developments can vary from low, as in the Per Capita Convergence approach (dependent on population only), to high, as in the Multi-Stage approach (dependent on population, income and emissions).

Form of commitment: The form of the commitment for countries may be equal for all, such as the binding emission target in the Kyoto Protocol, but may also be defined in a differentiated manner (see e.g. Baumert et al., 1999; Claussen et al., 1998; Philibert and Pershing, 2001). Instead of being fixed absolute targets, commitments may be defined as relative or dynamic targets, such as reduction in energy and/or carbon intensity levels, or in terms of policies and measures. There is also the option of non-binding commitments. In addition, the legal nature of the commitment can be either binding or voluntary.[6]

Scope of the commitment: This dimension is related to the question on whether the commitment covers all GHGs and sectors or is limited to particular GHGs or sectors. Particularly for developing countries, new commitments could be limited to particular sectors or GHGs for reasons of verification and monitoring, and because emissions certain sectors are difficult to predict and control (e.g. agriculture). The present commitments under the KP cover all GHGs and sectors but exclude emissions from international aviation and maritime activities.

We can now use all of the above dimensions to describe the main characteristics of the five regimes explored (Table 2.1). The PCC and PS approaches are the only ones based on the global commons paradigm and resource-sharing concept; the other approaches are based on the pollution problem paradigm and burden-sharing concept. All proposals, except for the Jacoby Rule, are based on a top-down approach for defining emission allocations. However, here too, the JR approach will be implemented in a top-down way for reasons of comparability. None of the approaches include limitations in the scope of the commitments (full coverage of GHGs and sectors), although, in practice the intensity targets of the MS approach could be restricted to some gases or sectors. All approaches provide a comprehensive approach in the sense that all country commitments are governed by the regime, but in contrast to the PCC and the PS approaches, the Multi-Stage, Brazilian Proposal and Jacoby Rule approaches include a threshold for taking on quantified commitments. The PCC and PS approaches pre-define the (shares in the) allocation of emissions largely irrespective of future developments with the exception of population growth. In ex ante analysis, emission allocations in the Multi-Stage and the Jacoby rule approaches are most strongly influenced by baseline projections of income and emission levels. The Multi-Stage approach is the only one that incorporates different forms of commitments (e.g. de-carbonisation or intensity targets in addition to fixed emission stabilisation and reduction targets).

[6] Formally, commitments are always voluntary in the sense that countries voluntarily commit themselves to international agreements. However, a country is formally bound to meet its obligations, once ratified. In the case of voluntary commitments there is no formal obligation to achieve a material result (e.g. reduction in emissions).

Table 2.1:Different approaches to international burden differentiation

Dimensions	Brazilian proposal	Multi-Stage	Per Capita Convergen	Preference Score	Jacoby Rule
Equity principles					
• *Responsibility*	X	X			
• *Capability*	(X)	X	(X)		X
• *Egalitarian*		X	X	X	
• *Acquired rights*			X	X	
Problem definition					
• *Pollution problem*	X	X			X
• *Global commons issue*			X	X	
Emissions limit					
• *Top-down*	X	X	X	X	(X)
• *Bottom-up*					X
Participation					
• *Partial*	X	X			X
• *All*			X	X	
Nature of Commitments					
• *Pre-defined*			X	X	
• *Path-dependent*	X	X			X
Form of Commitment					
• *Equal*	X		X	X	X
• *Differentiated*		X			
Scope of the Commitment					
• *Full coverage*	X	X	X	X	X
• *Partial coverage (of sector/GHGs)*		(X)			

X= applicable; (X) = partly applicable

Considering the need for a broadening of the participation of developing country Parties in future emission control, Berk and den Elzen (2001) indicated that the development of the international climate regime could take two different directions:

1. *Incremental regime evolution*, i.e. a gradual expansion of the Annex I group of countries adopting binding quantified emission limitation or reduction objectives under the UNFCCC, or,
2. *Structural regime change*, i.e. the adoption of a regime defining the evolution of emission allowances for all Parties over a longer time period.

The first approach would mean a gradual extension of the present Kyoto Protocol approach to differentiate the obligations of various Parties under the Convention (sometimes referred to as 'graduation'). This could be based on ad-hoc criteria, or on pre-defined rules for both participation and differentiation of commitments. This type of regime we call *'Increasing participation*'. In an increasing participation regime, the number of Parties involved and their level of commitment gradually increase over time. This can be done either in an incremental ad hoc way or according to specified participation and differentiation rules, such as per capita income or per capita emissions. This kind of regime can be based on either one threshold for participation, as in the case of the Brazilian proposal, or the Jacoby Rule approach, or, alternatively, developed into a so-called Multi-Stage approach by extending the number of stages or levels of participation for groups of countries.

The second approach would represent a shift away from the present approach towards a regime that – in absolute or relative terms - predefines commitments for all Parties and their evolution over a long-term period. We could call this type of regime *'full participation*'.

Examples of such approaches are the Per Capita Convergence and the Preference Score approaches.

Of course, other types of structurally different climate regimes can be thought of as well, like a regime based on technology standards, common policies and measures or sector-based approaches, as included in the so-called Triptych approach (Phylipsen et al., 1998). The latter approach was used within the EU to help define its internal differentiation of targets for the KP. Such approaches would be generally bottom-up in character, but could be combined with specific overall emission targets as well (as illustrated in the case of the EU). Such approaches will not be discussed in this report, but have been elaborated elsewhere. For a global application of the Triptych approach see den Elzen (2002) and Groenenberg (2002).

3 Global emission constraints and baseline emission scenario assumptions

3.1 Introduction

In 1996 the EU Council decided that prevention of the global mean temperature increases beyond 2 ºC over pre-industrial levels would be the long-term objective of its climate policy. We used this long-term climate target to develop two alternative greenhouse gas emission profiles that - at least in principle may be consistent with the 2 °C target, given the uncertainty about the sensitivity of the climate system (Eickhout et al., 2003). The emission profiles result in a stabilisation of greenhouse gas concentrations at a level of 550 and 650 ppmv CO_2 equivalents.[7] These profiles can be related to CO_2 emissions leading to stabilisation of atmospheric CO_2 concentrations of 450 and 550 ppmv, respectively. Only the CO_2 profiles will be used in the remainder of the report to analyse the implications of various approaches to differentiation of future commitments. This chapter will provide a concise description of the main assumptions used for constructing these CO_2 stabilisation profiles and the baseline used in this study. The chapter also evaluates the emissions reduction burden resulting from the baseline and the emission profiles. A more detailed description of the baseline emissions scenario, the CO_2-equivalent stabilisation profiles and their climate impacts can be found in (Eickhout et al., 2003).

3.2 Baseline scenario and emission profiles for the 2000 - 2100 period

In co-operation with IEPE, RIVM recently developed a new baseline called the Common POLES-IMAGE (CPI) baseline. This baseline was used to explore the implications of different options for the differentiation of future commitments using both models. The baseline describes the development in the main driving forces (population and economic growth), environmental pressures (energy-related, industrial and land-use emissions) and resulting effects, like temperature increase, for the 1995-2100 period. It is primarily based on the existing POLES reference scenario up to 2030 (see Criqui and Kouvaritakis, 2000) and extended to 2100 by using the IMAGE 2.2 model (IMAGE-team, 2001). The main features of this scenario are described in Textbox 2. For analytical reasons, this scenario does not include any explicit climate policies (the emission profiles that lead to stabilisation of greenhouse gases discussed in the next section take into account both the Annex I Kyoto Protocol targets and the Climate Change Initiative proposed by the Bush administration). The baseline assumptions are of major importance for constructing the global emission profiles and analysing the implications of various approaches for differentiation of future commitments. First of all, the baseline assumptions determine future land use, which, in turn, affects the carbon cycle. This refers specifically to 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 on future regional population levels and per capita income and emission levels are important as they are used to calculate regional emission allowances (such as participation and/or burden-sharing

[7] The 'carbon dioxide equivalent concentration' indicates the total greenhouse gas concentration forcing expressed in terms of the hypothetical carbon dioxide that would lead to the same radiative forcing. Although the concept is used for the same purpose as that of 'carbon dioxide equivalent emissions' (i.e. to bring all greenhouse gases under one denominator), they differ in terms of methodology. More details can be found in Textbox 2.1

criteria). Table 3.1 shows the change in regional population and per capita (PPP) income levels in the CPI baseline. Finally, the baseline assumptions determine the global and regional emissions reduction burden, i.e. the difference between global and regional emission constraints and baseline CO_2 emission levels.

Table 3.1 Main driving forces of the CPI baseline per region

	Population (in mln)			Per Capita Income (in PPP 1995$ per /year)			Per Capita Income (annual growth rates annually)	
	1995	2025	2050	1995	2025	2050	1995-2025	2025-2050
Canada	29	37	41	19,047	30,971	39,023	1.6%	0.9%
USA	267	325	350	26,316	43,835	57,717	1.7%	1.1%
Central America	159	235	273	2550	5556	10,199	2.6%	2.5%
South America	317	455	527	4113	7411	13,152	2.0%	2.3%
North Africa	131	205	251	1203	2461	4974	2.4%	2.9%
Western Africa	282	547	757	306	371	852	0.6%	3.4%
Eastern Africa	172	333	462	221	272	657	0.7%	3.6%
Southern Africa	134	261	361	1186	1443	2844	0.7%	2.8%
Western Europe	384	382	346	21,636	42,224	58,364	2.3%	1.3%
Central Europe	121	117	104	2822	9426	22,638	4.1%	3.6%
Former SU	293	298	273	1747	5323	14,750	3.8%	4.2%
Middle East	219	378	483	3282	6371	12,577	2.2%	2.8%
South Asia	1245	1865	2160	356	1560	4060	5.0%	3.9%
East Asia	1316	1616	1638	1360	8434	19,145	6.3%	3.3%
South-East Asia	482	677	801	1478	4944	12,401	4.1%	3.7%
Oceania	28	40	46	15,469	30,054	43,397	2.2%	1.5%
Japan	125	121	111	41,052	65,270	90,424	1.6%	1.3%
World	5706	7891	8984	4931	9052	14,413	2.0%	1.9%

Table 3.2: Main model results of the CPI baseline per 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	9375	12177	12676	0.48	0.62	0.70	0.73	0.77	0.55
USA	82473	109228	115697	5.39	7.19	7.52	7.04	8.43	7.88
Central America	7559	17019	28895	0.40	0.95	1.61	1.10	1.43	2.09
South America	14204	32872	60037	0.70	1.76	3.30	2.35	3.23	4.29
North Africa	4483	10607	18251	0.26	0.62	1.03	0.40	0.92	1.32
Western Africa	5882	12215	22478	0.11	0.51	0.95	0.81	3.74	5.54
Eastern Africa	3032	5668	11254	0.04	0.15	0.48	0.40	1.32	1.06
Southern Africa	6543	14678	27232	0.33	0.95	1.91	0.73	2.31	2.97
Western Europe	55318	68994	70231	3.34	3.92	4.07	4.33	4.51	4.47
Central Europe	10752	14386	16471	0.77	0.92	1.03	1.03	1.14	0.95
Former SU	37276	51960	57174	2.24	3.15	3.52	3.41	3.92	3.48
Middle East	15065	41306	67132	0.99	2.68	4.14	1.39	3.67	5.72
South Asia	25175	62,628	116495	0.92	3.67	7.26	2.38	5.90	9.61
East Asia	56118	131749	180215	3.56	8.62	11.15	6.12	11.62	13.02
South East Asia	15866	36987	71784	0.62	1.91	4.07	1.47	4.40	6.12
Oceania	4754	7955	9675	0.33	0.51	0.62	0.48	0.66	0.66
Japan	18866	22851	22480	1.14	1.36	1.32	1.36	1.58	1.50
World	372742	653278	908176	21.56	39.53	54.74	35.97	60.87	74.10

*The GHG included here are the 6 Kyoto gases: CO_2, CH_4 $_2O$, SF6, PFCs, HFCs. However, the F gases are excluded from the regional figures as only global estimates have been made. Thus the regional sub-totals do not add up to the world total.

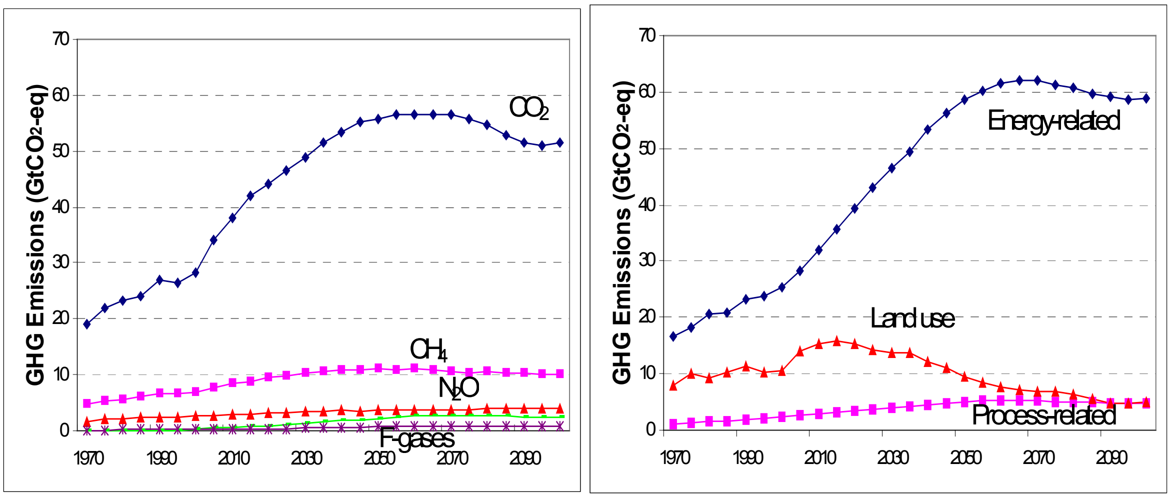


Figure 3.1 Greenhouse gas emission in carbon equivalents according to gas (left) and sector (right) of the CPI baseline (Source: IMAGE 2.2 model (IMAGE team, 2001)).

Box 2. The Common POLES-IMAGE (CPI) baseline scenario

The Common POLES-IMAGE_baseline scenario has been developed by using both the POLES model of IEPE and RIVM's IMAGE 2.2 model on the basis of the existing POLES Reference scenario up to 2030. The baseline scenario describes a world in which globalisation and technology development continue to be an important factor behind economic growth, although not as forcefully as assumed in the IPCC A1b scenario (IMAGE team, 2001; Nakicenovic et al., 2000), for example. Since economic growth rates lie between the IPCC A1b and B2 scenarios in almost all regions, the CPI baseline can therefore be put in the medium category. Since growth is generally more rapid in low-income regions than in high-income regions, the relative gap between the regions decreases (at least, in macro-economic terms). However, for economic growth to occur, regions will need to have reached a sufficient level of institutional development and stability. In the scenario it is assumed that these conditions will not be met in Sub-Saharan Africa in the first 20-30 years– which will result in this region clearly lagging behind. However, in this period the current barriers to economic development are slowly being reduced – and from 2025/2035 onwards the region 'takes off' in terms of its similar development, just as we have seen for Asian countries in the past. In this scenario, the role of 'market forces' increases, as indicated by continued market liberation and reduction of trade barriers, but also by the important role of economic considerations in decision-making processes. Finally, technological development continues at a similar pace as in the last decades – with moderate improvements in all major sectors.

Assumptions on main driving forces: population and economic growth

The population projection of the CPI baseline scenario is based on the UN Medium projection. The population scenario assumes the global population to stabilise at a level of 9.5 billion by 2100. See Table 3.1 for the regional projections.

In the 1995-2025 period, the economic growth rate in the Annex I regions varies between 1.5-2.0%per year. Afterwards, it slows down somewhat to around 1.0-1.2%. Growth rates for Asia, South America and North Africa, and the Middle East, are significantly higher and vary between 2.0% and 4.0%. As previously mentioned, we assume the current political instability and lack of institutional and social capital to limit the scope for economic development in Sub-Saharan Africa in next two decades. After 2025/2035 the region is able to resolve these problems – and finally experiences growth rates similar to those in Asian countries in the 1980s and early 1990s.

Energy use, land use and GHG emissions

The CPI baseline reflects historical developments in GHG emissions, including the slowdown in GHG emission growth at the end of the last century. This was due to the sharp reduction in emissions in the Former Soviet Union and Eastern Europe (in particular, following their economic downfall), and the reductions of the CO_2 emissions in China in the second half of the nineties. Both developments have slowed the growth in global GHG emissions over the last decade, but are considered to be temporary, with future emission again projected to increase substantially. With the projected increase in population and income, primary energy use will also continue to grow in almost all regions. Worldwide, primary energy use increases by about 75% in the 1995-2025 period and by another 40% in the 2025-2050 period – almost all of this growth occurs in non-Annex I regions. Oil continues to be the most important energy carrier up to 2040. After 2040 it is assumed that both natural gas and coal will take over this position, given the relative scarcity of oil, with, in particular, natural gas becoming the dominant energy carrier under assumed environmental considerations. As a result, energy-related CO_2 emissions increase sharply from 21.6 $GtCO_2$ in 1995 to 39.5 $GtCO_2$ in 2025 and 54.7 $GtCO_2$ in 2050 (see Table 3.2 and Figure 3.1) and continue to be the major source of GHG emissions. After 2050, stabilising population levels also slow down further growth of CO_2 emissions. The share of non-Annex I in energy-related CO_2 emissions increases from 37% in 1995 to 45% in 2025, and 66% in 2050.

Using the land-use projections of IMAGE 2.2 (IMAGE team, 2001), total GHG emissions can be assessed (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 particularly in high-income regions, where they can be converted into forestland. As a result, CO_2 emissions from land use increase slightly between 1995 and 2040 but decrease afterwards. Most of the land-use related emissions originate from developing regions, especially due to population growth. Consequently, the share of non-Annex I 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 until 2060, after which they remain more-or-less constant. Finally, industrial emissions, including especially the high-GWP gases and CO_2 emissions from cement production and feedstock increase slowly over the whole century, but remain relatively small compared to other sources.

3.3 Emission profiles for stabilisation of CO_2 concentration at 450 & 550 ppmv

The IMAGE 2.2 model (IMAGE team, 2001) was used to construct emission profiles up to 2100 for stabilising CO_2 concentrations at 450 and 550 ppmv in 2100 and 2150, respectively. These profiles start from the emissions resulting from the CPI baseline projections up to 2010, but also take account of the Annex I Kyoto Protocol targets and the implementation of the proposed GHG intensity target for the USA (-18% between 2002 and 2012) (de Moor et al., 2002; White-House, 2002a; White-House, 2002b). For emission trading, the profiles assume that about 80% of the surplus emission allowances (hot air) by the Former Soviet Union and Eastern Europe are banked on the basis of revenue optimisation in the first commitment period. Non-Annex I countries are assumed to be able to follow their baseline emissions in this period.

In the profiles for stabilising the CO_2 concentration at 450 and 550 ppmv, hereafter referred to as IMAGE S450c and IMAGE S550c, respectively, CO_2 emissions continue to rise in the first decades of the simulation. For stabilising the CO_2 concentration at 450 ppmv, we have assumed the growth of CO_2 emission to shift from an annual 1.95% increase in 2010 to a 2% decrease in 2020. After 2020, emissions will continue to decrease to allow stabilisation of CO_2 concentration. Post-2020 emissions are determined by using IMAGE 2.2. to inversely calculate allowable emission levels resulting from a pre-described CO_2 concentration profile. The CO_2 concentration profile is determined with a method similar to the one described in Enting et al. (1994). For stabilisation of the CO_2 concentration at 550 ppmv, the CO_2, emissions shift from an annual increase of 1.95% in 2010 to a 1.5%

decrease in 2040 For the period after 2040 he emissions are again back calculated to reach a stabilisation level of 550 ppmv in 2150.

The two CO_2 emission profiles are depicted in Figure 3.2. The profile for energy-related and industrial CO_2 emissions are derived from the CO_2 stabilisation profiles by subtracting land-use CO_2 emissions, already determined with the IMAGE 2.2 model. Table 3.3 summarises the characteristics of IMAGE S450c and IMAGE S550c profiles.. Assumptions for non-CO_2 greenhouse gas and sulphur emissions needed to be made to calculate the temperature increase resulting from the profiles. Sulphur emissions, which have a net cooling impact, have been assumed to develop in proportion to CO_2 emissions. This assumption returns modest reductions in SO_2 emissions that can be augmented by explicit air pollution policies (not the scope of this study). Assumptions on the non-CO_2 greenhouse gases are described in more detail in (Eickhout et al., 2003). Textbox 3 contains a description of the consequences of CO_2-equivalent emission profiles for the global-mean temperature increase.

Table 3.3: Main characteristics of the two constructed emission profiles (Source: IMAGE 2.2 model (Eickhout et al., 2003)

Characteristic	IMAGE S450c	IMAGE S550c
CO_2 emissions in 2010 ($GtCO_2$ per year)	37.58	37.58
Annual increase in 2010 (%)	1.95	1.95
Target year for pre-described annual CO_2 decrease	2020	2040
Level of annual CO_2 decrease in the target year (%)	2.0	1.5
Year of stabilisation	2100	2150
Level of CO_2 concentration	450 ppmv	550 ppmv
Sulphur emission levels	Constant CO_2/SO_2 ratio	Constant CO_2/SO_2 ratio

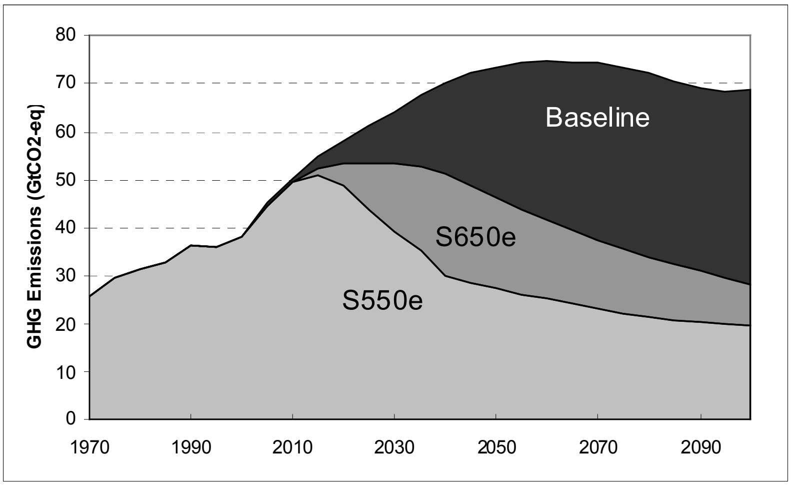


Figure 3.2 Global emission profiles for stabilising CO_2 concentrations at 450 ppmv (IMAGE S450c) and 550 ppmv (IMAGE S550c) (Source: IMAGE 2.2 model (IMAGE team, 2001)).

Box 3. Temperature increase in IMAGE S450c and IMAGE S550c

CO_2-equivalent emission profiles

Assumptions on the non-CO_2 greenhouse gas and sulphur emissions have to be made to assess the global-mean temperature increase resulting from the CO_2 emission profiles. Given the goal of this study, we have only taken the Kyoto gases into account: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). The CO_2 stabilisation profiles at 450 and 550 ppmv are assumed to lead to the stabilisation of CO_2-equivalent concentrations at 550 and 650 ppmv, respectively. CO_2-equivalent concentrations are calculated by summing the contribution of each Kyoto gas to the total radiative forcing (see also Eickhout et al., 2003).

The total amount of greenhouse gas emissions leading to 550 and 650 ppmv CO_2equivalent can also be summed using the Global Warming Potential (GWP) concept. This is a measure of the relative radiative effect of a given substance compared to CO_2 and integrated over a chosen time horizon (IPCC, 2001). Consequently, the GWP of CO_2 is by definition 1.0. We used the GWPs values from the Third Assessment Report with a time horizon of 100 years (IPCC, 2001c). Although there is much scientific criticism on the GWP concept, we decided for practical reasons to use this concept. The criticism is mainly on the choice of time horizon, suggesting that Kyoto gases can be summed over a comparable time axis, which is not the case. For example, CH_4 has an atmospheric lifetime of less than 10 years, whereas F gases can have lifetimes of over 500 years. See also Eickhout et al. (2003).

Global-mean temperature increase

By assuming the emission profile of SO_2 to follow the same ratio as the CO_2 profile, we are able to assess the consequences of the stabilisation profiles for the global mean temperature.[8] Given the, Our calculations show that – in principle – both the IMAGE S450c (equal to 550 ppmv CO_2-equivalent) and IMAGE S550c (equal to 650 ppmv CO_2-equivalent) profiles might meet the long-term climate objective of the EU Council of a maximum increase of 2 ºC since pre-industrial levels. This is due to the large uncertainty in the climate sensitivity. The climate sensitivity is described 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 ºC, with a medium value of 2.5 ºC (IPCC, 2001c). Figure 3.3 depicts the range of the global-mean temperature increase due to the uncertainty in the climate sensitivity of the IMAGE S450c and IMAGE S550c profiles.

'Climate sensitivity' is defined as the temperature increase resulting from a doubling in CO_2 concentrations. The IPCC estimates climate sensitivity to range between 1.5 and 4.5°C, with a median value of 2.5°C. A climate sensitivity close to the median value is much more likely than one near the boundaries of the uncertainty range. For a median climate sensitivity, the S550e profile already results in a 2°C increase by 2100, while the S650e profile exceeds it by about 0.3ºC. By 2100, equilibrium has not yet been reached for either profile , so further warming will still occur. It is estimated that with a median climate sensitivity, global temperature increase will eventually stabilise at 2.3 ºC and 3.0 °C for the S550 e and S650e profiles, respectively.

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 reduction of the cooling effect of SO_2 caused in the short term by CO_2 reductions.
As in Figure 3.3 the S550e profile can be concluded, in principle, to meet, or at least approach, the maximum global temperature increase in the EU target for a median to low climate sensitivity. The S650e profile only does so if the climate sensitivity is at the low end of the range. Therefore this

[8] In reality, assumptions for ozone precursors like CO, NO_X and VOCs need to be made as well, since these gases also indirectly contribute to the temperature increase (ozone is a greenhouse gas). However, we decided not to focus on any of this in the report. In Eickhout et al. (2003) we will pay more attention to this issue.

profile is unlikely to meet the EU target. If the climate sensitivity is high, the EU target will not be met in either profile.

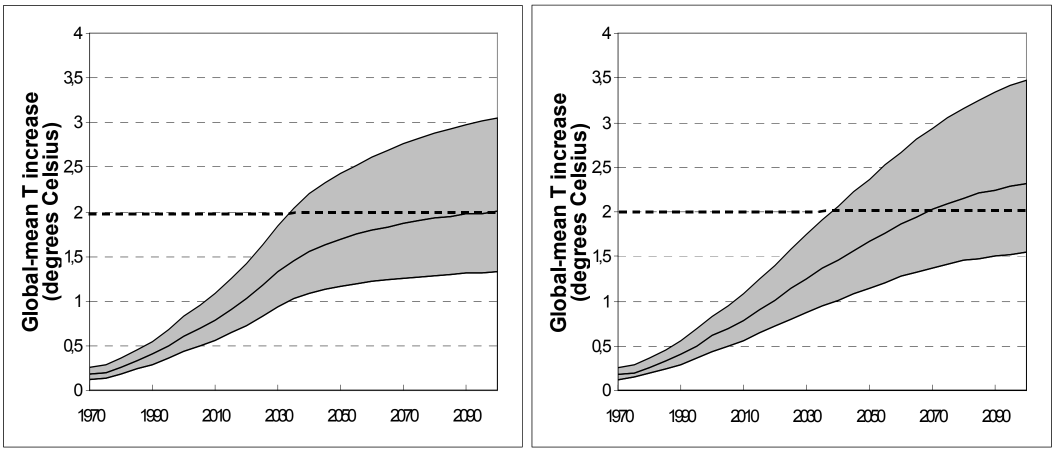


Figure 3.3: Global-mean temperature increase since pre-industrial levels for IMAGE S450c (left panel) and IMAGE S550c (right panel) using different climate sensitivities. The black horizontal line running across each graph displays the result for medium climate sensitivity. IMAGE S450c and IMAGE S550c are similar to stabilisation profiles at 550 ppmv and 650 ppmv CO_2-equivalent, respectively (Eickhout et al., 2003) (Source: IMAGE 2.2 model (IMAGE Team, 2001)).

The IMAGE S450c profile results from the incorporation of the climate policies up to 2010 (including the Kyoto Protocol - without the USA - and the Bush Plan (White-House, 2002a; White-House, 2002b). This profile is, in fact, a more-or-less a delayed response scenario compared to the profiles published earlier by Wigley, Reilly and Edmonds (referred to as the WRE profiles; Wigley et al., (Wigley et al., 1996). A further postponement of emissions reductions is difficult if very steep global emissions reductions (>2% per year) and an overshooting of the targeted concentration stabilisation levels are to be avoided.[9] This can also be illustrated when comparing the characteristics of the IMAGE profiles with the range reported by the IPCC (Table 3.4).

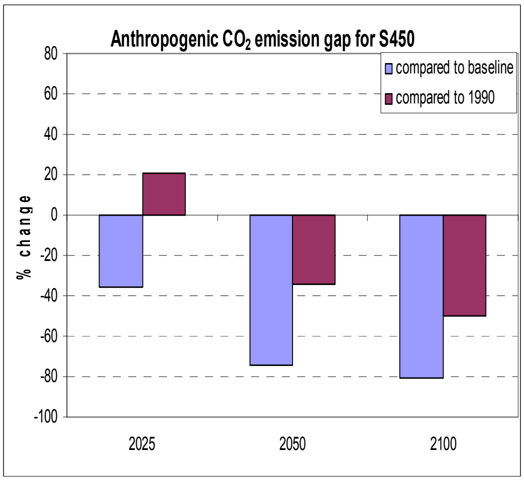
Table 3.4 Characteristics of the IMAGE 2.2 stabilisation profiles compared with those of the WRE profiles calculated with two IPCC models in the Synthesis Report (Eickhout et al., 2003; IPCC, 2001b)

Stabilisation profile	CO_2 emissions ($GtCO_2$ per yr)		Accumulated (net) CO_2 emissions ($GtCO_2$)	Year in which emissions:	
	2050	2100	2001-2100	Peak	Fall below 1990 levels
IMAGE S450c	16.5	8.1	1925	≈2015	2030 - 2035
450-WRE	11.0 - 25.3	3.7 - 13.6	1340-2695	2005 - 2015	<2000 - 2045
IMAGE S550c	34.8	18.3	3190	≈2025-2030	2065 - 2070
550-WRE	23.5 - 46.2	9.9 - 28.2	2165 – 4160	2020 - 2030	2030 - 2100

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

3.4 Emissions reduction effort

The emissions reduction resulting from the two sets of global emission profiles for stabilising the CO_2 concentrations at 450 and 550 ppmv, respectively, are depicted in Figure 3.4. Here, the percentage change is shown in energy- and industry-related CO_2 emission levels allowed under the global emission constraints in comparison with the CPI baseline and 1990 levels for the years 2025, 2050 and 2100. Values apply to energy- and industry-related emissions only; Table 3.4 takes land-use emissions into account as well.



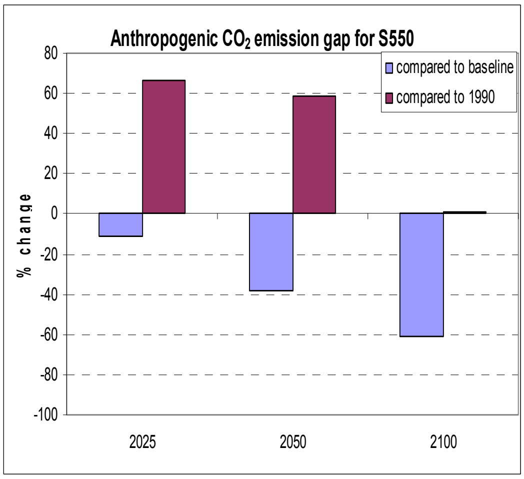


Figure 3.4: Global energy- and industry-related CO_2 emissions reduction efforts for stabilisation of CO_2 at 450 and 550 ppmv (Source: IMAGE 2.2 model (IMAGE team, 2001)).

From Figure 3.4 we can conclude that:

- substantial emissions reductions from the CPI baseline will be needed for both stabilisation at 450 CO_2 and 550 CO_2 concentrations, particularly in the long term.
- with respect to the 450 CO_2 case, global emission levels can, in 2025, still increase to about 20% above 1990 levels; however, this already implies a substantial emissions reduction of 35% compared to baseline levels. The reduction compared to the baseline is smaller (10%) for stabilisation at 550 CO_2 .
- with respect to stabilisation at 450 ppmv in 2050, the energy- and industry-related CO_2 emissions will have to be sharply reduced, not only compared to baseline level (about 75%), but also to 1990 levels (about 35%).
- with respect to stabilisation at 550 ppmv, the energy- and industry-related CO_2 emissions levels may, in contrast, still be 60% above 1990 levels by 2050. However, compared to the baseline global emissions, they need to be reduced by about 35%.
- by the end of the century, both stabilisation profiles for 450 CO_2 and 550 CO_2 concentrations imply that global emissions will be substantially reduced in comparison to CPI (about 80% and 60%,respectively). However, if compared to 1990, a reduction of 50% for stabilisation at 450 CO_2 is implied, with levels more-or-less stabilised at 1990 for the 550 CO_2 case.

Thus it is clear that stabilising CO_2 concentrations at 450 ppmv will require substantially larger and earlier global emissions reductions than stabilising CO_2 equivalent concentrations at 550 ppmv. On the other hand, the S450c profile is much more likely to meet the EU target than the S550c profile.

4 The Brazilian Proposal

4.1 Introduction

During the negotiations of the Kyoto Protocol, the Brazil delegation presented an approach for distributing the burden of emissions reductions among Annex I Parties based on the effect of their cumulative historical emissions (from 1840) on the global-average surface temperature (UNFCCC, 1997a). Although this proposal was initially developed to support discussions on the differentiation of future commitments among Annex I countries, it can also be used as a framework for discussions between Annex I and non-Annex I countries on future participation of all countries in emissions reductions. The Brazilian Proposal was not adopted but did receive support, especially from developing countries. To keep this concept on the agenda, the Third Conference of the Parties (COP-3) decided to ask the Subsidiary Body on Scientific and Technical Advice (SBSTA) of the UNFCCC to further study the methodological and scientific aspects of the proposal.[10]

The first international Expert Meeting was held in Brazil in May 1999, where it was concluded that the scientific and technical basis for putting the BP into operation would be sufficient (UNFCCC, 1999). During the second expert meeting in 2001, organised by the UNFCCC secretariat, the SBSTA encouraged Parties to pursue and support the research effort on the scientific and methodological aspects of the BP (UNFCCC, 2001), and to communicate such activities to the secretariat. In response to the results SBSTA asked the secretariat to:

- continue to co-ordinate the review of this proposal,
- organise the third expert meeting to further review the scientific and methodological • aspects of the proposal by Brazil,
- broaden participation of Parties in reviewing the proposal , and
- build up scientific understanding of this subject before the 17th session of the SBSTA (also known as SBSTA –17).

To this end, the secretariat encouraged research institutions active in the field of climate change research to participate in a co-ordinated modelling exercise (UNFCCC, 2002a). The primary objective of this exercise was to generate new and comparable results that could be discussed at an expert meeting. The results of this UNFCCC project, 'Assessment of Contributions to Climate Change (ACCC)' were discussed at the third expert meeting in September 2002. Details of the exercise can be found in the 'Terms of Reference' (ACCC-TOR) (UNFCCC, 2002a). RIVM was one of the research groups participating in the UNFCCC exercise. Its contribution is described in detailed in den Elzen et al. (2002).
As mentioned in the introduction, the general framework developed was considered promising, but the meeting also identified a range of scientific issues still to be resolved. It was advised to take a period of about two years to resolve the outstanding issues, and prepare a peer-reviewed and scientifically widely supported modelling framework to be presented to the UNFCCC Parties. An extensive scientific review will be included in the preparation. The main findings of the third UNFCCC expert meeting, as described in (UNFCCC, 2002b), were reported to SBSTA at its 17th session held in New Delhi, December 2002. There it was concluded that the scientific and methodological aspects of the proposal should be further explored with a view to improve the robustness of the results, and to provide a better insight into the uncertainty and sensitivity of the results to the different assumptions.

[10] See also the UNFCCC website (http://unfccc.int/issues/ccc.html).

Chapter 4 will include part of RIVM's contribution to the ACCC: specifically, the evaluation of the climate indicators for relative responsibility for climate change caused by greenhouse gas emissions, concentrations of these gases, radiative forcing, global temperature increase and sea-level rise attributable to individual regions. Here we have applied our methodology to the CPI baseline emissions scenarios instead of the IPCC SRES emission scenarios (ACCC). Section 4.2 describes the methodology for calculating the regional contributions to climate change, while in section 4.3, the Brazilian Proposal has been applied as a climate regime for differentiating future commitments on a global scale with an income threshold for participation of the non-Annex I regions.

4.2 Data and models for calculating contribution to climate change

For the calculation of the regional contribution to climate indicators we used the default UNFCCC climate model, as specified in the ACCC-TOR (UNFCCC, 2002a). This model consists of the integrated impulse response functions of the Bern carbon cycle model in Joos et al. (1996; 1999) used in the IPCC TAR. See also (Joos, 2002) and the Hadley climate model, along with a simple one-dimensional atmospheric chemistry model (as used in the IPCC TAR). This model is used to calculate the contributions to concentrations of greenhouse gases, and temperature and sea-level rise attributable to the emissions of the major greenhouse gases CO_2, CH_4 and N_2O in the 17 IMAGE 2.2 regions (den Elzen et al., 2002).

The historical greenhouse gas emissions are based on the CDIAC-ORNL database and EDGAR 1.4 (Emission Database for Global Atmospheric Research) database (Olivier and Berdowski, 2001; van Aardenne et al., 2001). The CDIAC-ORNL database includes the CO_2 emissions from fossil fuel combustion and cement production on country level for the 1751-1995 period (Andres et al., 1998; Marland et al., 1999). The regional CO_2 emissions from land-use changes are based on Houghton (1999). The CDIAC database does not include regional historical emissions of CH_4 and N_2O. The emissions of these gases from the sources, fossil fuel combustion, industrial and agricultural sources, biomass burning and deforestation, were taken from the EDGAR 1.4 database for the 1890-1995 period. The future greenhouse gases emissions are based on the trend in the CPI baseline scenario.

4.3 Differentiation rules: responsibility for climate change

Responsibility refers to countries' responsibility for human-induced climate change and is closely related to the 'responsibility principle': the greater one's contribution to the problem, the greater one's share of the burden. Figure 4.1 shows the relative contribution of Annex I and non-Annex I countries to climate change with the use of different indicators based on the methodology and emission data as described in the previous section. The choice of indicator can be shown here to make a major difference in the relative responsibility of countries. The left column of figures shows the impact of taking different emissions and sources into account; these are fossil CO_2 emissions only, all anthropogenic CO_2 emissions (including land-use CO_2 emissions), and all the anthropogenic emissions of CO_2, CH_4, N_2O in terms of anthropogenic CO_2-equivalent emissions. The date on which Annex I and non-Annex I contributions to the total global emissions become equal shifts from 2015 (fossil CO_2 emissions) to 2002 (CO_2-equivalent emissions). The middle column shows the impact of using different indicators in the cause–effect chain of climate change: anthropogenic CO_2 emissions, CO_2 concentration and temperature increase. The date on which Annex I and non-Annex I contributions become equal then shifts from 2005 to 2045. The last column shows the impact of per capita indicators: CO_2 emissions per capita contribution to CO_2 concentration per capita, and temperature increase per capita. For none of the per capita indicators do the contributions of Annex I and non-Annex I become equal.

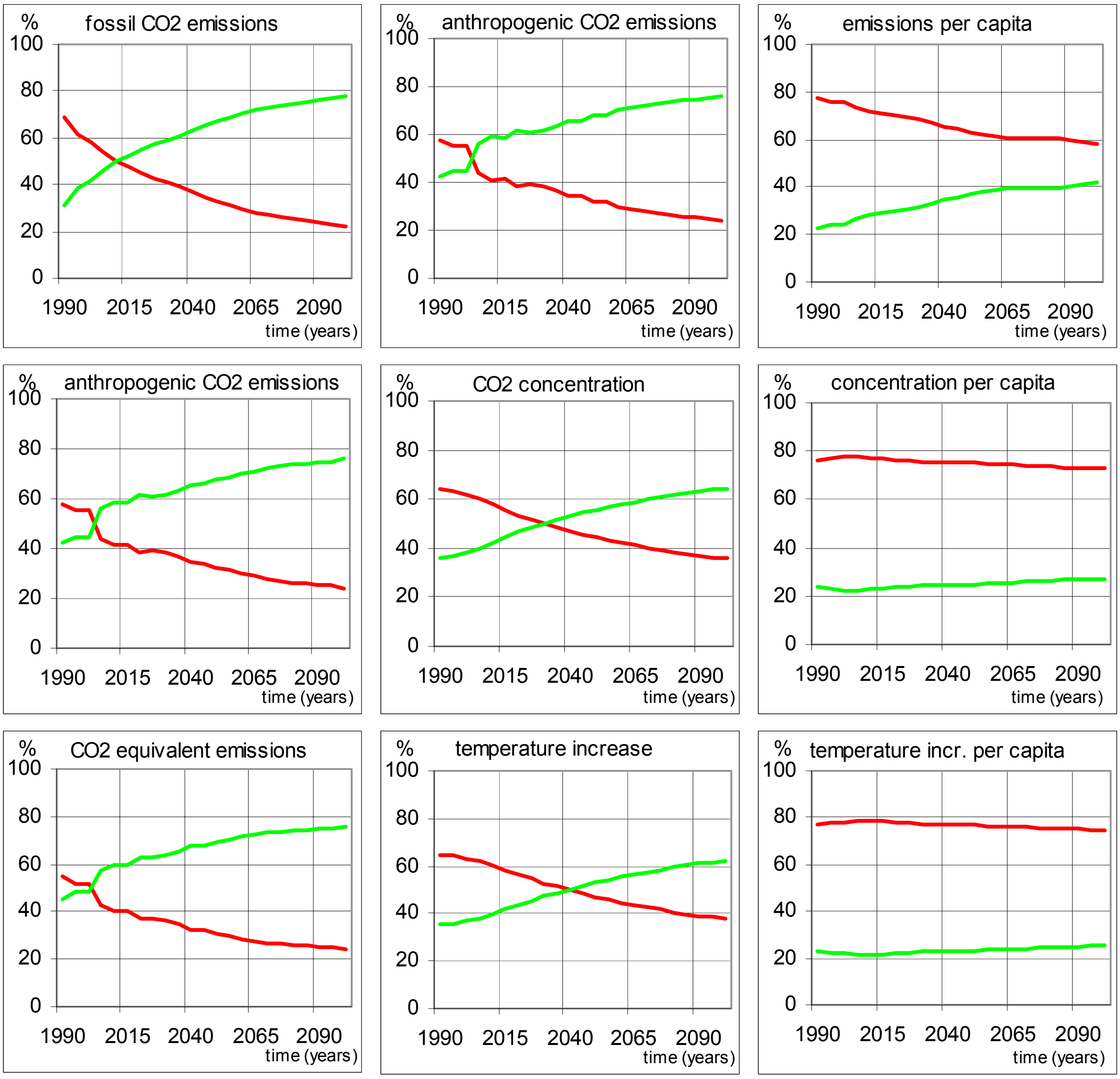


Figure 4.1: Indicators for the contributions of Annex I (red) and non-Annex I (green) countries to climate change according to the CPI Baseline scenario (Source: FAIR 2.0 model (den Elzen, 2002; den Elzen and Lucas, 2003)).

These findings are not only dependent on the baseline assumptions and uncertainties on historical emissions, but also on the model uncertainties and methodological choices, as discussed in den Elzen and Schaeffer (2002). Nevertheless, we can conclude that:

- It is very likely that the share of developing countries in global GHG emissions is going to surpass the share of the industrialised countries within 2 to 3 decades, but it will take another couple of decades before their contribution to concentration levels or temperature increase will be equal. On a per capita base their contributions will remain much lower than that of the industrialised countries.
- Emissions reduction-sharing criteria accounting for historical emissions and/or based on a per capita approach are favourable for developing countries, while inclusion of all GHGs and land-use emissions is favourable for the industrialised countries.

- Use of an indicator later in the cause–effect chain, such as the contribution to the temperature increase realised[11] instead of emissions, is favourable to developing countries

4.4 Brazilian Proposal with income threshold (reference case)

The reference case assumes a global application of the Brazilian Proposal (BP), i.e. burden-sharing based on the contribution to temperature increase, combined with an income threshold for participation of the non-Annex I regions. This participation threshold is chosen as a percentage of the 1990 PPP Annex I per capita income. This percentage is selected on the following grounds: (i) feasibility under the 450 ppmv stabilisation profile and (ii) timing of the convergence in the per capita fossil CO_2 emissions for the Annex I and non-Annex I regions. As an indicator of this convergence timing, we use the ratio of the per capita Annex I emissions divided by per capita non-Annex I emissions.

Figure 4.2 shows this indicator for the Brazilian Proposal for various participation threshold levels expressed as a percentage of 1990 Annex I per capita income (PPP$/capita). The 10% level leads to no convergence at all, since all non-Annex I regions have only limited space to increase their per capita emissions; they even have to start to reduce per capita emissions soon after 2020. A higher level of 50% would imply that the convergence in the per capita emissions in Annex I and non-Annex I regions is already reached by 2030. These levels also lead to high negative emission allowances for the Annex I regions after 2030, as major non-Annex I regions (East and South Asia) participate after 2030. Negative emission allowances indicate that a region's emissions reduction obligation (resulting from its share in the burden-sharing key and the total global emissions reduction burden) exceeds its remaining emission allowances from the previous commitment period. This happens in the case of the Brazilian Proposal under a stringent global emission constraint when, due to their large historical contributions to temperature change, the share of some Annex I regions - notably Europe - in the overall emission burden decreases less quickly than the share in total emission allowances over time.

For the reference case, we selected the participation threshold of 40% of 1990 Annex I regions per capita income (PPP$ per capita). This income threshold leads to a near convergence in the Annex I and non-Annex I per capita emissions by 2035 (as illustrated in Figure 4.2). Figure 4.3 shows the total and per capita fossil CO_2 emission allowances for this reference case of the Brazilian Proposal, i.e.:
- participation threshold of 40% of 1990 Annex I per capita income,
- burden-sharing based on contribution to (realised) temperature increase.

The upper left-hand figure of Figure 4.3 shows the results for the four aggregated IPCC SRES regions: (i) States that were members of the OECD in 1990 (OECD90), (ii) Eastern Europe and Former Soviet Union (REF), (iii) Asia (ASIA) and (iv) Africa and Latin America (ALM). The lower right-hand figure shows the results for the ten aggregated world regions: Canada & USA, OECD Europe, Eastern Europe and FSU (hereafter referred to as EEUR/ FSU), Oceania, Japan, Latin America, Africa, Middle East and Turkey (ME & Turkey), South Asia and South-East and East Asia (SE & E. Asia).

[11] For this attribution analysis the temperature increase of Annex I and non-Annex I is calculated as being due to the changes in the CO_2 concentrations only. Taking all GHGs into account implies a shift in the convergence year towards 2030 because of the larger share of non-Annex I regions in non-CO_2 greenhouse gas emissions.

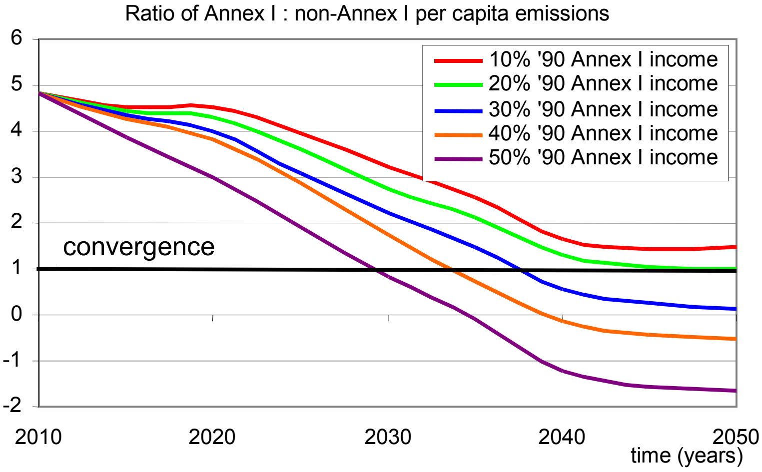


Figure 4.2a-b: The impact of various participation thresholds on the ratio of the per capita Annex I emissions divided by per capita non-Annex I emissions for the BP approach under the IMAGE S450c profile (Source: FAIR 2.0 model (den Elzen, 2002; den Elzen and Lucas, 2003)).

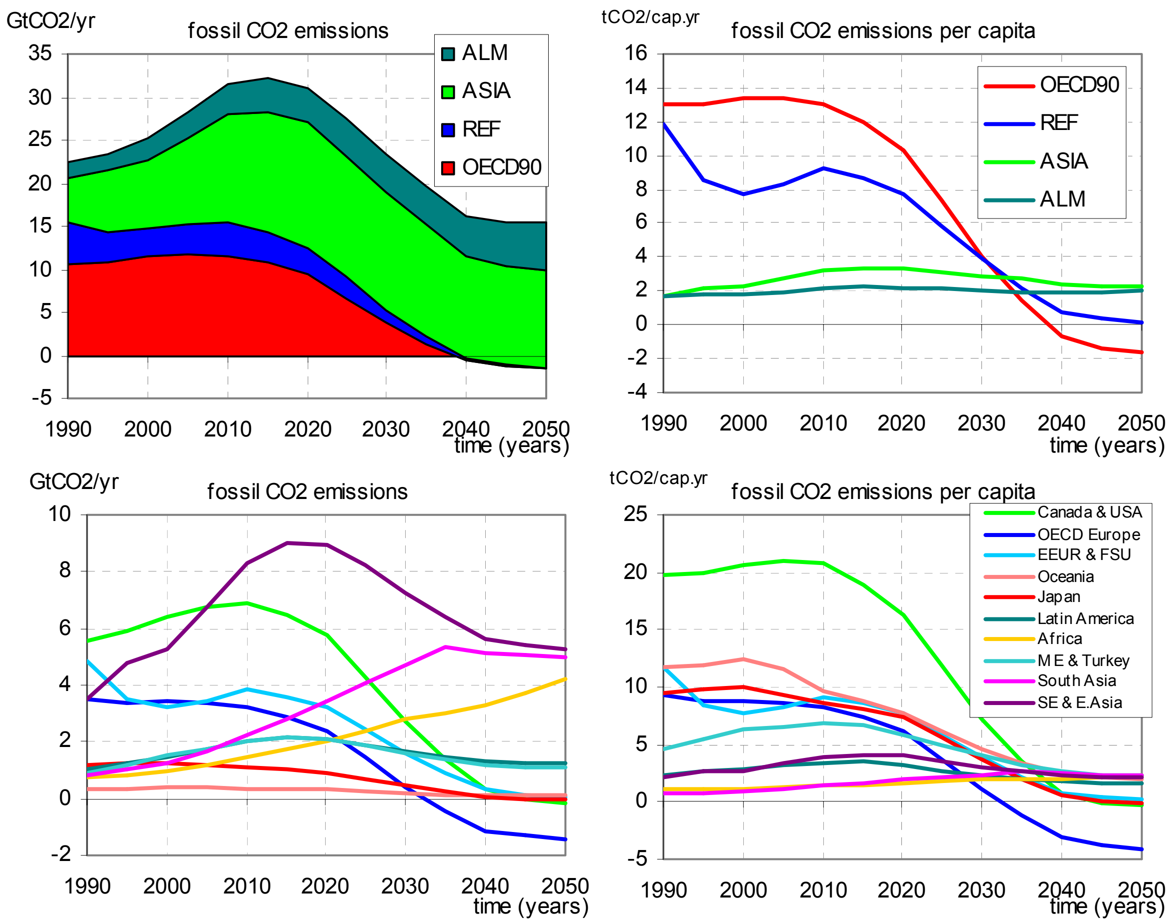


Figure 4.3a-b. Fossil CO_2 emission allowances for the Brazilian Proposal (reference case) for the four IPCC regions (upper) and ten regions (lower) under the IMAGE S450c profile (Source: FAIR 2.0 model (den Elzen, 2002; den Elzen and Lucas, 2003)).

The reference case shows that burden-sharing based on the region's contribution in realised global temperature increase can result in lower per capita fossil CO_2 emission allowances for Annex I regions than for non-Annex I regions. This is due to their larger contribution in realised global temperature increase than per capita fossil CO_2 emissions. The reference case leads to negative emission allowances for some of the Annex I regions (i.e. OECD Europe, Japan and FSU) due to their historical contribution to temperature increase[12], but also to negative emission allowances for Latin America due to their high land-use emissions over the past decades. By 2030, the Annex I regions still contribute about 50% to the global temperature increase (USA: ~20%; OECD Europe: ~15%; Japan: less than 5%), which is only 5% less compared to their contribution under the CPI baseline emissions scenario. Latin America too contributes about 10% to the global temperature increase by that time. The contribution in the global temperature increase leads to ongoing emissions reductions in the Annex I regions, which results in negative per capita emission allowances. The participation threshold of 40% of 1990 Annex I income implies that only the high- and middle-income non-Annex I regions (Latin America, ME & Turkey, SE & E. Asia) have to participate in the emissions reduction regime before 2025, whereas the low-income non-Annex I regions can follow their baseline emissions. By 2050, only West, East and South Africa are exempted from participating in the emissions reduction regime, but now, also South Asia and North Africa have to reduce their emissions (see Appendix II for more details of the calculations).

In conclusion, the Brazilian Proposal, combined with an income threshold as high as 40% of average 1990 Annex I per capita income, will generate relatively low emission allowances for the Annex I regions and Latin America.

4.5 Robustness of results

In order to explore the robustness of our findings, we below will present three alternative cases of the Brazilian Proposal reference case, with alternative participation threshold and burden-sharing keys. The basic idea behind these cases is to change one key parameter (see Table 4.1, indicated in bold) to assess the impact on the emission allowances. The three alternative cases are defined as:

1. BP with no income threshold, but full participation of all regions in the global emissions reductions after 2010 (BP part 2010);
2. BP with income threshold, combined with burden sharing based on the contribution in per capita temperate increase (BP temp p.c.);
3. BP with income threshold, with burden sharing based on the contribution in CO_2 concentration (BP CO_2 conc.).

Figure 4.4 shows the percentage change in the emission allowances relative to the 1990 emission level in the target year, 2025, for the reference and alternative cases.

[12] This depends on the assumed starting-year of the historical emissions (here 1765). Choosing a later year, for example 1950, would decrease the historical contributions of these Annex I regions, but still lead to negative emission allowances. To overcome the negative emission allowances, a starting-year of 1990 may be chosen, or an alternative burden-sharing key, such as cumulative emissions.

*Table 4.1. Reference case and the three alternative cases of the Brazilian Proposal (BP) under the IMAGE S450c profile**

Key parameters	*BP Reference case*	*1. BP part 2010*	*2. BP temp p.c.*	*3. BP CO2 conc.*
Participation threshold	40% of 1990 Annex I PPP income	**2010****	Same as reference	Same as reference
Burden-sharing key	Temperature increase	Same as reference	**Temperature increase per capita**	**CO_2 concentration**

* For the IMAGE S550c profile, the participation threshold has been raised to 75% of 1990 Annex I PPP per capita income.
** Key parameters are similar to the reference case, except for one, as indicated in bold.

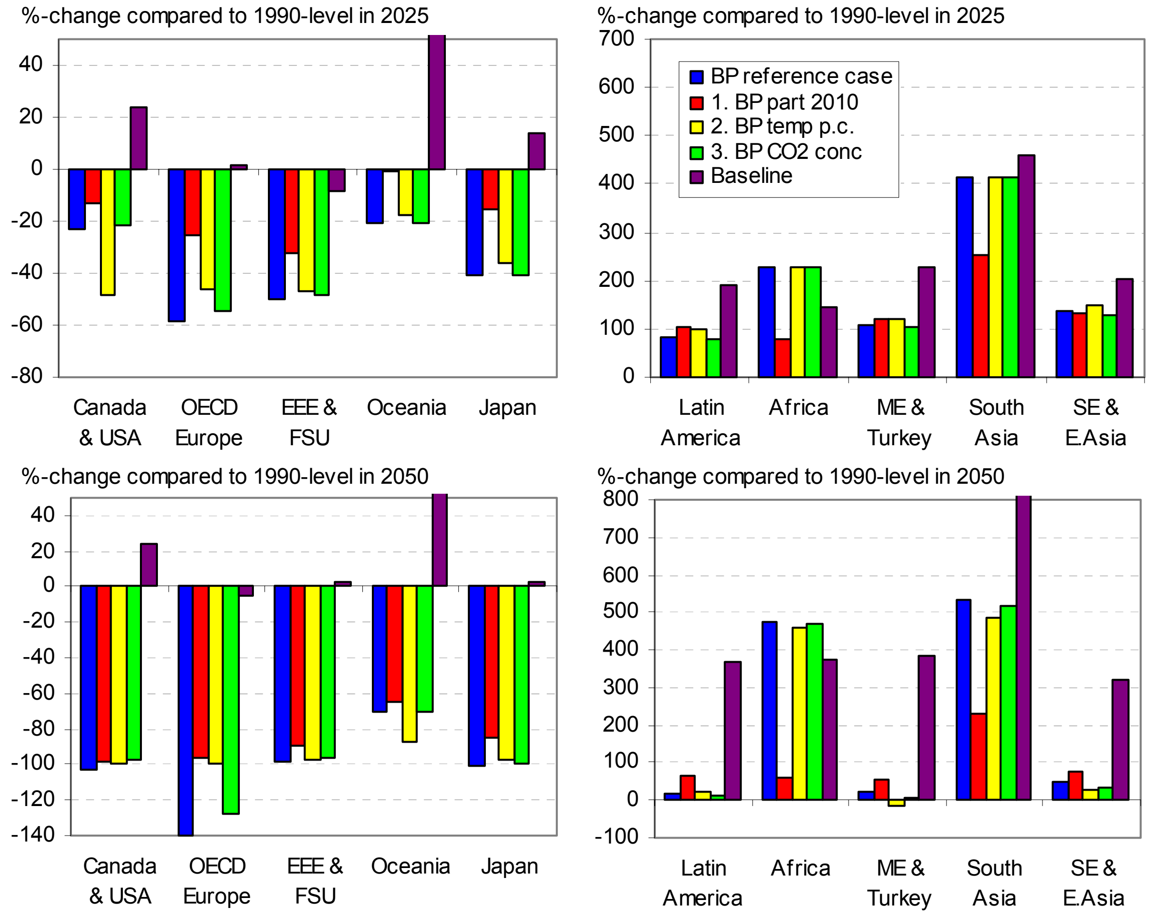


Figure 4.4: Percentage change in the emission allowances relative to the 1990 level for the Brazilian Proposal (BP) regime (reference case) and the alternative cases in the target years 2025 and 2050 under the IMAGE S450c profile (Source: FAIR 2.0 model (den Elzen, 2002; den Elzen and Lucas, 2003)).

The impact of the income threshold

The Brazilian Proposal without a threshold for participation implies that all regions will have to share in the emission constraint irrespective of their income and/or emission level. In the case of stabilisation of CO_2 at 450 ppmv, this results in substantial higher reductions for non-Annex I regions compared to their emissions reductions for the reference case before 2025, in particular for the low-income non-Annex I regions: Africa and South Asia. The only exception for the non-Annex I regions is Latin America, which gains from the global participation. A global application of the Brazilian Proposal is in favour of the Annex I regions, in particular, Canada & USA and Oceania. Generally, the threshold levels for participation have a large influence on the level of emissions reductions in the Annex I and non-Annex I regions: low or no threshold levels are to the advantage of Annex I regions and Latin America, and vice versa for the high-income threshold levels.

The impact of other burden-sharing keys
Figure 4.4 clearly shows that changing the burden-sharing key only affects the distribution of the emission allowances by 2025 for the Annex I and middle- and high- income Annex I regions. Due to the participation threshold of 40% of the 1990 Annex I income, the low-income non-Annex I regions only have to follow their baseline emissions.

Using the contribution to temperature increase, but now per capita, is, in the short-term (2025), only to the disadvantage of Canada and the USA due to their relatively high per capita emissions. All other Annex I regions gain from this burden-sharing key. For the long-term (2050), this advantage still holds for these regions. Now also, most of the non-Annex I regions participate in the regime, and such a burden-sharing key is to the disadvantage of some non-Annex I regions, in particular, those with high population growth (ME & Turkey, Africa, South Asia).

Using contribution to the CO_2 concentration as burden-sharing key is favourable for Annex I regions because it is an indicator earlier in the cause–effect chain, although it has a rather limited overall impact on the results. It is to the disadvantage of some regions with fast-growing emissions over the past two decades, notably Oceania, SE & E. Asia and ME &Turkey, and to the advantage of particularly OECD Europe with slow growing emissions.

Main findings

- The BP combined with an income threshold as high as 40% of average 1990 Annex I per capita income will generate relatively low emission allowances for the Annex I regions and Latin America.
- In the case of stringent climate targets an income threshold level of 50% of 1990 Annex I income results in high negative emission allowances for Annex I, as major non-Annex I regions (SE & E. Asia and South Asia) participate fairly late (after 2030).
- A low threshold leads to an early participation for the major non-Annex I regions irrespective of their income and/or emission level, and most non-Annex I regions will have to reduce their per capita emissions soon after 2025.
- Generally, the threshold level for participation has a large influence on the level of emissions reductions in the Annex I regions. Low threshold levels are to the advantage of Annex I regions and Latin America.
- Burden-sharing based on a region’s contribution to realised global temperature increase can result in lower per capita fossil CO_2 emission allowances for Annex I regions than for non-Annex I regions.
- Using per capita contribution to temperature increase as burden-sharing key is to the disadvantage of USA and Canada in the short term (2025). In the long-term (2050) it also to the disadvantage of the non-Annex I regions with high population growth (ME &Turkey, Africa, South Asia).

5 The Multi-Stage approach

5.1 Introduction

In the Multi-Stage approach the number of Parties involved and the type and level of commitments of the various Parties is based on (alternative) participation and burden-sharing rules (den Elzen et al., 1999; Gupta, 1998). The approach results in a system that divides regions into groups with different levels of commitments (stages). The aim of such a system is to ensure that regions with similar circumstances - in economic, developmental and environmental terms - have comparable commitments under the climate regime. Moreover, the system defines when their level of commitment changes following pre-determined rules related to a change in circumstances. The Multi-Stage approach was originally implemented in the FAIR model as a global application of the Brazilian Proposal. Here, the Brazilian approach was combined with a threshold for participation (Berk and den Elzen, 1998; Berk and den Elzen, 2001; den Elzen et al., 1999). Later the approach was extended to a Multi-Stage approach (Berk and den Elzen, 2001; den Elzen et al., 2001; den Elzen, 2002), based on the ideas from Gupta (1998).

5.2 Methodology

Basically, the regime starts with the selection of a long-term emission profile for stabilising the CO_2 concentration at a targeted level (in the illustrative case, 450 ppmv). The participation rules for each five-year time period determine who should participate and when. After 2010 (post-Kyoto) all Annex I regions (including the USA) enter the emission-reduction burden regime (stage 4). For the non-Annex I regions, the approach offers a four-stage regime to differentiate commitments among regions over time:

- *Stage 1. No quantitative commitments:* Non-Annex I regions first follow their baseline emissions until they meet a threshold for participation based on income and/or emissions, or a pre-selected starting-year, after which they enter the second stage.
- *Stage 2. Adoption of intensity targets*: In this stage the non-Annex I regions' allowable emissions are controlled by de-carbonisation targets, defined by the rate of reduction in the emission intensity of their economy (fossil CO_2 emissions per unit of economic activity expressed in PPP$ terms). A region moves to stage 3 when it reaches any of selected second participation thresholds.
- *Stage 3. Stabilisation of emissions*: The non-Annex I regions enter an emission stabilisation period, in which they stabilise their absolute or per capita emissions for a number of years before actually entering the emissions reduction regime.
- *Stage 4. Sharing the efforts of absolute emissions reductions*: Here the total reduction effort[13] to achieve the global emission profile is shared amongst all participating regions on the basis of a burden-sharing key (here, per capita emissions).

5.3 Multi-Stage approach with income threshold (reference case)

Previous analysis has shown that in the case of stringent climate goals, non-Annex I regions will have to start contributing to global emission control within the next few decades, e.g. Berk and den Elzen (2001). To stimulate early participation, while leaving room for an

[13] The difference between the remaining emissions, i.e. emissions from profile minus emissions from the regions in stages 1, 2 and 3, at times t and t-1 (den Elzen et al., 2001).

increase in emissions for economic development, the following Multi-Stage (MS) approach reference case has been chosen (see Table 5.1).

- Non-Annex I regions first follow their baseline emissions (stage 1), until they reach a participation threshold of 30% of 1990 Annex I per capita income (ca. PPPS$5000; about the income level of Poland, Bulgaria, Romania and Turkey) for the de-carbonisation stage (stage 2).
- Non-Annex I regions then start to adopt income-differentiated de-carbonisation targets (stage 2) (den Elzen, 2002). More specifically, a constant de-carbonisation target of 3% per year is assumed for the high-income regions (more than 5000 {PPP-corrected US$1995 PPP$ per capita). The middle-income regions (2500-5000 PPP$ per capita) start with a target of 2% per year after 2010, which increases linearly up to 3% per year by 2030. • The low-income regions (less than 2500 PPP$ per cap) start with a target of 1% per year after 2010, which increases up to 3% per year by 2050. The actual rates applied are dependent on the per capita income threshold level or starting-year chosen. In the following we will make a sensitivity analysis of the impact of these assumptions.
- Non-Annex I regions start to stabilise their emission for ten years (at least two commitment periods) when their per capita fossil CO_2 emissions reach the average world level (stage 3) before joining the Annex I regions and entering the emissions reduction regime (stage 4).
- In stage 4 the total reduction effort[14] to achieve the global emission profile is shared amongst all participating regions on the basis of a burden-sharing key (here, per capita emissions).

Figure 5.1 shows the total and per capita fossil CO_2 emission allowances for the Multi-Stage regime (reference case) under the IMAGE S450c profile, where burden- sharing is based on contribution to fossil emissions per capita, and a ten-year stabilisation period for the stabilisation stage is assumed.

The participation threshold chosen for de-carbonisation is 30% of 1990 Annex I per capita income to induce early participation before 2020 for high- and middle income non-Annex I regions, and participation by 2025 and 2050 for the low-income non-Annex I regions, South Asia and Africa, respectively. The participation threshold chosen for the burden-sharing regime (stage 4) is 40% of 1990 Annex-I per capita income based on the following: (i) feasibility under the 450 ppmv stabilisation profile; and (ii) making the cases comparable with the reference cases of the other approaches. Therefore, the same threshold of 40% of 1990 Annex I income is chosen for the participation of the burden-sharing regime, although actual participation in the burden-sharing regime is further delayed through the stabilisation period of ten years. Similar to the BP approach, this 40% level also leads to a convergence in the per capita Annex I and non-Annex I emission by 2050. A 50% level would lead to an early convergence by 2030, which does not seem very realistic (as illustrated in Figure 5.1). This reference case clearly shows the use of a per capita contribution to fossil CO_2 emissions as burden- sharing key to result in a convergence of per capita fossil CO_2 emissions amongst Annex I and non-Annex I regions by 2050.

[14] The difference of the remaining emissions, i.e. emissions from profile minus emissions of the regions in stages 1,2 and 3, at times t and t-1.

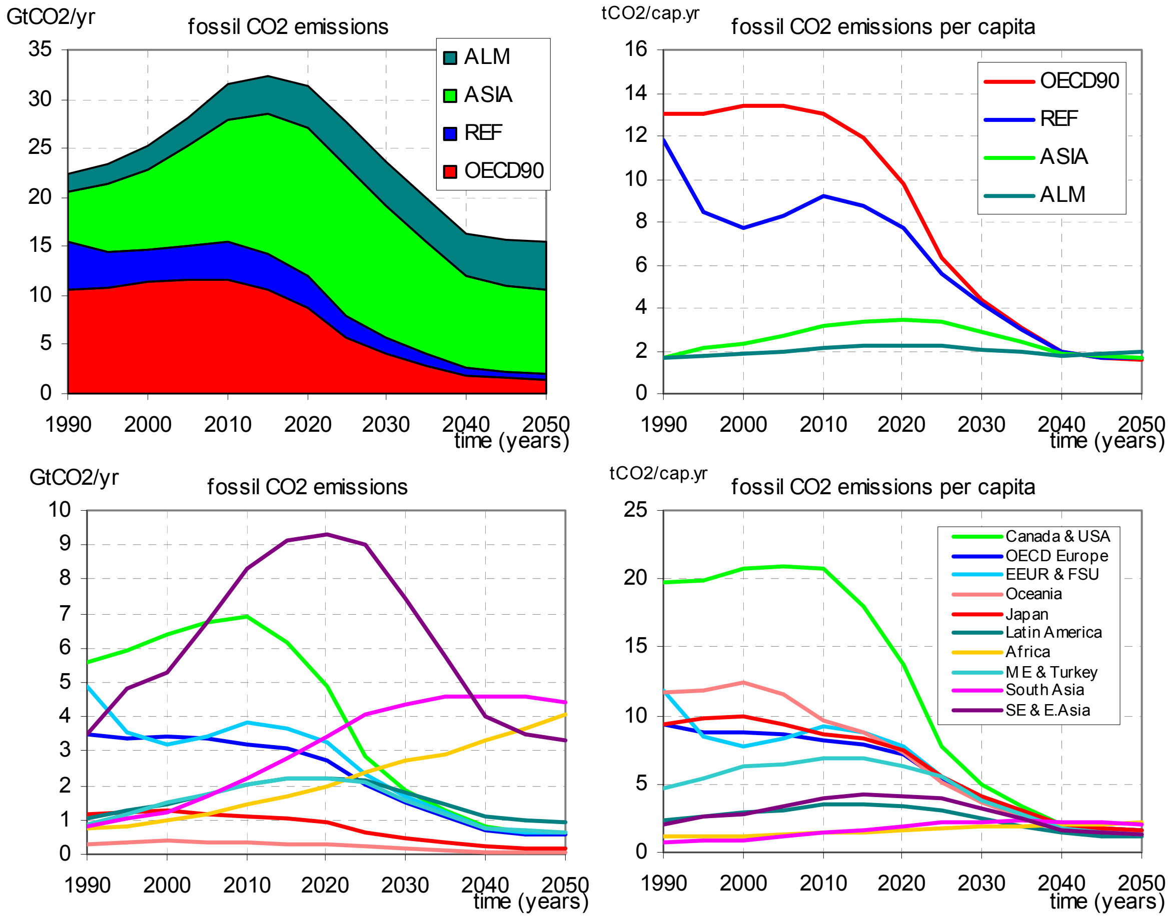


Figure 5.1a-b. Fossil CO_2 emission allowances for the ***MS (reference case)*** *for the four IPCC regions (upper) and ten regions (lower) under the IMAGE S450c profile (Source: FAIR 2.0 model (den Elzen, 2002; den Elzen and Lucas, 2003)).*

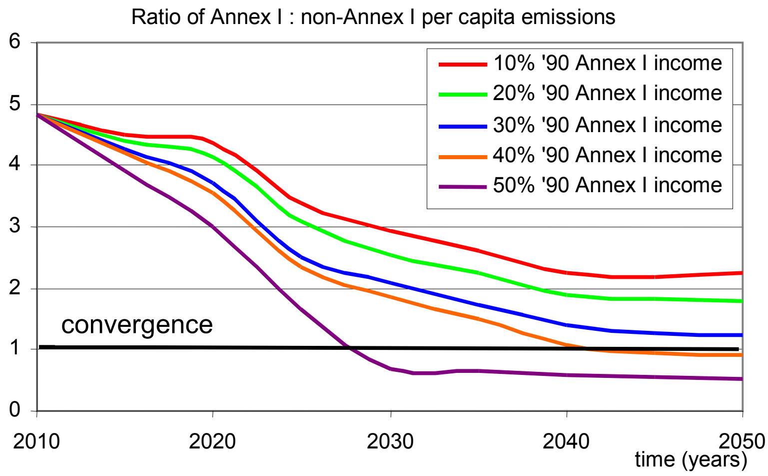


Figure 5.2. The impact of various participation thresholds for burden-sharing on the ratio of per capita fossil CO_2 emissions in Annex I to those in non-Annex I regions for the MS approach under the IMAGE S450c profile (Source: FAIR 2.0 model).

This reference case, with a participation threshold for de-carbonisation and burden- sharing of30% and 40% of 1990 Annex I per capita income, respectively, implies that in the short term, high- and middle income non-Annex I regions (Latin America, ME & Turkey, SE & E. Asia) may skip the de-carbonisation stage and enter the emissions reduction regime directly in 2020 after a ten-year stabilisation period. Most low-income non-Annex 1 regions enter the de-carbonisation stage before 2050. North Africa will first be allowed to continue to increase its emissions (stage 1) and just follow the baseline emissions until 2015; for South Asia and South Africa this will even be extended to 2030 and 2050, respectively. Only East and West Africa remain in stage 2, with only intensity target commitments. At the same time, the emission allowances for OECD Europe, Japan and, in particular, the USA, will diminish sharply (Figure 5.1).

However, in the long-term, achievement of a stringent climate target will not only demand large efforts from all Annex I regions (about 90% reductions compared to their baseline emissions; 40-60% compared to 1990) (Appendix III), but also from non-Annex I regions (about 40-90% compared to their baseline emissions).

5.4 Robustness of results

We have formulated three Multi-Stage cases with alternative participation thresholds and burden-sharing keys. Similar to the analysis of the Brazilian Proposal, the approach behind these cases is that all key parameters, but for one, are kept similar to the reference case (see Table 5.1).
In this way the impact of the key parameters on the emission allowances can be assessed. These are participation threshold for de-carbonisation and burden sharing, and the burden-sharing key. The following three alternative cases are defined:
1. MS approach with burden-sharing based on per capita income (MS income);
2. MS approach with burden-sharing based on emission intensity (MS intensity);
3. MS approach with world average per capita emission participation threshold for stage 4 (MS world average)

Figure 5.3 shows the percentage change in the emission allowances for the reference and the three alternative cases relative to the 1990 emission level in the target year (2025).

The impact of the burden-sharing key
Due to the participation threshold of 40% of the 990 Annex I income for burden-sharing and the ten-year stabilisation period, changing the burden-sharing key mainly affects the distribution amongst Annex I regions up to 2025 (Figure 5.3).

The first alternative case shows that the use of per capita income (PPP$) instead of per capita contribution to fossil CO_2 emissions as the burden-sharing key is to the disadvantage of the OECD regions, in particular, Japan and OECD Europe. This use is favourable for Eastern Europe and FSU and does not change in the long term (2050) for the Annex I regions. By 2050, almost all non-Annex I regions, except some African regions, participate in the burden-sharing regime. Use of per capita income (PPP$) instead of per capita contribution to such fossil CO_2 emissions as burden-sharing key is favourable for SE & E. Asia and ME & Turkey, and less favourable for Latin America.

Using emission intensity (the second case) instead of per capita contribution to fossil CO_2 emissions as the burden-sharing key is to the advantage of the OECD, and to the strong disadvantage of Eastern Europe and FSU. It is particularly favourable for Japan and OECD Europe, but also for the USA and Oceania, because of their relatively high per capita emissions. Using emission intensity is generally also less favourable for non-Annex I regions, in particular for ME & Turkey, Latin America and SE & E. Asia.

*Table 5.1. Reference case and the alternative cases in the MS approach under the IMAGE S450c profile**

Key parameters	*MS Reference case*	*1. MS income*	*2. MS intensity*	*3. MS part*
Stage 1				
No quantitative commitments				
Stage 2				
Adoption of intensity targets Participation threshold	30% of 1990 Annex I per capita income	Same as reference	Same as reference	Same as reference
De-carbonisation rate				
High-income NA-I Middle-income NA-I Low-income NA-I	2.5% after 2010** 1% 2010 - 2.5% 2030 0.5% 2010 - 2.5% 2050	Same as reference	Same as reference	Same as reference
Stage 3				
Stabilisation of emissions Participation threshold	40% of 1990 Annex I per capita income	Same as reference	Same as reference	**World average per capita fossil CO_2 emissions**
Stabilisation period	10 years	Same as ref.	Same as reference	Same as reference
Stage 4				
Burden-sharing regime	Per capita fossil CO_2 emissions	**Per capita PPP income**	**Fossil CO_2 emission intensity**	Per capita fossil CO_2 emissions

* For the IMAGE S550c profile, there is no participation threshold for the de-carbonisation stage 2 and the participation threshold for the burden-sharing stage 4 have been raised to 75% of 1990 Annex I PPP per capita income.
** De-carbonisation rate in PPP$. De-carbonisation rates in US$: High-income NA-I: 3% after 2010; Middle-income NA-I : 2% 2010 - 3% 2030; Low-income NA-I: 1% 2010 - 3% 2050 (den Elzen, 2002; den Elzen and Lucas, 2003).

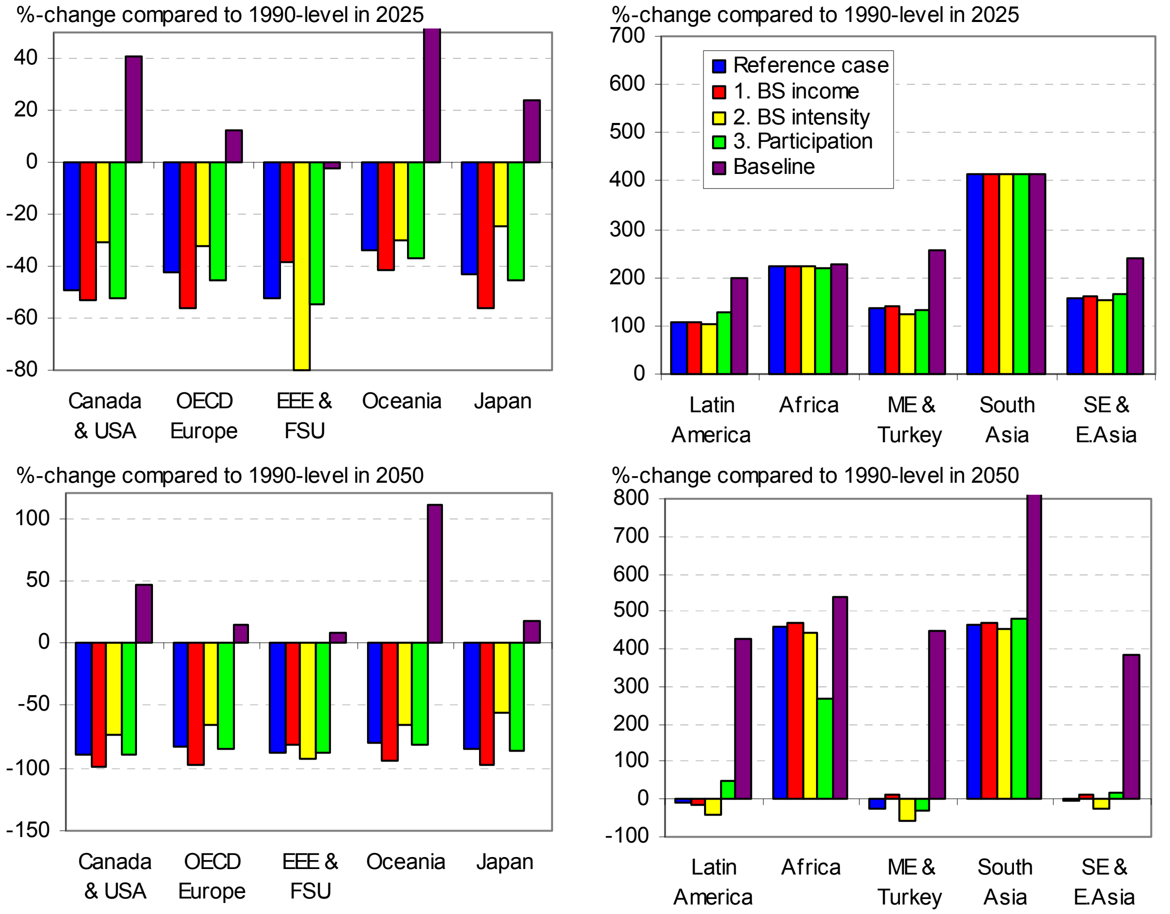


Figure 5.3. Percentage change in the emission allowances relative to the 1990 level for the ***Multi-Stage regime*** *(reference case) and the three alternative cases under the IMAGE S450c profile in the target years, 2025 and 2050 (Source: FAIR 2.0 model (den Elzen, 2002; den Elzen and Lucas, 2003)).*

The impact of the world average per capita emission participation threshold
A world average per capita fossil CO_2 emissions participation threshold is more favourable for the Annex I regions and Latin America and ME & Turkey than the per capita income threshold for burden-sharing. This is because some (other) non-Annex I regions then participate earlier (notably SE & E. Asia, South Asia and South Africa). World average per capita fossil CO_2 emissions tend to be less favourable for the least developed regions than the income threshold used in the reference case, in particular, for Africa. In general, using world average per capita emissions as a participation threshold rewards both emissions reductions by the industrialised regions (brings down the world average leading to an earlier participation of more non-Annex I regions in emissions reductions), and rewards the efforts by developing countries to control the growth in their emissions (e.g. improves their emission intensities).

For an elaborate sensitivity analysis of the impact of changing the other key parameters in the Multi-Stage regime, i.e. the de-carbonisation rate and stabilisation period on the emissions allowances please refer to den Elzen (2002). Den Elzen found that the de-carbonisation rate can indeed have a large influence on the emission allowances, especially when the non-Annex I regions enter the de-carbonisation stage directly after 2010.

Main findings:

- To meet the stabilisation of the 450 ppmv target, a participation threshold for respective de-carbonisation and burden-sharing of 30% and 40% of the 1990 Annex I per capita income is necessary. This would imply that in the short term, middle-income non-Annex I regions (Latin America, ME & Turkey and SE & E. Asia) could skip the de-carbonisation stage and directly enter the emissions reduction regime by 2020 after a ten-year stabilisation period. The low-income non-Annex I regions would enter the de-carbonisation stage before 2025.
- Using per capita fossil CO_2 emissions as a burden-sharing key tends to result in a convergence of per capita fossil CO_2 emissions amongst Annex I and non-Annex I regions in the long term (by 2050). This key is particularly unattractive for Canada & USA due to their high per capita emissions.
- Because of the participation threshold of 40% of the1990 Annex I income for burden-sharing and the ten-year stabilisation period, changing the burden-sharing key tends to mainly affect the distribution amongst Annex I regions up to 2025.
- Using per capita income (PPP$) instead of per capita fossil CO_2 emissions as burden-sharing key is to the disadvantage of the OECD regions, in particular Japan and the OECD Europe. It is much more favourable for the Eastern Europe and FSU, and in the long term also for SE & E. Asia and ME & Turkey, while less favourable for Latin America.
- Using emission intensity as burden-sharing key is to the advantage of the OECD, but is highly disadvantageous to Eastern Europe and FSU. Use of emission intensity is generally also less favourable for the non-Annex I regions, Latin America and SE & E. Asia.
- Use of the world average per capita fossil CO_2 emissions as a threshold for participation in burden-sharing is favourable for the Annex I regions, and Latin America and ME & Turkey since some (other) developing regions then participate earlier (notably SE & E. Asia, South Asia and Africa). Use of this threshold tends to be less favourable for the least developed regions.

6 Per capita convergence approach

6.1 Introduction

An alternative approach that would represent a major shift away from the present Kyoto Protocol approach is the so-called 'Contraction & Convergence' approach of the Global Common Institute (GCI) (Meyer, 2000)[15]. Instead of focusing on the question of how to share the emissions reduction burden, this approach assumes 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 Contraction & Convergence or Per Capita Convergence (PCC) approach, all Parties participate immediately in the climate regime (in the post-Kyoto period), with per capita emission allowances (rights) converging towards equal levels over time. The per capita emission convergence approach represents a combination of sovereignty/status quo rights and the need/egalitarian equity principle. It leaves aside differences in historical contributions to the problem[16]. The Global Common Institute (GCI) was the first to introduce the approach as 'Contraction & Convergence'. Early results of the approach were published at the Second Conference of the Parties (COP-2) and have been distributed widely since then. Later, the Indian Centre of Science and Environment (CSE) suggested to link up the concept with basic sustainable emission rights, related to both the idea of survival emissions and, and the idea of global commons (in particular the oceans) as a natural sink for $CO_{2.}$

6.2 Methodology

This regime uses a format similar to the Multi-Stage approach: a global atmospheric greenhouse gas concentration target is first selected, which creates a long-term global emission profile or global GHG emissions contraction budget. This budget is then allocated to regions so as to have the per-capita emissions converge from their individual values to a global average (Meyer, 2000). More specifically, over time, all shares converge from actual proportions in emissions to shares based on the distribution of population in the convergence year. In the original Contraction and Convergence approach[17] of the GCI, based on a non-linear 'equation', the actual degree of convergence in per capita emission rights depends on the convergence rate selected. This convergence rate determines whether most of the Per Capita Convergence takes place at the beginning or near the end of the convergence period. The higher the convergence rate, the more the convergence takes place towards the end of the convergence period and vice-versa. The default value in the original GCI PCC is 4, leading to a balance in the convergence. In the meantime, GCI has indicated that the non-linear convergence method is not an essential element of their approach, and that a linear approach with per capita converging linearly over time may be adopted as well. Since such an approach is simpler and avoids selecting an arbitrary value for the

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[15] See website: http://www.gci.org.uk.

[16] In principle, this could be combined with the convergence approach if the criteria were formed by a per capita contribution to the CO_2 concentration of temperature increase. However, these options have not been associated with the convergence concept and would be much more complex in nature.

[17] The non-linear convergence equation is: $S_r(t) = S_r(t-1) - [S_r(t-1) - P_r(t-1)] \cdot e^{[-\alpha(1-\tau)]}$, where $S_r(t)$ is the emission share (%) at time t, $P_r(t)$ the population share at time t, α the convergence rate coefficient and τ the time ratio ($\tau = 0$ at the start of the convergence t_{start} [here: 2010] and $\tau = 1$ at chosen convergence year).

convergence rate, we assume a linear convergence in our reference case[18]. 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[19]. In our reference case, the approach is applied without a cut-off year, and based on population projections of the CPI baseline scenario.

6.3 Per capita 2050 convergence (reference case)

The FAIR 2.0 model is used to analyse the regional distribution of emission allowances resulting from a linear convergence of per capita fossil CO_2 emissions allowances between 2010 and 2050 (convergence period of 40 years) under the 450 ppmv stabilisation profile. Figure 6.1 shows the total and per capita fossil CO_2 emission allowances for the reference case.

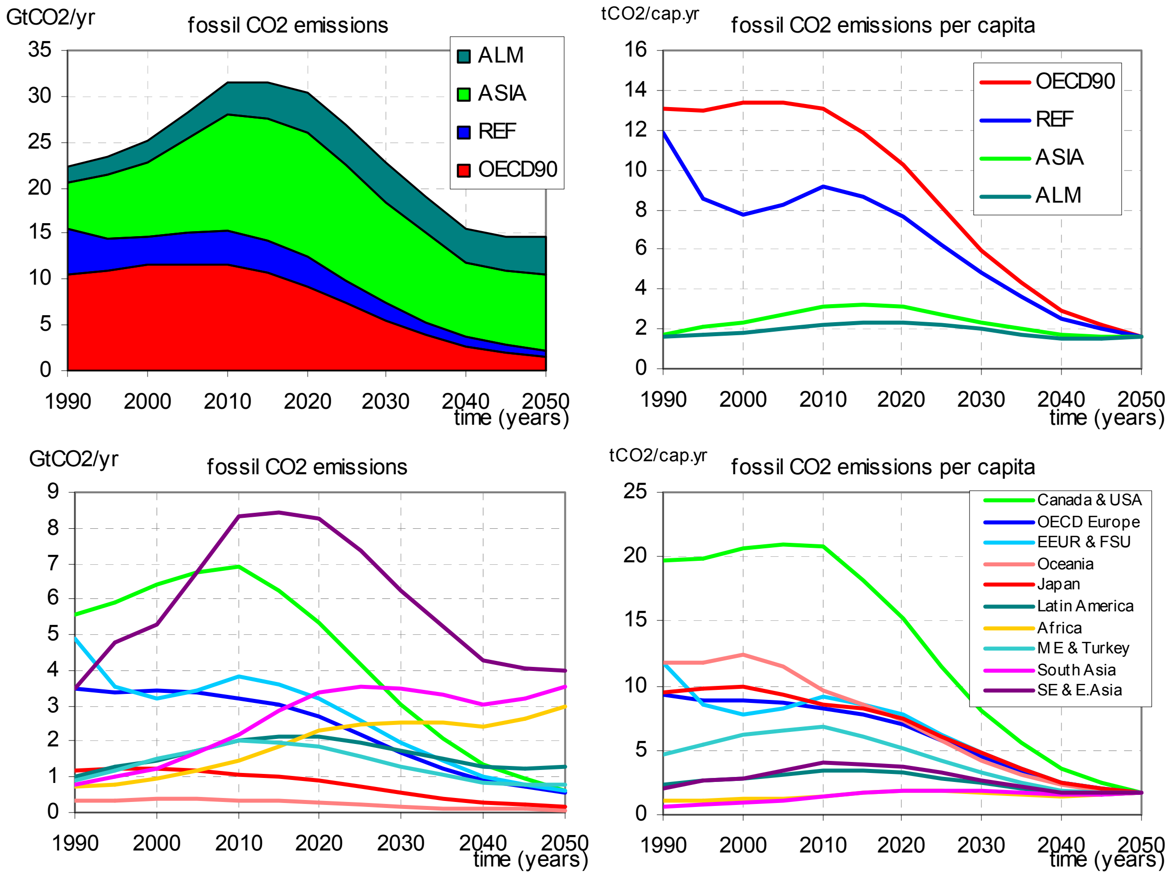

Figure 6.1a-b. Fossil CO_2 emission allowances for the ***Per Capita Convergence 2050 regime (reference case)*** *for the four IPCC regions (upper) and ten regions (lower) under the IMAGE S450c profile (Source: FAIR 2.0 model).*

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[18] The linear convergence equation is: $S_r(t) = S_r(t_{start}).(1-\tau) + P_r(t).\tau$.

[19] Note that there is no assumption made about what populations will or should be beyond the cut-off year, but merely that population growth after that year should not be awarded additional emission rights.

Convergence in per capita emission allowances under the S450c profile will imply a sharp reduction in allowable emissions for Annex I regions after the Kyoto Protocol, in particular for the USA, Canada and the FSU and Eastern Europe (around 90% compared to actual 1990 emission levels by 2050). At the same time, there is only limited space for non-Annex regions to still increase their capital emissions, and in these regions total emissions even start to decline well before 2050 (Figure 6.1). In fact, the per capita emission allowances for ME & Turkey already decrease after 2010, whereas for Latin America and SE & E. Asia, this decrease starts by 2020. South Asia is allowed to increase its per capita emissions, but these remain below their per capita baseline emissions. In some of the developing regions, i.e. East and West Africa, emission levels allowed exceed the baseline levels, resulting in surplus emission allowances.

Appendix IV shows the results for the 15 aggregated regions in more detail. The reduction efforts by 2025 are, compared to their baseline emissions for the individual Annex I and non-Annex I regions, shown to differ widely: from 37% for Eastern Europe up to 59% for Oceania, and from 51% for ME & Turkey up to 14% increase for sub-Saharan Africa in 2025. In 2050, the reductions double at the global level, especially for the non-Annex I regions; for South Asia in particular, the reductions more than double (more than four times as high in 2050 and about 55% in 2050 compared to 12% in 2025).

6.4 Robustness of results

We have formulated three alternative Per Capita Convergence cases with the assumptions for the key parameters similar to the reference case, except for one key parameter (see Table 6.1):

1. *Early convergence 2030*: linear Per Capita Convergence by 2030 instead of 2050;
2. *Non-linear convergence*: non-linear Per Capita Convergence by 2050;
3. *Cap population case*: linear Per Capita Convergence by 2050 with a population cut-off year of 2010.

In this way the impact of other values of the key parameters, i.e. convergence year (case 1), convergence rate (case 2) and population cap (case 3) on the emission allowances can be assessed. Figure 6.2 shows the percentage change in the emission allowances relative to the 1990 emission level in the target years 2025 and 2050 for the reference case and the three alternative Per Capita Convergence cases.
The figure clearly shows the convergence year (duration of transition period) and convergence rate to have the greatest impact on the outcomes. An early convergence year (2030) and a non-linear convergence rate are both disadvantageous for the Annex I regions and ME & Turkey.

*Table 6.1. Reference case and the three alternative cases for the Per Capita Convergence (PCC) approach under the IMAGE S450c profile**

Key parameters	*Reference case*	*1. Early convergence*	*2. Non-linear conv.*	*3. Cap population*
Year of convergence	2050	**2030**	Same as reference	Same as reference
Convergence rate	Linear	Same as reference	**Non-linear GCI**	Same as reference
Cap population	Not applied	Same as reference	Same as reference	**Cut-off (2010)**

* Similar to cases under the IMAGE S550c profile.

The impact of the convergence year
Shifting the convergence year from 2050 to 2030 sharply decreases the emission allowances for the Annex I regions and the ME & Turkey. The 2030 convergence leads to higher emission allowances for the non-Annex I regions by 2025, except for ME & Turkey. It creates substantial amounts of surplus emission allowances in the low-income non-Annex I regions (Africa, South Asia). More specifically, an early convergence results in less

(cumulative) emission permits over the convergence period, leading to the highest reductions in the emission allowances relative to the 1990 emissions level for the Annex I regions by 2025. Reductions include –57% for the USA (compared to the -24% in the reference case) and about -52% for OECD Europe (-39% in the reference case) (Figure 6.3 and Appendix IV).

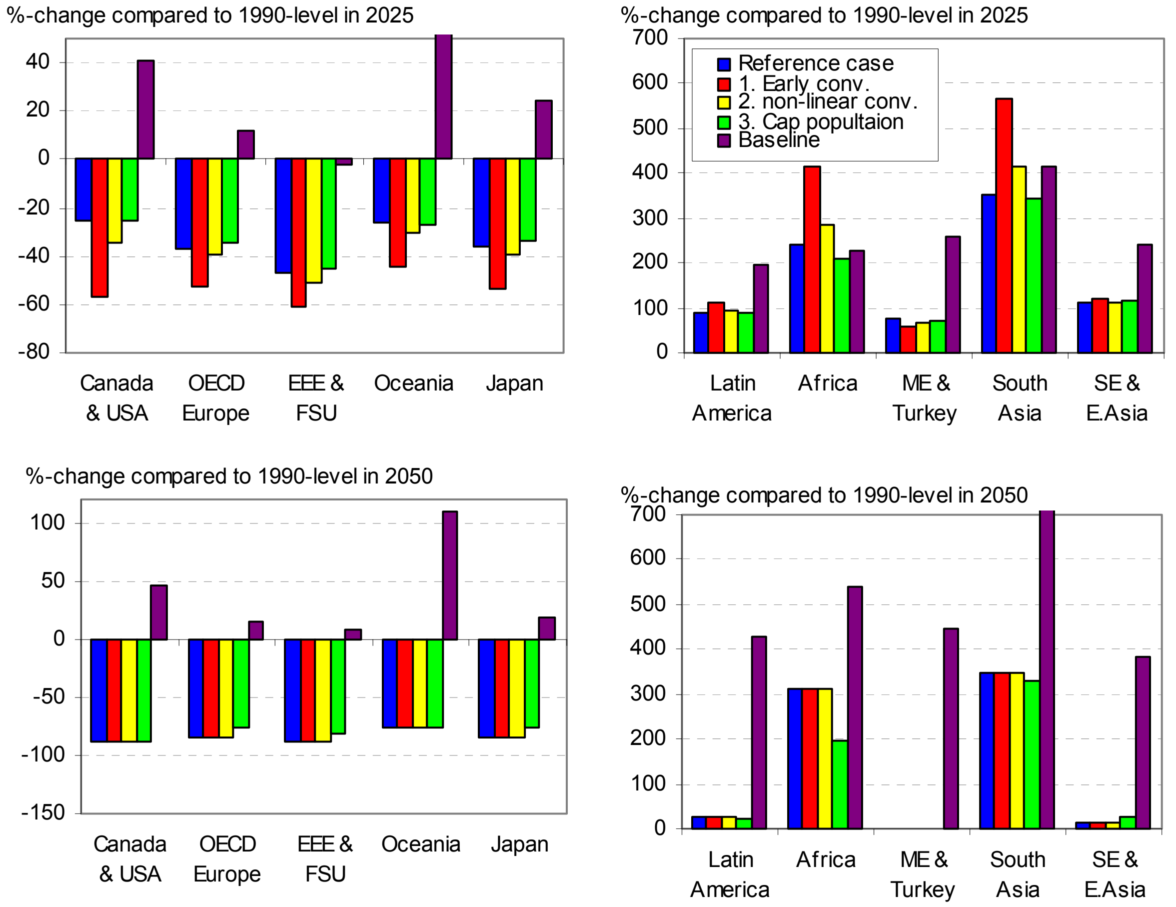

Figure 6.2. Percentage change in the emission allowances relative to the 1990 for the ***Per Capita Convergence (PCC) regime (reference case)*** *and the alternative cases in the target years 2025 and 2050 under the IMAGE S450c profile (Source: FAIR 2.0 model).*

The impact of a non-linear convergence rate

The non-linear Per Capita Convergence with a convergence rate of 4 implies the convergence to be almost equal to the linear convergence; however, after 2020 the convergence rate is somewhat higher, leading to a full convergence of per capita emission allowances as early as 2040. Such a non-linear convergence case is also to the advantage of the non-Annex I regions (except for ME & Turkey), although not as much as the early 2030 convergence case. It leads to large emissions reductions for the Canada & USA and Oceania. Here, the occurrence of surplus emission allowances is limited to Africa; in South Asia emission allowances more or less equal their baseline emission levels. Compared to the 1990 level the reductions now become -34% (was 24%) for the USA and –39% (compared to 37%) for OECD Europe. Thus, non-linear convergence affects the USA more than OECD Europe (and Japan).

The impact of a population cap

Accounting for a cap on population growth (population cap case) for calculating the emission allowances is to the disadvantage of countries experiencing a high population growth. This concerns mainly non-Annex I regions, in particular, Africa and South Asia.

The only exception amongst the non-Annex I regions is SE & E. Asia (including China), since its population growth is lower than the world average. Generally, a population cap is favourable for the Annex I regions, except for Oceania with also substantial population growth.

Figure 6.2 also shows no long-term (2050) difference in emission allowances between the reference case, and the early 2030 convergence and non-linear convergence cases; because in all cases per capita emission allowances have converged to equal levels, although via different routes. Only the population cap case leads to minor differences in the emissions allowances, in particular lower emissions allowances for Africa and South Asia, and higher emissions allowances for the other regions.

For an elaborate sensitivity analysis of the impact of changing the key parameters in the convergence regime on the emissions allowances see den Elzen (2002).

Main findings:

- In the case of a stringent climate target (stabilisation of the CO_2 concentration at 450 ppmv), a convergence of per capita fossil CO_2 emissions by 2050 not only implies emissions reduction efforts from Annex I regions, but also from most non-Annex I regions as early as 2025. Only for the least developed regions, notably Africa, will emission allowances exceed baseline emission levels.
- For especially China, but also the Middle East, a convergence regime will lead to high reductions, since their per capita emissions are close to the world average, and therefore, they do not gain from converging per capita emissions.
- The convergence year has a major influence on the emissions of Annex I and non-Annex I regions. An early convergence year results in much higher reductions in Annex I emissions in both the short and longer term. An early convergence year also creates substantial amounts of surplus emission allowances for low-income non-Annex I regions (Africa, South Asia).
- Non-linear convergence according to the rate in the original GCI approach implies that most of the convergence in per capita emissions takes place in the first half of the convergence period (till 2030), resulting in an almost full convergence in per capita emissions by 2040. Such a non-linear convergence is thus also to the advantage of the non-Annex I regions, except for ME & Turkey, although not as much as in the early 2030 convergence case.
- A 2010 population cap is to the disadvantage of the non-Annex I regions with their high population growth, in particular Africa and South Asia. This is not valid for SE & E. Asia, with a population growth of lower than the world average. Generally, a population cap is favourable for the Annex I regions, except for Oceania, where population growth is also substantial.
- The convergence year and the convergence rate have the greatest impact on the distribution of emission allowances. The impact of the population cut-off year is limited.

7 Preference Score

7.1 Introduction

The Preference Score approach is based on the Preference Score method (Müller, 1999), which can be used to ascertain consensus in a multi-base distribution. To solve conflicts between Parties, the Preference Score method creates a weighted, arithmetic mean for base proposals and Party preferences. For the Preference Score, consensus is sought in a doubled-based - population and emissions - distribution proposal on sharing global emission allowances. More specifically, in the Preference Score approach the allocation of global emissions is based on a population-weighted preference for emissions or population distributions. The approach is based on resource sharing, not on burden sharing (see Chapter 2).

7.2 Methodology

Since no participation threshold is used, all regions join the emission allocation regime immediately after the Kyoto period. The calculation of the regional emission allowances takes place in two steps: first, the voting step followed by an allocation of emissions on the basis of a population weighted averaging of the preferences. In the voting step, each region determines its preferred (=most favourable) distribution method (per capita or grandfathering). On the basis of the total share of the world population in favour of each method, weight factors for grandfathering (α) and per capita allocation (β) are determined. Next, the emission shares per region (S_R) are calculated as the (population) weighted mean between the population (*PC*) and grandfathering (*GF*) shares using the calculated weights as follows:

$$S_R(t) = \alpha(t_{ref}).GF(t_{ref}) + \beta(t_{ref}).PC(t_{ref}), \qquad (1)$$

where t is the year of calculation. The calculation of the shares is dependent on the policy delay assumed (*pd*). This policy delay is used to calculate the reference year ($t_{ref} = t - pd$), which is the year from which the data is used to calculate the emission shares and weights. The absolute allowable emissions are dependent on the global emission profile.

7.3 Preference Score (reference case)

The FAIR 2.0 model is used to analyse the regional distribution of emission allowances resulting from the application of the Preference Score (PS) approach between 2010 and 2050. Here the 450 ppmv stabilisation profile (reference case) is used. The policy delay is 10 years. On the basis of the calculations with the shares of emissions and populations in the starting year, 2010, the Annex I regions, along with ME & Turkey, will have a preference for grandfathering, while the other non-Annex I regions will prefer a population share. Figure 7.1 shows the total and per capita fossil CO_2 emission allowances for the PS approach (reference case) under the IMAGE S450c profile with respect to the four IPCC and selected regions.

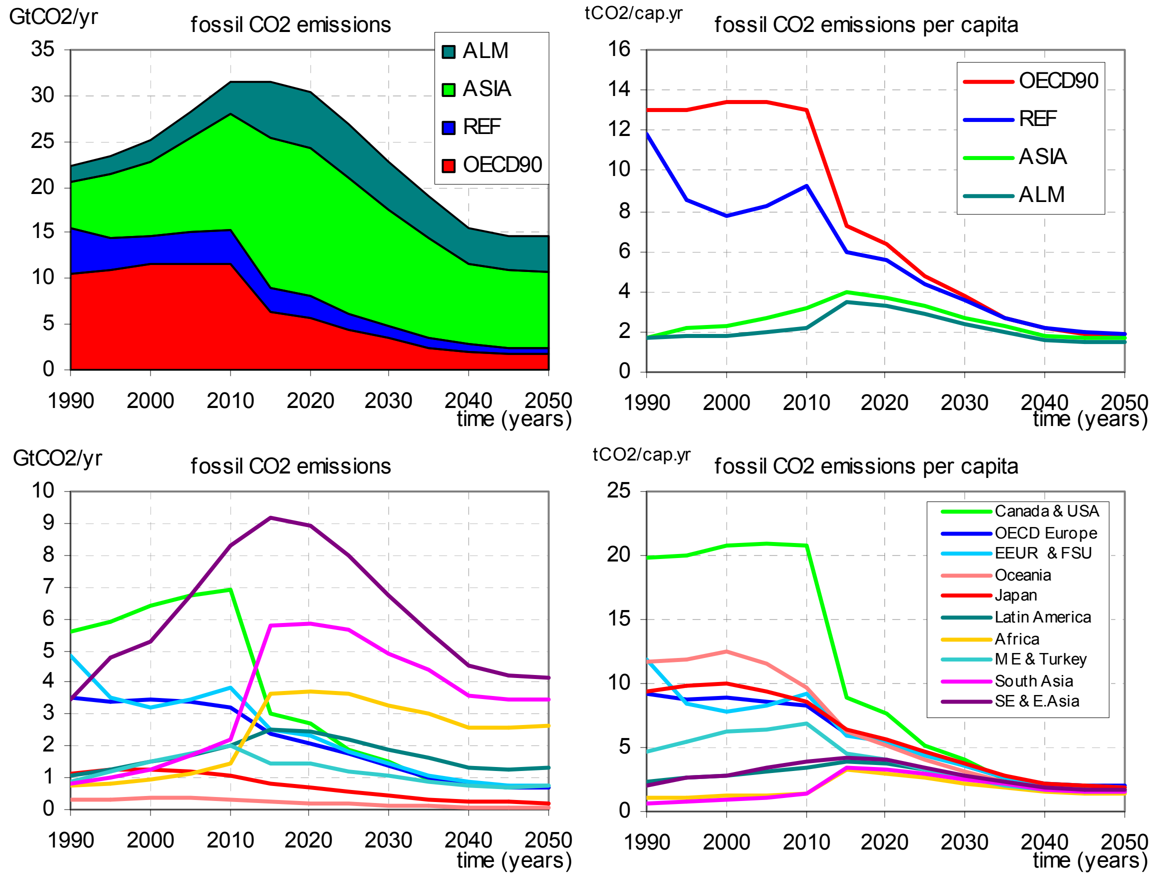

Figure 7.1a-b. Total and per capita fossil CO_2 emission allowances for the ***Preference Score approach (reference case)*** *for the four IPCC regions (upper) and selected regions (lower) with respect to the IMAGE S450c profile (Source: FAIR 2.0 model).*

In the short term, all Annex I regions show very large reductions in emission allowances compared to their 1990 emission levels, whereas the non-Annex I emission allowances increase sharply compared to their 1990 emissions. However, due to the global emission constraint, most non-Annex I regions already have to reduce their emissions in comparison to their baselines. Only Africa and South Asia experience surplus emission allowances.

In the short term, regional emission allowances of the PS approach differ significantly from the PCC (compare Figure 7.1 and 6.1), while regional emission allocations in the long term are about the same. Where the PCC approach starts from an emission allocation-based on grandfathering, the PS approach starts with an instant re-allocation of the emission allowances based on the weighted share of grandfathering and per capita emission distributions. This re-allocation has the greatest negative effect for Canada & USA and Oceania. Both regions show a large decline in emission allowances (more than 50%) between 2010 and 2015, mainly due to their relatively large emissions per capita and small population. This initial decline is smaller (although substantial) for the three other Annex I regions of OECD Europe, Eastern Europe (EEE)/FSU and Japan, and the non-Annex I region, ME & Turkey, because their per capita emissions are closer to the world average. The largest increase in emission allowances can be seen for South Asia and Africa, which all have relatively low per capita emissions and a large population. The effect on the non-Annex I regions, Latin America and South East & East Asia, is very small because their per capita emissions are also close to the world average.

In the long term (2050), all Annex I regions face a reduction of emission allowances of approximately 80% to 90% compared to 1990 levels, while Latin America, ME & Turkey and SE & E. Asia attain their 1990 emissions level (see also Figure 7.3 and Appendix V). The per capita emissions tend to converge by 2040 (see Figure 7.2), although the emissions of the Annex I regions remain slightly above the emissions of the non-Annex I regions.

7.4 Robustness of results

We have formulated three alternative Preference Score cases where the assumptions for the key parameters are similar to the reference case, except for one (see Table 7.1):
1. *No policy delay Preference Score*: the policy parameter is set at zero
2. *Large policy delay Preference Score*: the parameter is set at 20 years;
3. *Cap population case*: Preference Score with the population cut-off year, 2010;

This allows for assessing the impact of the key parameters, i.e. policy delay (cases 1 and 2) and population cap (case 3) on the emission allowances. Figure 7.2 shows the absolute emissions and the emissions per capita for the selected regions related to cases 1 and 2. For the reference case and the three alternative PS cases, Figure 7.3 shows the percentage change in the emission allowances relative to the 1990 emission level in the target year, 2025.

*Table 7.1. The Preference Score approach under the IMAGE S450c profile showing reference case and its two alternative cases**

Key parameters	*Reference case*	*1. No policy delay*	*2. Large policy delay*	*3. PS population cut-off, 1995*
Policy delay	10 years	**0 years**	**20 years**	Same as reference
Cap population	Not applied	Same as reference	Same as reference	**Cut-off (2010)**

* Similar cases under the IMAGE S550c profile.

Impact of the policy delay

Figure 7.2 shows the impacts of the policy delay setting on the regional emission allowances for the selected regions. Changing the policy delay results in the same trends as for the reference case: i.e. Africa and South Asia gain significantly in the short term, while Canada, the USA and Oceania have to decline drastically. The magnitude of the emissions reduction or surplus emissions is dependent on the policy delay, however.

Changing the policy delay from 10 to 0 years results in greater efforts than the reference case for all Annex I regions, while the effort for the non-Annex I regions decreases (see Figures 7.2a and 7.3). The latter results in a larger number of surplus emission allowances for Africa and South Asia, while both effects are larger in the short term than in the long term. If the policy delay is changed to 20 years, the effects described above are reversed: i.e. the emissions reduction efforts for the Annex I regions decrease with respect to the reference case, while the efforts of non-Annex I regions increase, and the total amount of surplus emissions declines. The policy delay assumption has the largest effects on Africa in the long term.

Due to a large projected increase of both emissions and the population for both South Asia and Africa, a short policy delay results in a large emission share, while a long policy delay results in a small share. For SE & E. Asia, only the emissions grow fast, while the population remains about the same. Therefore a change in policy delay does not have a large effect on the emission allowance of SE & E. Asia. The same holds for Latin America, because their population increase is much larger than their emission increase.

Generally, regions with emissions per capita much higher than world average gain from a longer policy delay, while regions with per capita emissions below world average gain largely from a shorter policy delay.

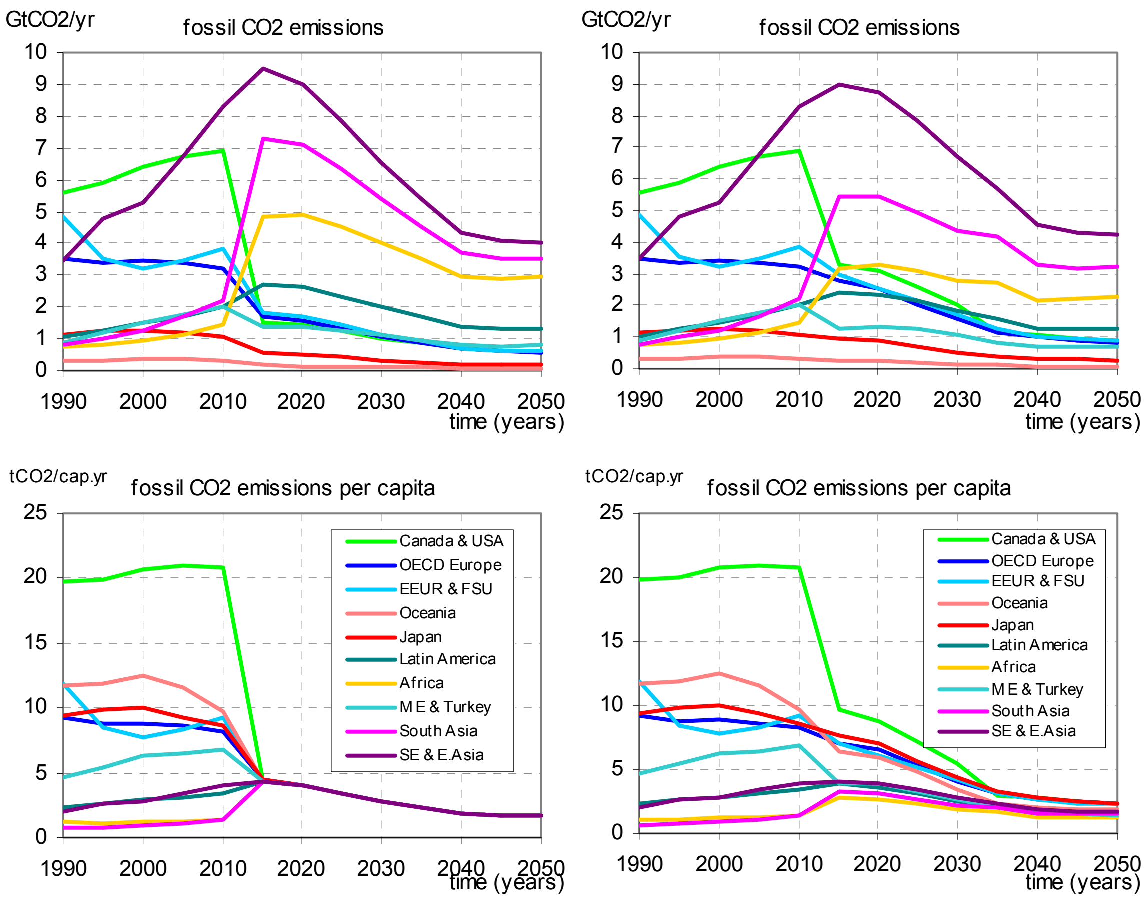

Figure 7.2a-b. Total and per capita fossil CO_2 emission allowances for ***no policy delay case (left) vs. the 20-year policy delay case (right)*** *for the selected regions with respect to the IMAGE S450c profile (Source: FAIR 2.0 model).*

The impact of cap on population

Accounting for a cap on population growth for calculating the emission allowances is to the disadvantage of countries with a fast-growing population between 2000 and 2025. This is especially true for non-Annex I regions with a high population growth; in particular, Africa, and to a lesser degree, South Asia, although the effect is only significant in the long term. An exception in non-Annex I is SE & E. Asia (including China) because there the population growth is lower than the world average. For the Annex I regions, a population cap in the long term is generally favourable, except for Oceania, which experiences a substantial population growth. However, in the short term, the population cap is not favourable, in particular, for Canada and the USA. This is a result of the change in China's preference. While China's initial preference was a per capita distribution, grandfathering becomes more favourable in 2025 in the 'no cap' case due to a decrease in their world population share, whereas under a cap this is further delayed. Therefore, no cap implies a larger weight for grandfathering, which is definitely favourable for the Annex I regions, whereas presence of a cap implies a much smaller weight for grandfathering, which is preferable for the non-Annex I regions.

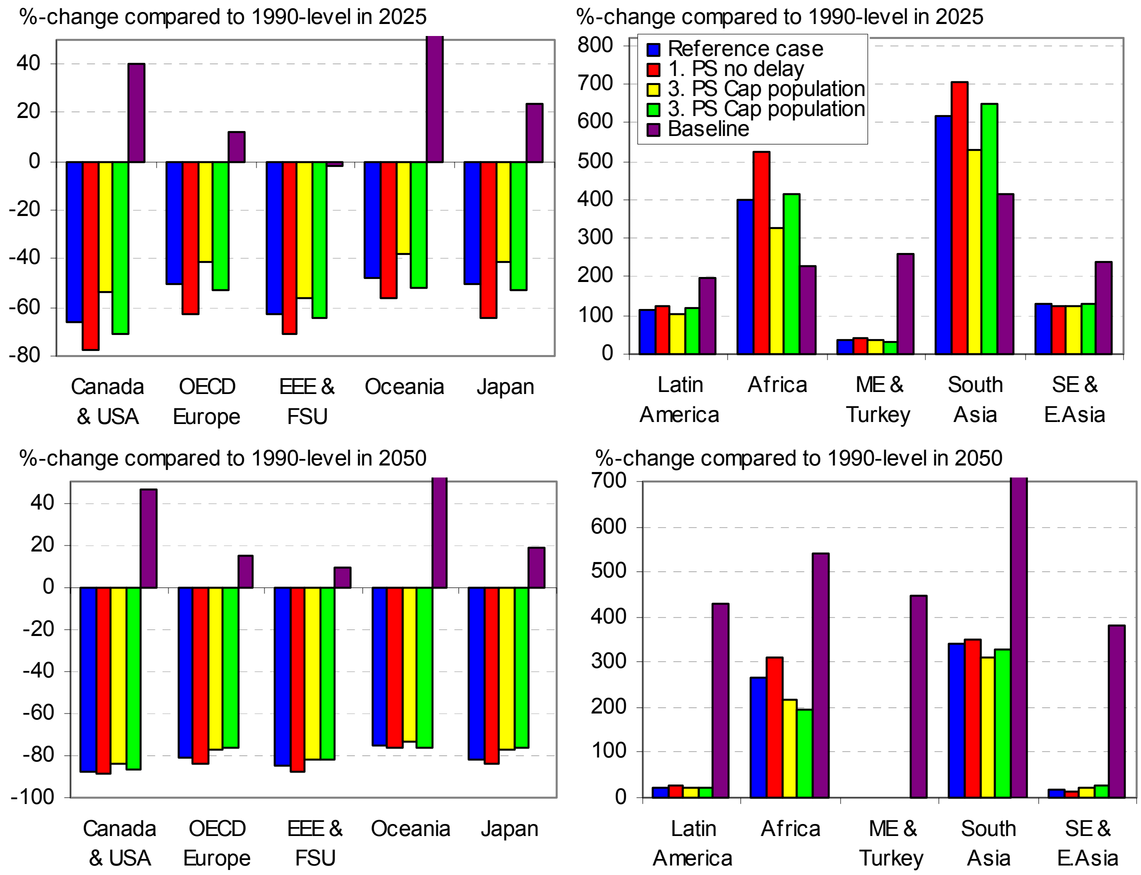

Figure 7.3: Percentage change in the emission allowances relative to the 1990 level for the Preference Score (PS) regime (reference case) and the three alternative cases in the target years 2025 and 2050.

Main findings:

- The PS approach results in a rapid initial change in the allocation of emission allowances. This is due to an initial reshuffle of the regional emission allowances based on the weighted mean of shares in emissions (grandfathering) and global population (per capita distribution). Since the largest share of the world population is initially in favour of a per capita division, regional per capita emission allowances strongly converge.
- In the short term, the PS approach is favourable to non-Annex I regions due to the initial reshuffle, while in the long term, the emissions per cap show a convergence. However, per capita emissions of the Annex I regions remain slightly above the per capita emissions of the non-Annex I regions.
- The emission allowances for Canada & USA and Oceania show the largest decrease, while the allowances for Africa and SE & E. Asia show the largest increase. Even in the case of a stringent climate target (stabilisation of the CO_2 concentration at 450 ppmv), the PS approach initially results in a large surplus of emission allowances, particularly in the African and South Asian regions.
- The policy delay has a large effect on the year of convergence of the per capita emissions. A large policy delay results in late convergence and a less drastic initial re-allocation, while a small policy delay results in earlier convergence and a more drastic initial re-allocation. Where no policy delay is applied, the emissions per capita show an almost immediate convergence.

- A 2010 population cap is to the disadvantage of the non-Annex I regions with high population growth, in particular, Africa and South Asia, but not for SE & E. Asia, with a population growth lower than the world average. In the short term, however, a population cap is to the disadvantage of the Annex I regions, since China's preference is now per capita division, enhancing the weight for grandfathering. In the long-term, a population cap is more favourable for the Annex I regions, except for Oceania, which also has a substantial population growth.

8 Jacoby rule

8.1 Introduction

A more bottom-up approach for burden-sharing is the so-called 'Jacoby rule', introduced by Jacoby et al. (1999) as an illustrative model of accession and burden-sharing. The basic principle behind this approach is the ability to pay. In comparison to the other approaches being analysed here, the regional emission allowances are not calculated by sharing the emission space of the global emission target profile using pre-defined burden-sharing rules, but by using a mathematical equation for calculating the emission allowances. The basis of this equation is that Parties only enter the international climate regime (and reduce their emissions) once they have exceeded a level of per capita welfare (a welfare 'trigger'), otherwise they will follow their reference emissions (unconstrained no-policy emissions trajectory). The emissions reduction is calculated on the basis of the difference between the per capita welfare income trigger level and a region's per capita welfare. Therefore, the total regional emissions are calculated from bottom-up, which implies these emissions are not by definition equal to the global emission profile. To make the results comparable to those of the other approaches, uniform scaling has been applied to the emission allowances of all participating regions to fit the IMAGE S450c profile.

8.2 Methodology

The most important variable in this regime is the per capita welfare trigger. This trigger allows regions to commit themselves to joining the emissions reduction scheme. The emissions reduction rate of region r at time t ($\eta_r(t)$) is then calculated using the difference between the welfare trigger (per capita income) (w^* in PPP$ per capita per year) and the per capita welfare of the previous time-step, $w_r(t-1)$:

$$\eta_r(t) = \gamma - \alpha.(w_r(t-1) - w^*)^{\beta} \qquad (8.1)$$

Using this equation, the emission allowance of region r at time t ($E_r(t)$ in GtC per yr) is:

$$E_r(t) = E_r(t-1) + \eta_r(t).E_r(t-1) \qquad \text{if } w_r(t-1) > w^* \qquad (8.2)$$

otherwise

$$E_r(t) = BEref_r(t)$$

where $BE_r(t)$ represents the baseline emissions of region r; $E_r(t-1)$ is the emission allowance of region r of the previous time-step. The welfare trigger is the key parameter in this approach, whereas the three parameters α, β and γ are tuning variables used to reproduce the global emissions (sum of the regional emissions) which best fit the global emission profile.

The variable γ determines the so-called grace period. In this period the regions should slow down their annual growth of emissions prior to the beginning of absolute reductions. The coefficients α and β influence the overall rate of emissions reduction. Parameter α has a large impact on the emission allowances of regions with a per capita income slightly above the welfare trigger *w**, while parameter β strongly affects emissions reduction rates when welfare is far from this threshold (Jacoby et al., 1999) (see also Figure 8.1).

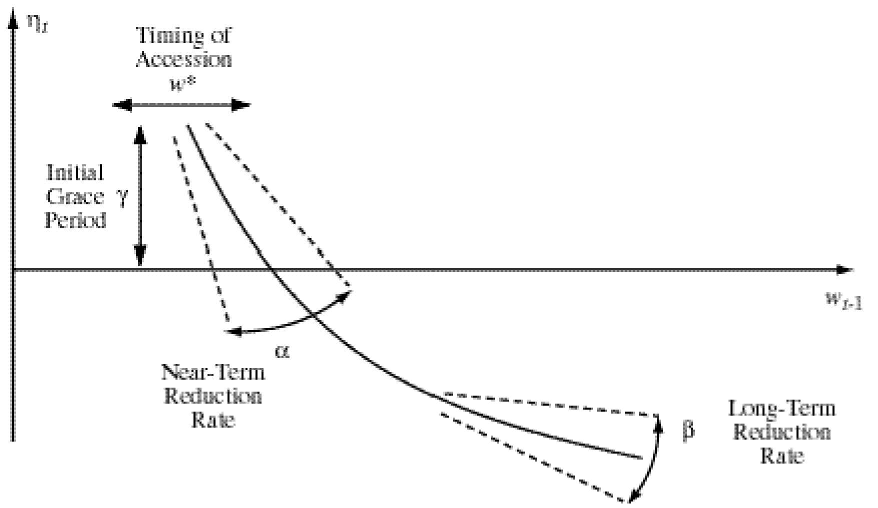

Figure 8.1. An example to illustrate the method behind the Jacoby rule (Jacoby et al., 1999).

For the analysis, the per capita welfare trigger is chosen as a percentage of the 1995 per capita welfare of the Annex I regions. After this key parameter is chosen, the three tuning parameters are set by trial an error. First the initial grace period γ is selected, avoiding abrupt changes in regional emission allowances, followed by the tuning of the parameters α and β to reproduce the global emission profile as best as possible.

When all parameters are set, a scaling factor is introduced which is calculated as the global emission profile minus the emission allowances for the regions not joining the burden-sharing, divided by the emission allowances of all participating regions. The calculated emission allowances for the regions that join burden-sharing are then multiplied by this scaling factor, reproducing the global emission profile.

8.3 The Jacoby rule approach (reference case)

In the reference case a welfare trigger of 40% of 1990 Annex I income (in PPP$) is used based on the following: (i) feasibility under the IMAGE S450c profile; and (ii) making the cases comparable to the reference cases of the other approaches. For the Jacoby rule approach, this does not lead to a convergence of the per capita Annex I and non-Annex I emission by 2050, as shown in Figure 8.2.

Figure 8.2 shows the results in terms of the ratio per capita fossil CO_2 emissions for Annex I and non-Annex I for various welfare thresholds. This clearly shows that the regional emission allowances under the Jacoby rule approach will highly depend on the assumptions for the welfare trigger. In the case of stringent climate targets (stabilisation of CO_2 at 450 ppmv), the income threshold needs to be below 75% of the 1990 Annex I income. A welfare trigger as low as 30% of the 1990 Annex I income leads to per capita emissions in Annex I of three times as high as the levels in non-Annex I. The default value of 40%, as in our reference case, still does not lead to convergence. A welfare trigger as high as 50% of the 1990 Annex I income would indeed lead to convergence in the per capita emissions by

2040. We will analyse the impact of changing the welfare trigger on the regional emissions allowances in more detail in the next section.

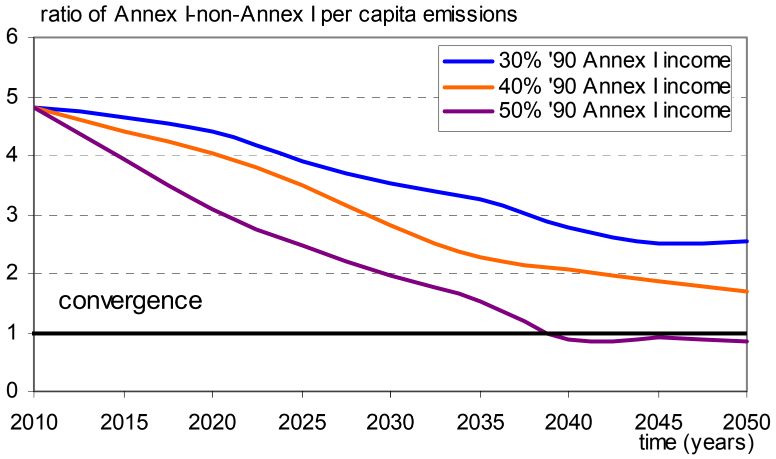

Figure 8.2. The impact of various levels of welfare thresholds for the Jacoby rule approach on the ratio per capita fossil CO_2 emissions for Annex I and non-Annex I under the IMAGE S450c profile (Source: FAIR 2.0 model).

Figure 8.3 shows the total and per capita fossil CO_2 emission allowances for the reference case of the Jacoby rule approach under the IMAGE S450c profile in the four IPCC and the selected regions. This shows how the reference case leads to sharp reductions in allowable emissions after the Kyoto period for almost all regions except Africa and South Asia. Figure 8.3 clearly shows a sharp reduction in emissions per capita for Annex I regions in comparison to 1990, while the emissions per capita for the non-Annex I regions first increase up to about 2020, and then start to decrease to below the 1990 per capita emission levels. This result can be explained with the chosen welfare trigger.

A welfare trigger as high as 40% of the 1990 Annex I per capita income implies that besides the Annex I regions (participating after 2010), only the high-income non-Annex I regions (regions Latin America, ME & Turkey and SE & E. Asia) are joining the regime in the short term (2025). The low-income non-Annex I regions gain from the chosen welfare trigger of 40% of the 1990 Annex I income, since their income does not reach this level before 2025, so they will just have to follow their baseline emissions.

Therefore in the short term (2025), the Jacoby rule approach implies not only large emissions reductions for the Annex I regions, but also for the high-income non-Annex I regions, i.e. Latin America, ME & Turkey and SE & E. Asia (See also Figure 8.4, reference case). Of all Annex I regions, the EEUR & FSU show the largest decline by 2025 as a result of the lower 2010 emission level, at which reductions starts.

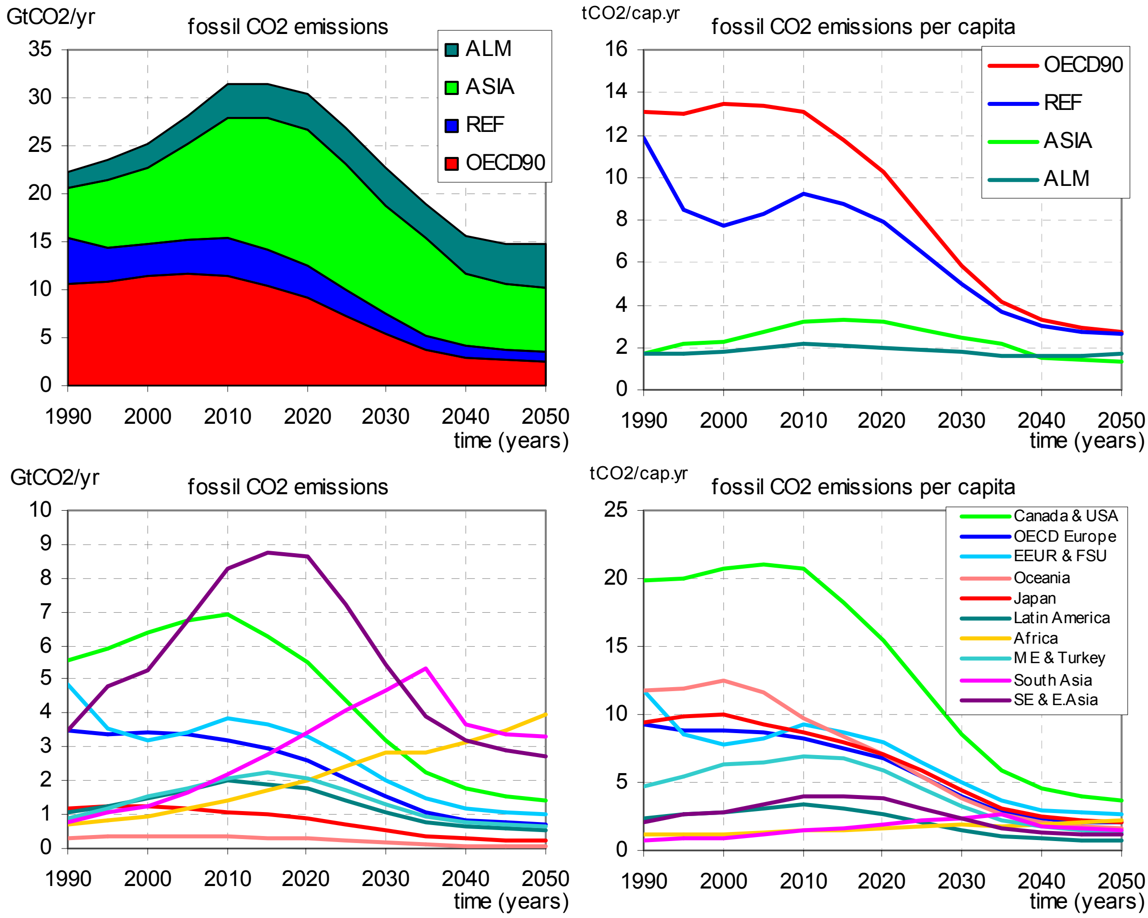

Figure 8.3a-b. Total and per capita fossil CO_2 emission allowances for the ***Jacoby rule regime (reference case)*** *for the four IPCC regions (upper) and the selected regions (lower) with respect to the IMAGE S450c profile (Source: FAIR 2.0 model).*

In the long-term the non-Annex I regions still also gain from the early participation of the high-income non-Annex I regions, while their reductions remain moderate (for more detailed information, see Appendix VI). South Asia joins the regime after 2040, resulting in a strong increase in emission allowances up to this year and a fast decline thereafter. The entry of South Asia into the burden-sharing regime obliges it to reduce its emissions, resulting in less decline for the rest of the joining regions. Only Africa shows an increase in its per capita emissions between 2010 and 2050, which results from the fact that most of Africa does not join the regime yet.

8.4 Robustness of results

We have formulated two alternative Jacoby rule cases, where the assumptions for the key parameter are similar to the reference case, except for one – the welfare trigger (see Table 8.1).

1. Jacoby rule approach with a low-income welfare trigger
2. Jacoby rule approach with a high-income welfare trigger

*Table 8.1: Reference case and the two alternative Jacoby rule case approach under the IMAGE S450c profile **

Key parameters	*Reference case*	*1. JR low welfare trigger*	*2. JR high welfare trigger*
Welfare trigger (gdp_0)	40% 1990 Annex I PPP per capita income	**30% 1990 Annex I PPP-per capita income**	**50% 1990 Annex I PPP per capita income**
Tuning parameters			
α	0.050	0.050	0.050
β	0.040	0.040	0.040
γ	0.040	0.050	0.020

*If $gdp_{(t-1)} > gdp_0$ (GDP per capita), $E_{(t)} = E_{(t-1)} + (\gamma - \alpha^*(gdp_{(t-1)}-gdp_0)^{\beta})^*E_{(t-1)}$ else $E_{(t)} = Reference_{(t)}$, where γ sets the period during which emissions can increase, αis the short-term emissions rate and β is the long-term reduction rate.

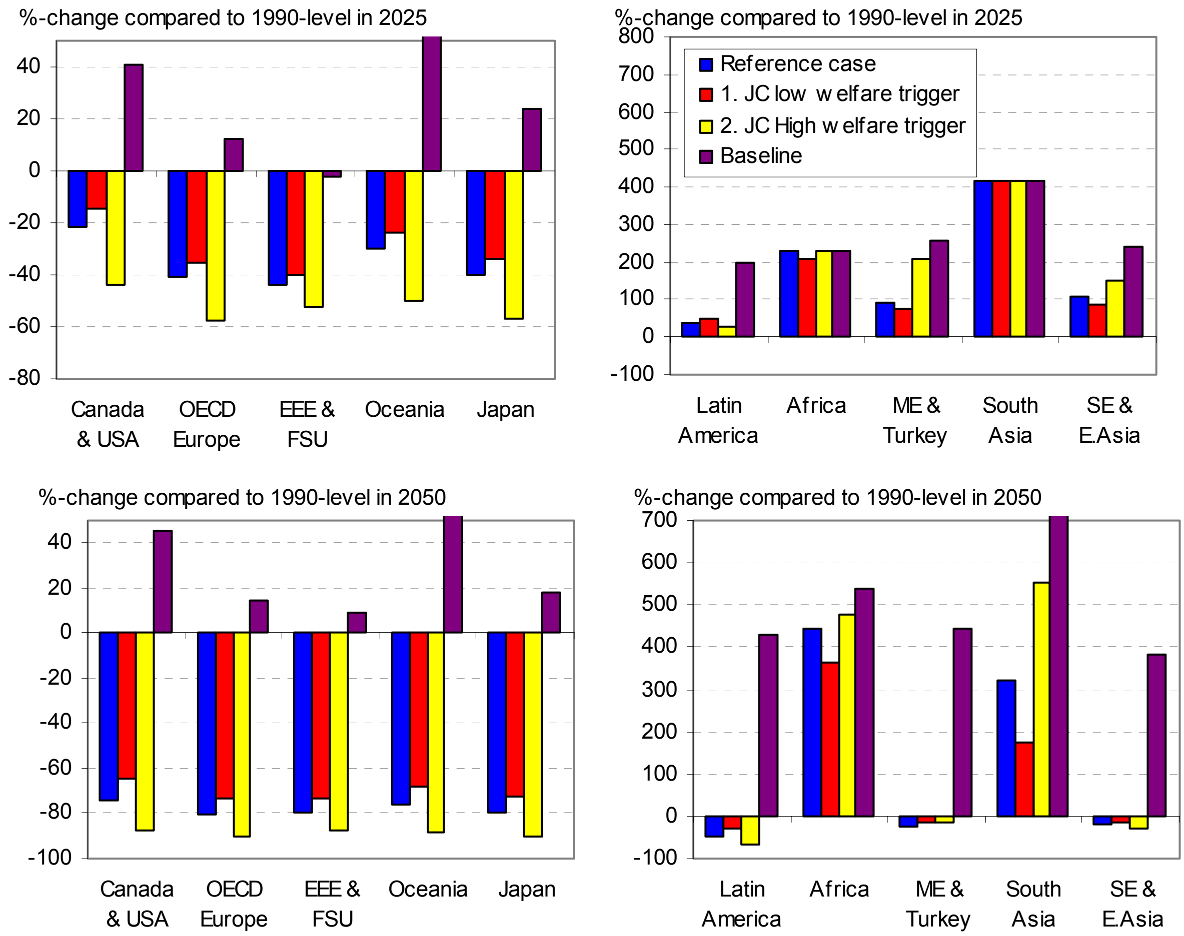

Figure 8.4: Percentage change in the emission allowances relative to the 1990 level for the ***Jacoby rule regime*** *(reference case) and the two alternative cases in the target year, 2025 and 2050 with respect to the IMAGE S450c profile (Source: FAIR 2.0 model).*

The impact of the welfare trigger

The first case with a lower welfare trigger leads to an earlier participation of the low-income non-Annex I regions (although just before 2025). The Africa and South Asia regions now participate much earlier in the regime, resulting in much lower emission allowance for these regions compared to the reference case. In general, a low welfare trigger is less attractive for all non-Annex I regions, and evidently, attractive for the Annex I regions. The Jacoby rule approach with the low welfare trigger delays the convergence in the per capita emissions for Annex I and non-Annex I after 2050.

South Asia also gains from surplus emission allowances in the short term. However, this is a result of the applied scaling. The bottom-up character of the methodology implies a necessary scaling of the calculated emission allowances to fit these to the global emission profile. This scaling may result in surplus emission allowances or discontinuities for regions that have just entered the regime. This is particularly true for South Asia in the case of a low welfare trigger. South Asia then already joins the burden-sharing regime in 2020, when the region is still in its initial grace period with its emission allowances. still increasing. Because of the positive scaling factor for this period, some surplus emission allowances are created for South Asia.

A high welfare trigger (case 2) leads to moderate non-Annex I emissions reductions, and larger emissions reductions for the Annex I regions. In the short-term, especially, ME & Turkey, and SE & E. Asia, gain from the somewhat high welfare trigger. They join the regime by 2020, and their emissions by 2025 show almost no difference with their baseline emissions. Of all non-Annex I regions, only Latin America loses from this welfare trigger. Especially Africa and South Asia enter the reduction regime at a very late date; the emissions of both regions can grow for a long time, leaving less emission space for the regions that have joined the regime. This implies that in the long-term (2050), all other regions will show the highest emissions reductions here.

In general, the methodology itself much depends on the welfare trigger chosen. The other tuning parameters are just meant to obtain a good fit with the global emission profile, and have no actual representation in real life. For low welfare triggers, different combinations of tuning parameters are possible. Also important are the scaling factors. While the Jacoby rule approach is initially bottom-up, scaling factors are needed to adjust the method for a top-down approach as applied here. These scaling factors can produce discontinuities in the results (for example, countries receive surplus emission allowances after entering the reduction stage). The level of discontinuities also depends on the tuning parameter values chosen, which may hamper the matching up of the bottom-up outcomes with the global emission profile. This problem occurs mainly for cases with high welfare triggers, since only then does a limited group of regions participate in the emissions reduction regime.

Main findings:

- The regional emission allowances under the Jacoby rule approach highly depends on the assumptions for the welfare trigger. In the case of stringent climate targets (stabilisation of CO_2 at 450 ppmv), the income threshold needs to be below 75% of the 1990 Annex I income.
- In the short term, the Jacoby rule approach implies not only to high emissions reductions compared to baseline emissions for the Annex I regions, but also to reductions for the high-income non-Annex I regions (Latin America, ME & Turkey and SE & E. Asia). The reductions of these non-Annex I regions become even greater in the long term than the Annex I reductions. For the low-income non-Annex I regions the chosen welfare trigger of 40% of 1990 Annex I income is attractive, since their income does not reach this level before 2025, and they just follow their baseline emissions. In the long-term these regions gain from the early participation of the high-income non-Annex I regions, while their reductions are still moderate.
- A low welfare trigger leads to earlier participation of the low-income non-Annex I regions (although just before 2025). In general, a low welfare trigger is less attractive for all non-Annex I regions, and evidently, more attractive for the Annex I regions. The Jacoby rule approach with low welfare triggers delays the convergence in the per capita emissions for Annex I and non-Annex I after 2050.

- A high welfare trigger leads to moderate non-Annex I emissions reductions, and high emissions reductions for the Annex I regions. The emissions per capita for Annex I and non-Annex I converge towards 2050, which makes the regime more attractive for the non-Annex I regions. Especially Africa and South Asia show a very late entry into the reduction regime, leaving little emission space for the regions already joined up.
- Due to the bottom-up character of the Jacoby rule approach, scaling factors are needed to adjust the method for the top-down approach as applied here. These scaling factors can create discontinuities in the results. Combined with the sensitivity of the three tuning parameters, the approach is largely parameter-dependent and therefore does not create very robust results.

9 Overall analysis of climate regimes

In the first section of this chapter we will evaluate the emissions reduction levels for the Annex I and non-Annex I regions for both the reference cases and the five approaches for differentiation of commitments explored here under the S450c profile. This will be followed in section 9.2 by a more detailed discussion on the differences between the approaches for the different regions. We will start by evaluating approaches for the reference cases to see which are more and less favourable for the various regions in the short (2025) and long terms (2050). In section 9.3 we will examine the robustness of the findings by comparing the approaches for reference cases with policy settings favourable for either Annex I or non-Annex I regions. This will be followed in section 9.4 by some general findings from the comparison of approaches. Finally, we will evaluate to what extent the relative attractiveness of the various approaches is affected by using the global CO_2 emission profiles for stabilising CO_2 concentrations at 550 ppmv (section 9.5).

9.1 Analysing the Annex I and non-Annex I reductions under the S450c profile

9.1.1 Annex I regions

Figure 9.1 shows the results of the analysis of approaches for all the reference cases in terms of the percentage change relative to the 1990 emission level for the short-term target year, 2025, and for the long-term target year, 2050, under the IMAGE S450c profile. Approaches comprise the Brazilian Proposal (BP), Multi-Stage (MS), Per Capita Convergence (PCC), Preference Score (PS) and Jacoby rule (JR). Figure 9.1 shows that in 2025 reductions in emission allowances for all Annex-I regions of at least 20-60% compared to the 1990 levels are necessary to achieve the 450-ppmv target. Except for the Brazilian Proposal cases, the reductions in 2050 are 70-90% (S450c). The Brazilian Proposal case shows high emissions reductions of more than 100%, (i.e. negative emission allowances), except for Oceania. For OECD Europe, the reductions compared to 1990 levels are for S450c 40-60% in 2025 and 80-90% in 2050 (apart from the Brazilian Proposal with reductions of more than 100% in 2050).

9.1.2 Non Annex I regions

In the short term (2025), non-Annex I regions can still increase their emissions compared to their 1990 levels, while Annex I regions have to decrease their emissions substantially (Figure 9.1). The changes are generally more differentiated across non-Annex I regions than across Annex I regions. The low-income non-Annex I regions (i.e. Africa and South Asia) experience small emission constraints compared to baseline levels in all cases, while the middle- and high-income non-Annex I regions (Latin America, the Middle East and the SE & East Asia regions) take an intermediate position between low income non-Annex I and Annex I regions.

In 2025, the low-income non-Annex I regions under the S450c profile experience very limited emissions reductions, and their emissions may even be higher than in the baseline, resulting in surplus emissions as in the PS and PCC cases. The PS case leads, in particular, to high levels of surplus emissions for South Asia and Africa. For the PCC case only Africa gains from surplus emissions (see also Table 9.1). In the other middle- and high-income non-Annex I regions reductions increase to about 30-60% for Latin America and Middle East, and to 30-40% for SE& East Asia.

In 2050 and under the S450c profile, the emissions reductions of the middle- and high-income non-Annex I regions turn out very similar to that of Annex I regions, as they all participate in the absolute emissions reduction system. The required reductions are very similar across the five approaches, with about 70-80% reduction level for SE& East Asia, and 80-90% for Latin America and Middle East. Reductions remain limited for Africa and South Asia (around 30-40%). For the low-income non-Annex I regions, the reductions compared to the baseline emissions are still less compared to these regions, but already reach values up to 10-40% for Africa and 40-60% for South Asia.

In conclusion, major non-Annex I regions (East Asia and South Asia) need to reduce their emissions before the middle of this century, irrespective of the emission allocation approach and type of threshold chosen. This implies that non-Annex I regions will have to start participating in global emissions reductions at significant lower per capita income and emission levels than Annex I under the KP.

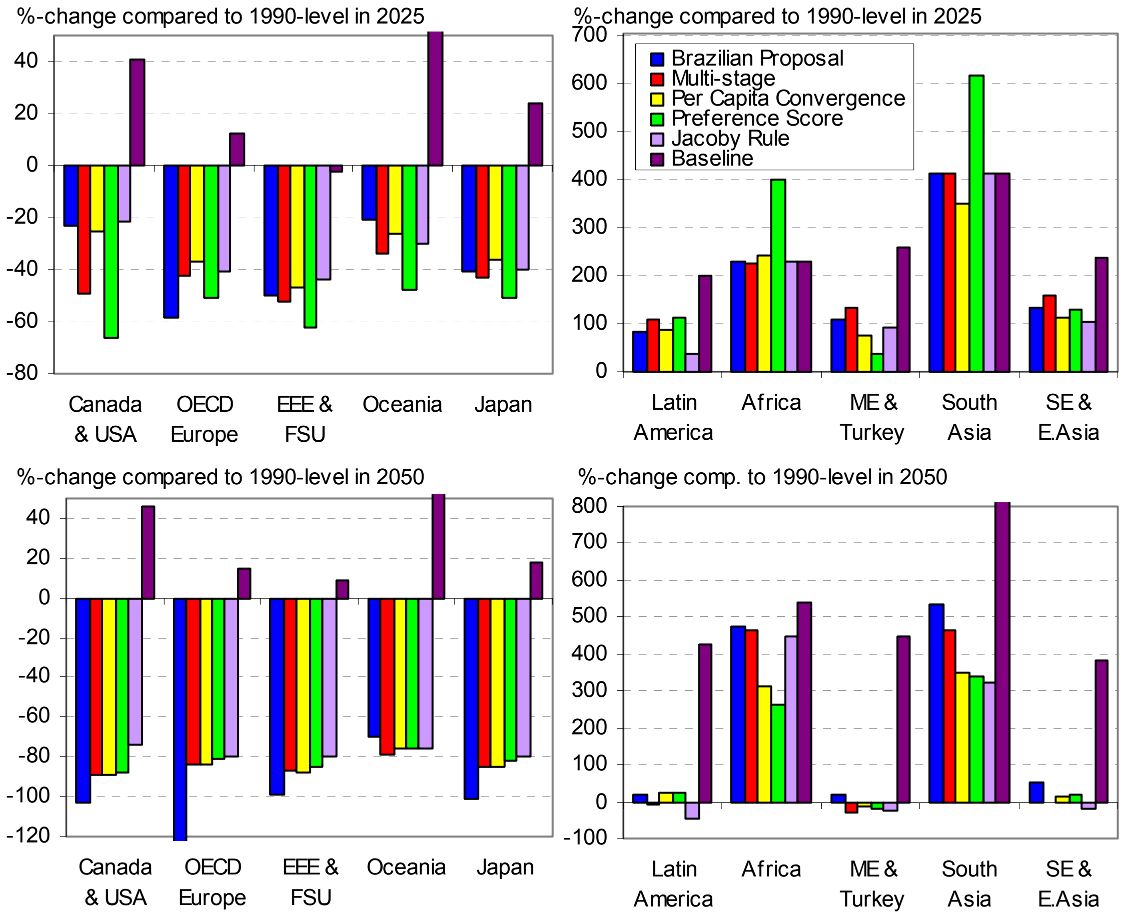

Figure 9.1: Percentage change in the emission allowances relative to the 1990 level for the ***reference cases*** *of the regimes under the IMAGE S450c profile for 2025 (upper) and 2050 (lower) (Source: FAIR 2.0 model).*

9.2 Comparing the reference cases of the regimes explored under the S450c profile

9.2.1 Short-term (2025)

Table 9.1 ranks the percentage change relative to the baseline-emission level for the target year, 2025, of each regime in comparison to the outcomes of the other regimes explored. The approach resulting in, relatively speaking, the lowest relative emissions reductions (or highest emission allowances) is indicated in green, hereafter classified as the most favourable or most attractive approach compared to the other regimes explored. The approach resulting in the highest relative emissions reductions (or lowest emission allowances) is indicated in red; this will be forthwith classified as the most favourable or most attractive approach compared to the other regimes explored. White indicates an intermediate position. It should be noted that this ranking is always in relative comparison to the outcomes of the other regimes explored.

*Table 9.1. Regional relative scores reached for the **reference cases** of the different approaches by **2025** in comparison to baseline under the IMAGE S450c profile**

	Brazilian Proposal	Multi-Stage	Per Capita Convergence	Preference Score	Jacoby Rule
Canada & USA	-45**	-64	-47	-76	-44
OECD Europe	-63	-49	-44	-56	-47
EEUR & FSU	-49	-52	-46	-62	-43
Oceania	-55	-63	-59	-70	-61
Japan	-52	-54	-49	-60	-51
Latin America	-39	-31	-37	-28	-53
Africa	0***	-1	4	52	0
ME & Turkey	-42	-34	-51	-62	-46
South Asia	0	0	-12	39	0
SE & E. Asia	-31	-24	-38	-33	-39

** Green areas indicate the most attractive regime and red areas, the least attractive regime for each region. White shows intermediate positions.*
*** If the differences between two approaches are not significant (less than 5% in absolute terms), both are placed in the same group.*
**** If the differences between more than two approaches are not significant (less than 5% in absolute terms), all are placed in the white areas (intermediate position)*

Findings for the reference cases (short-term):

- The BP approach reference case, i.e. the allocation of emissions reduction based on a region's contribution in realised global temperature increase (combined with an income participation threshold), is particularly unattractive for OECD Europe and Japan. This is due to the region's relatively large historical contribution to temperature increase. The non-Annex I regions, such as Latin America, with high historical land use emissions, are also assigned relatively large reduction targets.
- The MS approach reference case is one of the least attractive approaches for Canada & USA due to the per capita emission burden-sharing key. It is generally attractive for middle- & high-income non-Annex I regions (Latin America, ME & Turkey and SE & E. Asia). Moreover, the per capita burden-sharing key turns out to be more favourable for these regions than the contribution to (realised) temperature (BP) and PPP$ income (JR). The MS approach reference case is also attractive for low-income non-Annex I regions, because they can follow their baseline emissions. However, for Africa it is less attractive than the PS and PCC approaches because it does not experience surplus emissions.

- Per capita convergence (PCC) is the most attractive approach for OECD Europe and Japan, because of their relatively low per capita emissions and the fact that under PCC, all countries contribute. The latter makes PCC, relatively speaking, the least attractive approach for South Asia and East, and SE & E. Asia. South Asia is better off with respect to the income thresholds under the BP, MS and JR reference cases. Since the per capita emissions for SE & E. Asia are close to the world average per capita emissions, they do not gain from the per capita convergence, and therefore the PCC reference case is the least attractive approach for SE & E. Asia (China).
- The PS approach reference case is clearly the least attractive approach for most OECD regions due to the initial re-allocation in per capita emission towards convergence. For the same reason, the PS is the most attractive approach for most non-Annex I regions, except for ME & Turkey, with their relatively high per capita emissions.
- The JR reference case is particularly attractive for the EEUR & FSU regions because of the relatively high emission intensities of their economies. It is also relatively attractive for Canada & USA. With respect to the non-Annex I regions, it is particularly unattractive for Latin America and, to a lesser extent, for SE & E. Asia due to their relatively high per capita income levels.

9.2.2 Long-term (2050)

The results for 2050 are presented in Table 9.2. Figure 9.2 also gives the emission allowances in time for the reference cases of the five regimes explored for each of the ten regions. This clearly shows how time can change the attractiveness of an approach, in particular, for the BP, PCC and PS cases. The findings summarised below focus on these changes.

Table 9.2. Regional relative scores reached for the ***reference cases*** *of the different approaches by* ***2050*** *in comparison to baseline under the IMAGE S450c profile**

	Brazilian Proposal	Multi-Stage	Per Capita Convergence	Preference Score	Jacoby Rule
Canada & USA	-102	-92	-92	-91	-82
OECD Europe	-135	-86**	-86	-83	-83
EEUR & FSU	-99	-88	-88	-86	-81
Oceania	-86	-90	-89	-88	-89
Japan	-101	-87	-87	-84	-83
Latin America	-77	-83	-76	-77	-90
Africa	-10	-12	-36	-43	-15
ME & Turkey	-78	-87	-84	-85	-86
South Asia	-37	-44	-56	-57	-58
SE & E. Asia	-69	-80	-76	-75	-84

** Green areas indicate the most attractive regime and red areas, the least attractive regime for each region. White shows intermediate positions.*
*** If the differences between more than three approaches are not significant (less than 5% in absolute terms), all are placed in the white area (intermediate position).*

Main findings of the reference cases (long-term):

- In 2050, the differences between the cases for the Annex I regions are small, except for the BP case, whereas for the non-Annex I regions there is more variation between cases.

The BP approach reference case is the least attractive regime for almost all Annex I regions. Regions even experience negative emission budgets due to their large contribution to global temperature increase via their high historical emissions. Consequently, the BP approach allows more emission space for the non-Annex I regions, and therefore BP becomes the most attractive approach for them. Their contribution to the global temperature increase is much less as a result of their lower historical emissions.

- The MS reference case takes an intermediate position in comparison to the other cases for all Annex I regions, with results in the long term comparable to those of the PCC and PS reference cases. MS becomes more attractive for the low-income non-Annex I regions than for the higher income regions, since it takes time for them to join the reduction group. The MS reference case becomes more attractive for the low-income non-Annex I regions than the PCC and PS reference case.
- By 2050 none of the low-income non-Annex I regions experiences surplus emissions for the PCC reference case; instead, they have to reduce their emissions as well.
- The PS reference case is no longer the least attractive approach for most Annex I regions, and the most attractive for the non-Annex I regions, but, instead, results in emission allowances comparable to the PCC case. Due to the weighting between grandfathering and per capita allocation, the PS approach leads to somewhat fewer reductions in Annex I and somewhat larger reductions in non-Annex I regions.
- The JR reference case becomes the most favourable case for the Annex I regions, and the least favourable for the non-Annex I regions. All non-Annex I regions join the burden sharing by 2050, while the reduction rate is almost the same for all regions. This results in relatively large reductions for the middle- and high-income non-Annex I regions, leaving more emission space for the Annex I regions.

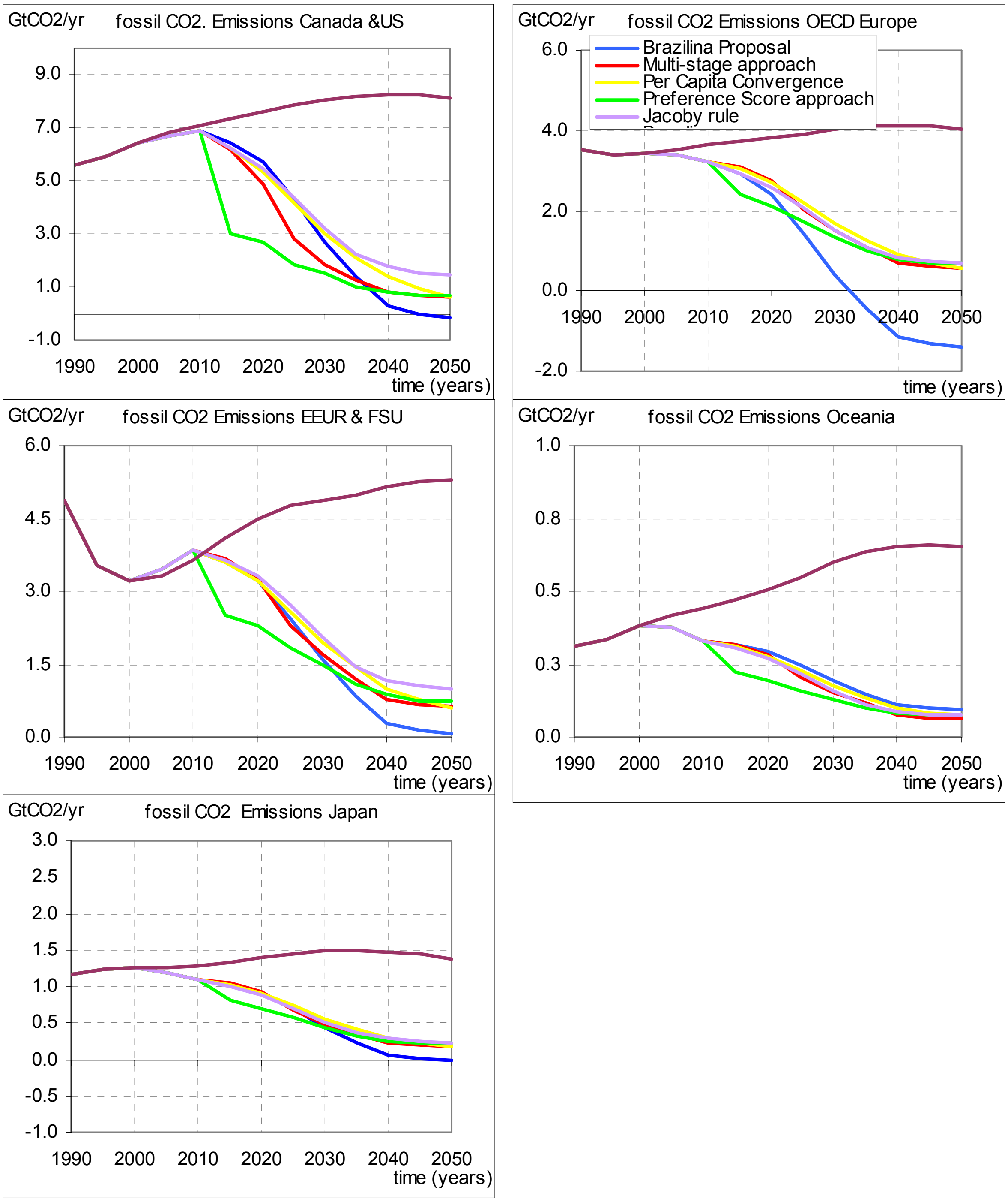

Figure 9.2a. Climate regimes under the IMAGE S450c profile for the Annex I regions (Source: FAIR 2.0 model).

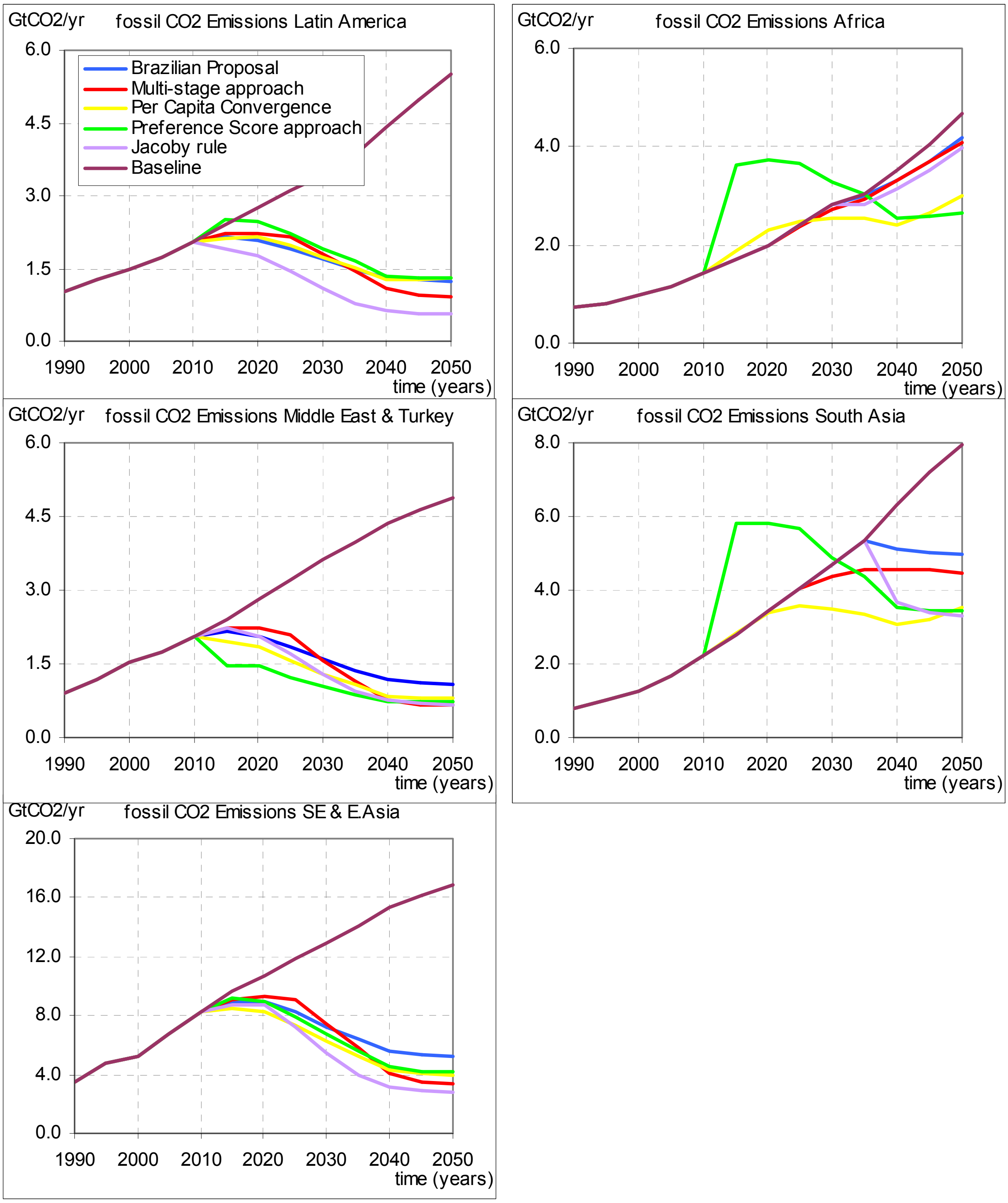

Figure 9.2b. Climate regimes under the IMAGE S450c profile for the non-Annex I regions (Source: FAIR 2.0 model).

9.3 Robustness of results for the S450c profile

To explore the robustness of the findings on the relative attractiveness of the regimes for various regions in both the short and long terms, we compared the alternative cases with parameter settings favourable for either Annex I or non-Annex I regions. This sensitivity analysis is performed to assess the impact of a change in assumptions for the key policy parameters on the emission allowances, and thus the robustness of the relative attractiveness of regimes for the various regions. The analysis is based on the previously presented variants of the reference cases, in which all but one of the key parameters are changed. Depending on the settings of the policy parameters, the cases are grouped as either Annex I-favourable (AF) or non-Annex I-favourable (NAF). The AF cases lead to relatively smaller Annex I emissions reductions compared to those for the reference case, while the NAF cases correspond to parameter settings leading to less stringent non-Annex I commitments relative to the non-Annex I commitments under the reference cases. Table. 9.3 overviews the grouping of the AF and NAF cases.

Table 9.3. Annex I favourable (AF) en non-Annex I favourable (NAF) variants of the reference cases of the various regimes

Annex I favourable (AF) cases	**Non-Annex I favourable (NAF) cases**
BP: all Parties participate starting in 2010	BP: burden-sharing key based on temperature increase per capita
MS: burden-sharing key based on emission intensity	MS: burden-sharing key based on PPP income
PCC: cap on population	PCC: 2030 convergence
PS: 20-year policy delay	PS: no policy delay
JR: low welfare trigger	JR: high welfare trigger

9.3.1 Short term (2025)

Table 9.4 presents the results of the Annex I-favourable (AF) and Non-Annex I-favourable (NAF) cases of the various regimes by 2025. Indicated are the relative changes in emission allowances compared to the baseline emission levels under the IMAGE S450c profile.

Findings of AF & NAF cases (short-term):

- The most important finding of these AF and NAF cases is that regional emission allowances depend just as much on the different regimes chosen as on the chosen parameters settings, except for the Preference Score approach. The sudden re-allocation of commitments makes the PS approach in the short term always the least attractive for Annex I and Middle East, and in general, the most attractive for the rest. The most important policy parameters are threshold levels, burden-sharing key and convergence dates.
- The finding that the BP case is not attractive for OECD Europe is no longer valid if the BP approach is applied without a threshold for participation (AF case). Assuming full participation after 2010, the BP approach would become an attractive approach for all Annex I regions, although this only holds for the short-term. However, this would imply that the developing countries have no room for increasing their emissions after KP. Except for Canada & USA, and OECD Europe, the emissions reductions for most Annex I regions under the BP NAF case differ only marginally from the BP reference case. This makes the BP approach the most attractive NAF case for most Annex I regions.
- The AF and NAF cases of the MS approach show almost no differences for the non-Annex I regions, since these regions have either not or only just entered the de-carbonisation regime; a different burden-sharing key has therefore no effect. However, for the non-Annex I regions, the MS NAF case becomes relatively less

favourable compared to other NAF cases. Contrary to most other Annex I regions, the MS AF case (with burden sharing based on emissions intensity) is particularly unfavourable for the FSU.

- All PCC cases (reference, AF and NAF) lead to the same conclusions for the non-Annex I regions, namely that PCC is attractive for Africa (due to surplus emission allowances) and unattractive for SE & E. Asia, and ME & Turkey. For the Annex I regions both the PCC and the MS cases still hold an intermediate position compared to the others. However, the early convergence year, 2030, in the NAF case has a large impact on the results.
- The PS approach remains the least attractive approach for Annex I even in the AF case. The results for the non-Annex I regions are also little affected by the AF and NAF cases: the PS approach remains the most attractive case for most non-Annex I regions.
- The JR approach shows fairly robust results for Canada & USA and the FSU. In comparison to other approaches, this one remains attractive for these regions. The approach is also fairly robust for Latin America, where it remains the least attractive due to the relatively large per capita income level of Latin America and therefore its early participation.

Table 9.4. Regional relative scores for different approaches for the Annex I favourable (AF) and Non-Annex I favourable (NAF) cases by ***2025*** *compared to baseline under the IMAGE S450c profile**

AF cases	**Brazilian Proposal**	**Multi-Stage**	**Per Capita Convergence**	**Preference Score**	**Jacoby Rule**
Canada & USA	-38	-51	-47	-67	-39
OECD Europe	-34	-39	-42	-48	-42
EEUR & FSU	-31	-80	-44	-56	-39
Oceania	-44	-60	-59	-64	-57
Japan	-32	-39	-47	-52	-47
Latin America	-31	-32	-37	-31	-50
Africa	-45	-1	-6	29	-6
ME & Turkey	-38	-37	-52	-61	-50
South Asia	-32	0	-14	22	0
SE & E. Asia	-31	-25	-37	-34	-45

NAF cases	**Brazilian Proposal**	**Multi-Stage**	**Per Capita Convergence**	**Preference Score**	**Jacoby Rule**
Canada & USA	-63	-66	-69	-84	-60
OECD Europe	-52	-61	-58	-67	-62
EEUR & FSU	-46	-37	-60	-70	-50
Oceania	-53	-67	-69	-75	-72
Japan	-48	-65	-62	-71	-65
Latin America	-33	-31	-29	-24	-58
Africa	0	-1	56	90	0
ME & Turkey	-39	-32	-56	-60	-13
South Asia	0	0	29	57	0
SE & E. Asia	-26	-23	-36	-34	-26

** Green areas indicate the most attractive regime and red areas, the least attractive regime for each region. White shows intermediate positions.*

*** If the differences between two approaches are not significant (less than 5% in absolute terms), both are placed in the same group.*

**** If the differences between more than two approaches are not significant (less than 5% in absolute terms), all are placed in the white areas (intermediate position).*

9.3.2 Long-term (2050)

The results of the AF and NAF cases under the S450c profile are again compared for the year 2050 (Table 9.5).

Findings of AF & NAF (long-term):

- The BP approach takes over the position of the PS approach as the most unfavourable one for the Annex I regions. Since this is also true for the AF this is a robust finding, explainable by the large share in the historical emissions for the Annex I regions, while the non-Annex I regions are very late starters.
- The AF and NAF cases show the relative attractiveness of the MS approach to both Annex I and non-Annex I regions in the long term to be dependent on the burden-sharing key chosen. Burden sharing based on emission intensity is particularly unfavourable for EEUR/ FSU, ME & Turkey, and SE & E. Asia, while burden sharing based on PPP income is particularly unfavourable for Oceania and Japan.
- The results of the PCC and PS approaches are very similar, because both result in some sort of convergence in emissions per capita in 2050. Both approaches are more favourable for non-Annex I regions in the short term than in the long term.
- The JR approach remains among the more favourable cases for Annex I in both the AF and NAF cases. For non-Annex I the JR approach remains unattractive in the long term, even in the NAF case, especially for Latin America and SE & E. Asia, due their relatively large per capita income level and therefore early participation.

*Table 9.5. Regional relative scores for different approaches for the Annex I favourable (AF) and Non-Annex I favourable (NAF) cases by **2050** compared to baseline under the IMAGE S450c profile**

AF cases	**Brazilian Proposal**	**Multi-Stage**	**Per Capita Convergence**	**Preference Score**	**Jacoby Rule**
Canada & USA	-99	-82	-91	-89	-76
OECD Europe	-97	-70	-79	-80	-77
EEUR & FSU	-90	-94	-83	-83	-75
Oceania	-83	-84	-89	-87	-85
Japan	-87	-63	-80	-81	-77
Latin America	-68	-89	-77	-77	-87
Africa	-75	-15	-53	-51	-27
ME & Turkey	-72	-92	-87	-85	-85
South Asia	-68	-45	-58	-59	-73
SE & E. Asia	-63	-85	-73	-75	-82

NAF cases	**Brazilian Proposal**	**Multi-Stage**	**Per Capita Convergence**	**Preference Score**	**Jacoby Rule**
Canada & USA	-100	-99	-92	-92	-91
OECD Europe	-99	-98	-86	-86	-92
EEUR & FSU	-98	-83	-88	-88	-89
Oceania	-94	-98	-89	-89	-94
Japan	-98	-98	-87	-87	-92
Latin America	-76	-84	-76	-76	-94
Africa	-13	-11	-36	-36	-10
ME & Turkey	-84	-79	-84	-84	-84
South Asia	-42	-44	-56	-56	-36
SE & E. Asia	-74	-77	-76	-76	-85

9.4 Other findings for the IMAGE S450c profile

Before presenting overall findings on the results of the various approaches under the global emission profile for stabilising the CO_2 concentrations at 450 ppmv by 2100, we will first look at the full range of outcomes of all cases (reference and sensitivity) for each of the regime approaches (Figure 9.3). Depending on the selected policy parameter settings, the results indicate that the range of regional outcomes for each approach may show strong deviation. This is particularly clear for the BP and PCC cases, but for some regions also for other approaches, such as the MS approach in case of the EEFSU and the JR approach in case of Africa. The range of outcomes is such that it can strongly change the relative attractiveness of the various approaches for the different regions (see Figure 9.3).

On the basis of the analysis in the previous sections and the uncertainty ranges presented above, we can now present more general robust findings of the analysis for the outcomes for the various approaches under the S450c stabilisation profile.

- For all Annex I regions, the PS regime is generally the least attractive in the short term, while the BP approach is the least attractive in the long term. In fact, the BP approach can result in negative emission allowances for Annex I regions under S450c.
- Except for the BP approach, the differences between the requirements of the other approaches under the S450c profile in the long term seem of relatively minor importance given the fact that, in all cases, large reductions of between 80 and 90% are needed.

In the case of approaches with a threshold, OECD Europe and Japan are relatively less sensitive to the burden-sharing key chosen than other Annex I regions (apart from the BP approach).

- For approaches with a threshold, there are also clear differences in interest between high and low-income non-Annex I regions. The high-income non-Annex I regions have an interest in early participation of the low-income non-Annex I regions, but here too the burden-sharing key chosen also plays a significant role.
- For the less developed non-Annex I regions, participation is more attractive than non-participation where their allowable emission levels are greater than their baseline emissions, as in the case of PS and PCC approaches in the short term.[20]
- For the more developed non-Annex I regions, PCC can be less attractive than approaches with income thresholds, depending on the threshold level and burden-sharing key selected. For China and the Middle East, in particular, a PCC approach is more stringent than MS.
- The PS and PCC cases differ mainly in the short term; the long-term results tend to fully converge. At the same time, the attractiveness of both the PCC approach and the PS approach for the non-Annex I regions tends to decrease over time.
- In approaches with thresholds, a (relatively) high threshold for participation results in non-Annex I regions experiencing a strong shift from their baseline toward emissions reductions once having entered the burden-sharing regime.[21]

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[20] However, ET can make participation attractive even if (limited) reductions from baseline are required.
[21] This can be problematic as it may result in non-compliance.

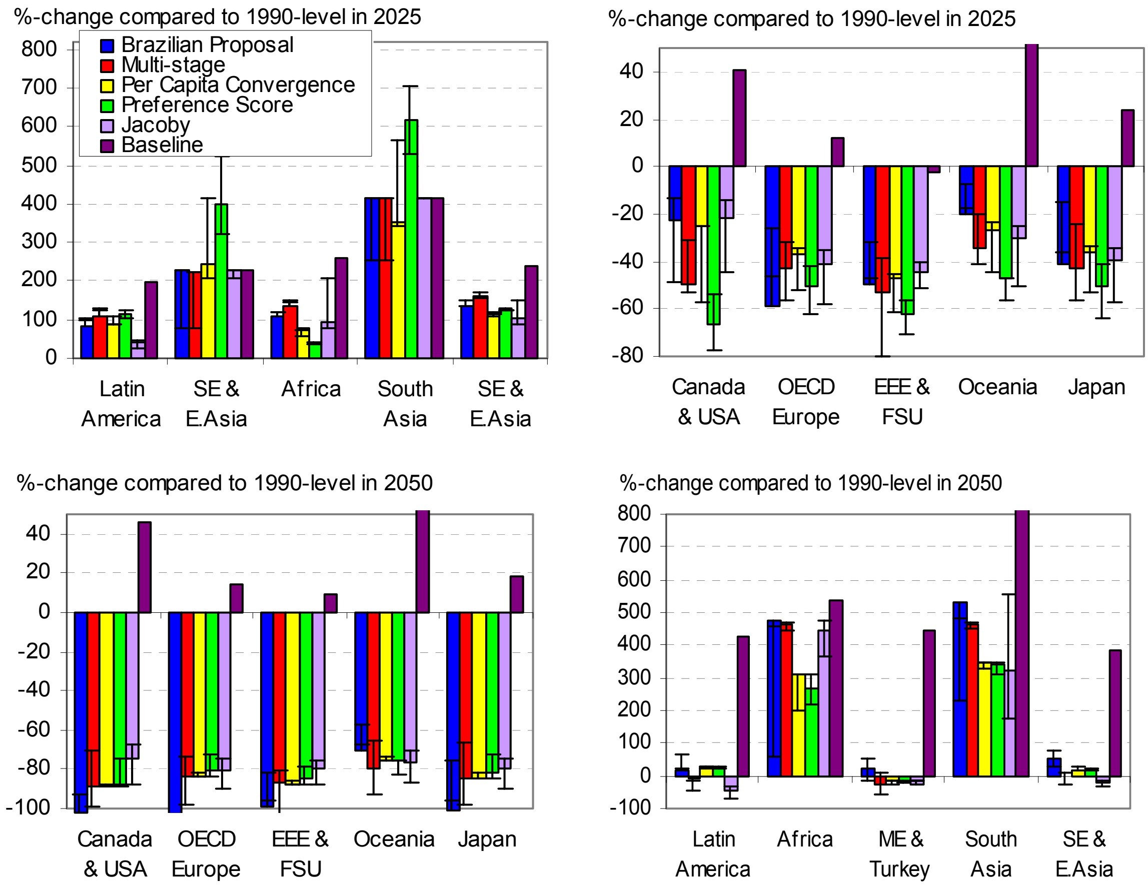

Figure 9.3. Range of percentage change in the emission allowances relative to the 1990 level for the reference cases ***(coloured bars) and uncertainty cases (uncertainty bars)*** *of the various regimes under the IMAGE S450c profile for 2025 and 2050 (Source: FAIR 2.0).*

9.5 Analysing the Annex I and non-Annex I reductions for the S550c profile

In this section we will analyse the Annex I and non-Annex I emissions reductions under the S550c profile for the reference cases of the regime approaches explored, as given in Figure 9.4.

9.5.1 Annex I regions

It is clear that the level of emissions reductions required under the S550c emission profile for the Annex I regions by 2025 is substantially lower than under the S450c profile in both the short and the long terms. The range of emissions reductions for Annex I regions resulting from various regime approaches also increases when shifting from S450c to S550c, particularly in the long term. While under the S450c profile, Annex I regions have to reduce their emissions in 2025 in all cases by 20-60% compared to 1990 levels, the S550c profile is showing a much wider range. In some cases emissions still increase up to 30% compared to their 1990 levels, while in other cases emission allowances decrease up to 50%. In 2050 Annex I regions in all approaches have to reduce their emissions also under the S550c profile by 15-70%compared to 1990 levels, instead of 70-90% under the

S450c profile. The wider ranges also indicate a greater sensitivity to the choice of the burden-sharing keys.

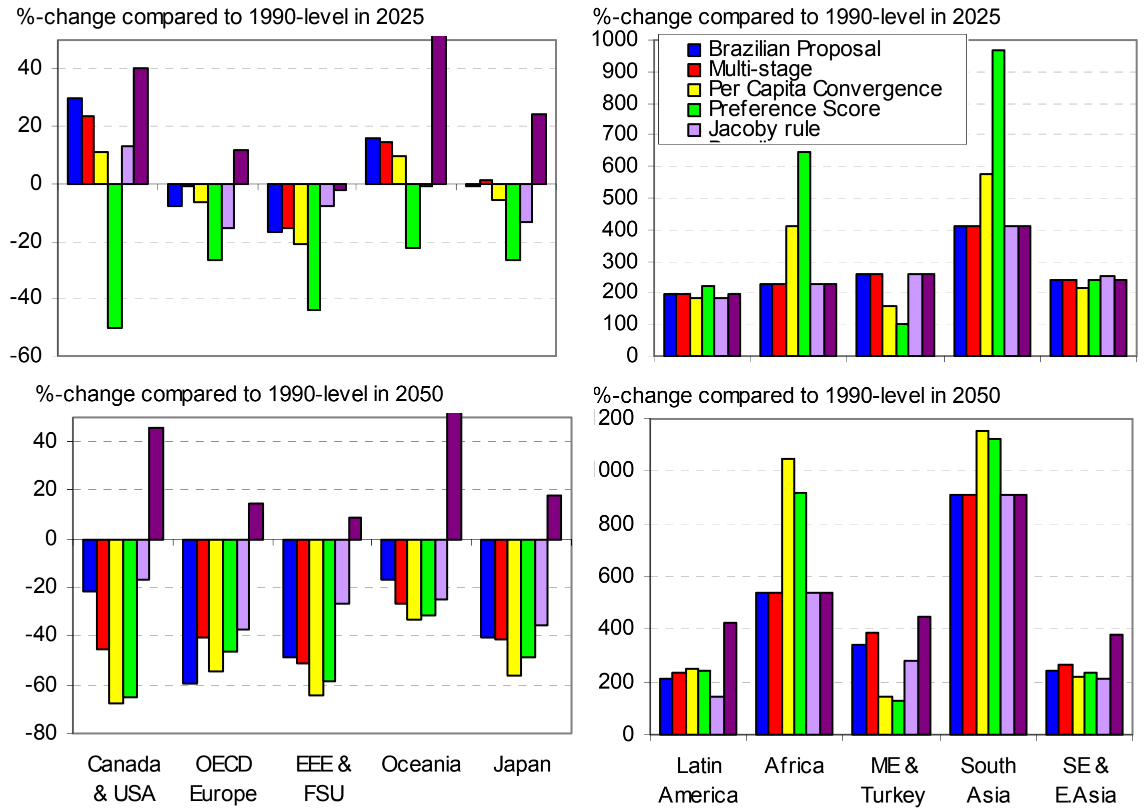

Figure 9.4. Percentage change in the emission allowances relative to the 1990 level for the ***reference cases*** *of the regimes under the IMAGE S550c profile for 2025 (upper) and 2050 (lower) (Source: FAIR 2.0).*

9.5.2 Non-Annex I regions

In 2025, most non-Annex I regions hardly have to limit their emissions and in some cases receive large surplus emission allowances. Due to the higher threshold values and the looser global constraint under S550c, most non-Annex I regions can just follow their baseline emissions. Under the PS and PCC cases, South Asia and Africa receive much larger surplus emission allowances than under the S450c profile, while LA is also experiences some surplus emissions with the PS approach.

9.6 Comparing the reference cases of the regimes for S450c and S550c

We will now compare the outcomes of the various approaches for the S450c and S550c reference cases. In this way we not only evaluate how the level of effort required would change if CO_2 concentrations were to be stabilised at 550 ppmv instead of at 450 ppmv, but also how the relative attractiveness of the various approaches may change. Clearly, these results need to be considered with some care since the outcomes are dependent on the policy settings of the reference cases chosen. Moreover, for stabilising CO_2 concentrations at 550 ppmv there is a wide range of emission pathways available to realise this goal.

The wider range in outcomes under S550c is likely to result in larger differences between the attractiveness of the various approaches under the S550c profile as opposed to the S450c profile in the long term than in the short term. This is indeed found to be true when we compared again the relative attractiveness of the various approaches for the S450c and S550c profiles on the basis of the difference between allowable emissions and regional baselines (see Table 9.6).

However, the relative attractiveness of the approaches to the various regions (under the assumptions made) was found in some cases to be hardly affected. For example:

- The PS approach remains the least attractive for Annex I and the Middle East in the short term and the most attractive for most other non-Annex I regions.
- The Jacoby Rule approach remains the least attractive for Latin America in the short term.
- The PCC approach still remains unattractive for SE & E. Asia and the Middle East, with their per capita emissions close to the world average.

At the same time, there are also some remarkable changes:

- Due to the less stringent profile the BP approach is no longer the least attractive approach for Annex I in the long term, as it does not result in negative emission allowances.
- For South Asia, the PS and PCC approaches have become more attractive than the approaches with an income threshold because surplus emissions are now received. This indicates that occurrence and level of surplus emissions is dependent on the stringency of the profile. For S450c, surplus emissions only apply to the least developed regions, notably West and East Africa, whereas for S550c there is much more surplus, also in other regions, in particular, South Asia.
- In general, a Multi-Stage regime is more favourable than a convergence regime (2050) for Annex I and the Middle East, and under S550c; this regime is turned around for the more stringent S450c profile. This is mainly due to much more surplus emissions for the low-income non-Annex I regions under S550c and the convergence regime, which have to be compensated by more reduction for the Annex I regions.

Table 9.6. Regional relative scores for different approaches by ***2025*** *(upper) and* ***2050*** *(lower) for the* ***reference cases*** *compared to baseline under the IMAGE S550c profile.*

2025	**Brazilian Proposal**	**Multi-Stage**	**Per Capita Convergence**	**Preference Score**	**Jacoby rule**
Canada & USA	-7	-12	-21	-64	-20
OECD Europe	-17	-11	-16	-34	-24
EEUR & FSU	-15	-13	-19	-43	-5
Oceania	-35	-35	-38	-56	-44
Japan	-20	-18	-24	-41	-30
Latin America	0	0	-6	7	-5
Africa	0	0	55	127	0
ME & Turkey	0	0	-27	-43	0
South Asia	0	0	31	10	0
SE & E. Asia	0	0	-7	0	0

2050	**Brazilian Proposal**	**Multi-Stage**	**Per Capita Convergence**	**Preference Score**	**Jacoby Rule**
Canada & USA	-46	-63	-78	-76	-43
OECD-Europe	-64	-48	-61	-53	-45
EEUR & FSU	-53	-55	-68	-62	-33
Oceania	-60	-65	-68	-67	-64
Japan	-50	-50	-63	-57	-46
Latin America	-41	-36	-33	-34	-54
Africa	0	0	79	59	0
ME & Turkey	-19	-11	-55	-58	-30
South Asia	0	0	24	21	0
SE & E. Asia	-29	-24	-34	-31	-34

** Green areas indicate the most attractive regime and red areas, the least attractive regime for each region. White shows intermediate positions.*
*** If the differences between two approaches are not significant (less than 5% in absolute terms), both are placed in the same group.*
**** If the differences between more than two approaches are not significant (less than 5% in absolute terms), all are placed in the white areas (intermediate position).*

10 Qualitative evaluation of the regime approaches

In the previous chapters we quantitatively assessed the implications of the various regimes for allocating emissions among the various world regions for two different global emission profiles. On the basis of this analysis we indicated which approach would, relatively speaking, be the most favourable and unfavourable for each region. This may give some indication of the likely attractiveness of the regime approaches for the various regions. However, in practice, regime proposals will be evaluated on the basis of a much wider set of considerations. In this chapter we will therefore extend our assessment to a qualitative multi-criteria analysis to identify relative strengths and weakness of the regime approaches evaluated in this report.

10.1 Climate-regime evaluation criteria

In defining evaluation criteria, we elaborated on a number of recent studies, notably Torvanger et al. (1999), Berk et al. (2002) and Höhne et al. (2003). We also profited from a discussion with the Dutch Ministry of the Environment[22]. Just as in the study by Höhne et al. (2003) we made a general distinction between environmental, political and technical criteria. However, we added a category of general policy criteria. While in some cases closely related to the other sets of criteria, these cannot be reduced to any of the previous criteria and are therefore listed separately. Several specific criteria have been identified for all types.

The first set comprises **environmental criteria**. Given the objective of the UNFCCC to avoid dangerous human interference with the climate system (Article 2) a clear first requirement of any regime is *environmental effectiveness*, i.e. the ability to effectively control and eventually reduce global greenhouse gas emissions with the aim of stabilising GHG concentrations. The effectiveness of a climate change regime depends on a number of factors, such as (a) the level of participation of significant emitters; (b) the comprehensiveness of the regime with respect to the gases and sources covered, and (c) the stringency of the commitments adopted.
With countries outside the regime, part of the efforts could be offset by leakage: the increase in the emissions of non-participating countries due to factors such as lower international energy prices, and relocation of production and improvement in competitiveness. Moreover, with the growing share of developing countries in global GHG emissions, the environmental effectiveness of any post-Kyoto climate regime will, to a large extent, become depend on the action taken, in particular, by the larger developing countries. For this reason a subsequent environmental criterion is to see whether the regime approach provides *incentives for developing countries to take action* to control their emissions. This does not necessarily need to be by way of participation in formal commitments; it can also result from incentives to control emissions before taking on commitments under the climate regime.
The knowledge of climate change is still far from complete and new future insights or a change in the valuation of climate change risks may result in a desire to adjust policies. This is particularly important when more stringent action would be considered necessary. For the environmental effectiveness of a regime, its *ability to adjust to more stringent*

[22] Specifically, an inter-ministerial working group on future action. However, the selection of criteria is the sole responsibility of the authors. More generally, this chapter represents the view of the authors, not the official views of the Netherlands in the UNFCCC process.

targets is strategically important. Finally, as controlling climate change is just one of the dimensions of pursuing sustainable development, and because there are, particularly in developing countries, many other more pressing environmental concerns a climate change regime preferably also meets the criterion of *promoting sustainable development*. In any case, the regime should not hinder sustainable development by providing the wrong incentives. In this respect, we must mention a final criterion in this set: *inducing technological change.* Technological change will probably make the largest contribution to a drastic reduction in GHG emissions in the long term. However, the level of emissions reductions needed is unlikely to result from incremental improvements; instead, it will still require some technological breakthroughs to reduce mitigation costs. A climate change regime can provide the incentives for realising such technological breakthroughs, particularly when it provides certainty on future climate targets (and thus on returns on investments), and when regimes are based on technology-oriented targets.

The second set, **political criteria,** generally relates to factors directly affecting the political acceptability of a climate change regime. The most salient political criterion of regimes defining and differentiating future commitments is *comprehensiveness regarding equity principles*. As discussed in Chapter 2 prominent allocation-based equity principles are responsibility, capability, no-harm to (right to) development, the egalitarian and the sovereignty principles. Perceptions about an equitable differentiation of future commitments differ widely. In looking for acceptable climate change regimes it thus seems wise not to focus on any single equity principle, but instead to look for approaches embracing different equity principles (Berk et al., 2002). The *comprehensiveness with respect to equity principles* is thus considered a relevant initial criterion. At the same time, the UNFCCC is clear in stating the principle that *developed countries should take the lead* (UNFCCC, Article 3.2).

Notwithstanding the importance of equity principles in substantiating and legitimising policy claims and broad acceptability of an international climate change regime, it is clear that such a regime is unlikely to come about or be effective when it fundamentally conflicts with the positions of key countries. Thus the idealism of the principles should be balanced by the realism of power relations resulting from the need for *acceptability for major countries,* in particular, those with significant emissions such as the USA, FSU, EU, China and India.

Up to now there has been a clear policy divide between the developed and developing countries in the climate change negotiations, with developing countries sticking together in the G77, notwithstanding their clear differences in opinion and interests (for example, between AOSIS and OPEC states). This policy divide has its background in a decades long (post-colonial) history of international negotiations on various issues of development (pre-dating the climate change negotiations). Developing countries join their (limited) negotiating forces to strengthen their positions vis-à-vis developed countries and counter divide-and-rule policy tactics (Gupta et al., 2001). This was reinforced by their general distrust towards developed country intentions. This historical North-South policy divide will have to be overcome in order to broaden participation and differentiate developing country commitments in the climate change regime. An important policy criterion for a climate change regime is therefore the extent to which the regime is *supportive to trust building*. Generally, this trust can be enhanced by making the decision fairly and transparently, by agreement on regime rules binding all Parties (avoiding arbitrariness in future decision-making) and by respecting previously agreed stipulations in the UNFCCC.

Finally, a regime proposal should, ideally, provide sufficient structure by shaping a clear framework for negotiation on the one hand, while, on the other, be sufficiently flexible so as to leave *room for negotiation* to reach a compromise.

A third set comprises the **economic criteria.** An initial and clear economic criterion, stipulated by the UNFCCC (Art. 3.3), is *cost-effectiveness*. The abatement of GHGs emissions should take place efficiently, i.e. at the lowest cost. This criterion is important because the potential and costs of GHG emission abatements differ widely between countries. An inefficient approach would not only result in unnecessarily large economic losses, but also in the adoption of less stringent emissions reductions. The introduction of the Kyoto Mechanisms (KMs), international emission trading and project-based Joint Implementation and Clean Development Mechanism, have given countries (and companies) the option of allocating emissions reductions abroad if this is more cost-effective than internal reductions. The KMs have thus created so-called ‘where’ flexibility. If these mechanisms were to be preserved in the future climate change regime they would help in attaining a high level of cost-effectiveness regardless of the allocation of commitments. However, the cost-effectiveness to be expected from emission trading is higher than for JI and CDM because of lower transaction costs and an easier utilisation of reduction potentials (accessibility factor). In the case of CDM there is also the risk of inflated baseline projections and leakage: increasing emissions outside the projects not accounted for. This not only reduces the environmental effectiveness of the climate change regime, but also its cost-effectiveness, implying that the highest level of cost-effectiveness is reached in a regime where most countries are able to participate in emission trading.
Another important economic criterion is *certainty about costs.* Certainty about the level of costs and related economic impacts is not just important to avoid the risk of high cost, possibly resulting in a disproportional or abnormal burden (see under equity), but is also important for the willingness of countries to take on commitment (Philibert and Pershing, 2002). This is particularly the case for developing countries who fear that taking on climate change commitments will pose a threat to their economic development. Given the uncertainty about future economic developments, adopting a fixed target may turn out to be very expensive. Reducing the uncertainty about future mitigation costs may thus increase both the willingness of developing countries (and of Australia and the USA) to take on emission control commitments and the willingness of KP countries to strengthen their efforts after the first commitment period.
Next, it will be important that a climate change regime is *accounting for different national circumstances* (Art. 3.3) resulting from factors such as geographical situation, (energy) resource endowment, and economic structure and international specialisation. If such circumstances are not accounted for, climate change regimes may not just be unfair, but also politically unacceptable. Disregarding national circumstances may also result in outcomes that conflict with other criteria in the UNFCCC and the KP: e.g. *minimising adverse (economic) effects* (Art. 2.3, KP), enabling sustainable economic development (Art. 2 and 3.4 UNFCCC) and *avoiding disproportional or abnormal burdens* for some (groups of) countries, like energy exporters (Art. 3.2 and 3.4, UNFCCC). Of these criteria, the last one seems the most important.

Apart from political and economic criteria there are also **technical and institutional criteria.** These criteria concern technical and institutional requirements of regime approaches related to both the negotiation process and the implementation and monitoring of commitments. These requirements may be technical, legal or organisational in nature.

The first criterion is *compatibility with the Kyoto Protocol and UNFCCC.* From a legal point of view, and given the importance of continuity in policy-making, it is desirable to have a future climate change regime that does not require major legal revisions of the UNFCCC and/or the KP. It preferably should not result in a discontinuity of policy efforts and policy expectations, such as the investments in the development of the KMs.

A second criterion is *simplicity of the negotiation process*. Regime approaches that are complex in nature, either due to their concept, need for complex calculations, information requirements or their large number of policy variables, complicate international negotiations. They make it more difficult for Parties to assess the implications of regimes, will result in a long and complex negotiation process and are hard to communicate to high-level policy-makers and constituencies. Complex regime approaches particularly disadvantage developing countries, where less scientific and analytical capacity, and negotiating staff, are available.

A third related criterion is *technical and institutional feasibility of implementation, monitoring and enforcement.* Even conceptually speaking, simple approaches can pose major implementation problems due to their technical and institutional requirements, particularly in less developed countries. Any regime approach that implies monitoring and enforcement action from least developed countries will face major implementation problems. Involving these countries in international emission trading will be difficult due to lack of reliable emission data, statistical capacity to meet eligibility requirements, and sufficient capacity for verification and enforcement (see Baumert and Figueres, 2003).

Finally, there is set of what can be called **general policy criteria.** These are criteria that are less directly environmental, political, economic or technical/institutional in nature, but important from a strategic policy development perspective. Such an initial criterion is *regime stability or robustness.* The design of the regime should be such that it is robust to changing economic and political circumstances. It should discourage non-compliance and defection. Regime instability may occur if incentives to participate change quickly, i.e. when net winners suddenly become losers.
A more technical criterion concerns the *internal consistency or compatibility.* When a climate regime is based on different types of commitments these may be (partially) incompatible. Such inconsistencies may hamper the effectiveness of a regime. Emission trading between countries with fixed targets and countries with intensity targets may be complicated and result in undesirable effects (leakage, false competition) (Gielen et al., 2002). Common policy and measures setting equal standards may limit unfair competition, but at the same time reduce the gains of emission trading and incentives for innovation.

Finally, a more general policy concern about a climate change regime is *linkage to national policy concerns.* For an international regime to become effective it needs to be implemented at the national level. Implementation of an international regime is likely to be easier when it links up to more day-to-day policy (development) concerns of national policy-makers and civil society.

10.2 Multi-criteria evaluation

The above set of criteria will be used to qualitatively evaluate to what extent the various regime approaches meet these criteria. Such an evaluation inevitably carries some level of arbitrariness, as no objective scale is available. The results are thus open for further discussion.

10.2.1 The Brazilian Proposal

The Brazilian Proposal (BP) as applied by RIVM on a global scale by introducing an income threshold for participation scores rather well on the criterion of environmental effectiveness because of its top-down approach. However, the need for a relatively high-income threshold for participation leaves many developing countries outside the group with quantified commitments which, in turn, limits the environmental effectiveness and results in a substantial risk of leakage. The approach does not provide for specific incentives promoting technological change or sustainable development but does provide some incentive for countries to limit their GHG emissions, since it affects their share in the overall emissions reductions after participation.

The Brazilian Proposal focuses mainly on the issue of responsibility and thus does not cover the various equity principles well. It also seems unlikely that the approach, at least in its original form, will be acceptable to key countries, as it results in extreme reductions of emission allowances for some Annex 1 regions, notably Europe, in the case of stringent emission profiles. This may change, however, if the burden-sharing key were to be based on another indicator for historical responsibility, like cumulative emissions since 1950 or 1990 (e.g. Blanchard, 2002). The approach could help in building trust, as it would set clear rules for the differentiation of future commitments.

With respect to economic criteria, the KMs could allow a fairly cost-efficient application of the BP approach on a global scale. Due to the income threshold many developing countries will only be able to participate via the CDM, but once they reach the threshold, they will participate fully on the basis of fixed emissions reduction targets. The latter types of target will result in substantial uncertainty about the economic costs of commitments. Moreover, the approach does not account for differences in national circumstances, which might result in a disproportional or abnormal burden for some countries.
The BP approach seems fairly compatible with the UNFCCC and KP approach. Determining countries' contribution to global temperature change is technically complex and cannot be unambiguously resolved, as it also involves several normative choices (UNFCCC, 2002b). Although this complicates the negotiation process, it does not seem to pose insurmountable political problems. Once targets have been settled, the implementation of the BP regime could be hampered by a lack of institutional and technical capacity in the developing countries, particularly to monitor emissions and to meet eligibility criteria set for participating in global emission trading.

In principle, the BP approach seems able to adjust to both new insights regarding the desired stringency of emission control and historical responsibility. The stability of the regime may be endangered if the rigidity of the approach results in extreme outcomes in the longer term (e.g. negative emissions allowances). The approach has no clear link to national policy concerns whatsoever.

10.2.2 The Multi-Stage approach

The environmental effectiveness of the Multi-Stage (MS) approach seems generally well secured by the top-down character of the RIVM implementation of the approach. However, the dynamic nature of the intensity targets during the second stage introduces some uncertainty about the environmental gains of the commitments. The approach is also prone to leakage, both towards countries without quantitative commitments (stage 1) and countries with intensity targets (stage 2). Industries may move from countries with fixed targets to countries with intensity targets. While increasing overall emission levels, this may even be attractive for countries with intensity targets if these industries are relatively efficient. The income thresholds chosen in the Multi-Stage reference variant does not provide an incentive for non-participating developing countries to take action before the entering the second stage. As the intensity targets are related to the level at the moment of entering the second stage, it may even be attractive to postpone action. On the other hand, the per capita emission burden-sharing key of the fourth stage provides an incentive to limit greenhouse gas emissions as much as possible. The (income) thresholds in the MS reference may limit the ability of the MS approach to adjust to more stringent targets.

Changing these thresholds over time may meet opposition because the change would result in an unequal treatment of countries. Adjusting the overall stringency of the commitments within the stages seems less of a problem, although the intensity targets normally should leave room for an increase in absolute emission levels, considering that the next stage will require a stabilisation of emissions. The MS approach does not seem to directly promote technological development or sustainable development. While the stringent fixed targets for the industrialised countries may induce technological change, this will be tempered by both emission trading and carbon leakage to developing countries.

The MS approach performs well when it comes to the coverage of equity principles. It also very much resembles the principle of developed countries taking the lead. On the other hand, the economic implications of the approach do not need to be balanced as well (see below). In general, the MS approach does not seem to face principle objections in principle from any of the key countries. The intensity targets seem appealing to developing countries as well as to the USA. However, at the same time, the USA may object to some of its features, such as the top-down approach, fixed targets for the industrialised countries and, in particular, to the per capita emission burden-sharing key. The latter is also likely to meet resistance from the FSU, which would be better off with an income-related burden-sharing key. On the issue of building trust, the MS approach could strike a fair balance between developed countries taking the lead on the one hand, and developing countries committed to following suit (in a predictable way) on the other. The MS approach offers, in principle, much room for negotiation because of the various thresholds, and different types of targets and flexibility in setting the levels of these targets.

The cost-effectiveness of the MS approach is fairly well secured if KMs are available. However, it is less than optimal because a group of countries does not engage in emission trading (only in CDM), while the adoption of intensity targets complicates the functioning of the international emission-trading market. Meanwhile, the intensity targets take away some of the uncertainty about the economic impacts of quantitative commitments for developing countries (Baumert et al., 1999; Philibert and Pershing, 2001). However, as pointed out before, additional clauses or arrangements will be needed to avoid negative impacts under conditions of economic stagnation or relapse (van Vuuren et al., 2002; Kim and Baumert, 2002).

The MS approach takes into account the differences in capabilities between countries at different levels of development, but only partially amongst countries at a similar level of development. As the intensity targets are defined as percentage improvement, the MS approach accounts for different starting positions of developing countries. However, in the burden-sharing stage structural differences between developed countries are no longer adjusted for. This also implies that the MS approach can still result in disproportional burdens for some regions (notably the FSU and Middle East & Turkey).

The MS approach fits in well with the protocol approach taken under the UNFCCC, where commitments for groups of countries are based on annexes to the Convention. A number of additional annexes can be created for the MS, which would imply the need for negotiating both the conditions (thresholds) for countries being listed under different annexes as well as the differentiation of commitments amongst the group of countries in each annex. This will make the negotiations more complex, but once the thresholds for the annexes have been defined, these are no longer likely to be changed. Negotiating the differentiation of commitments amongst countries will be structured by the default differentiation proposed. The introduction of intensity targets is likely to complicate the negotiation process because of it novelty and implications for international emission trading. The need for acquiring both reliable emission and economic data from developing countries, and additional emission trading requirements, will make the MS approach far more complex than the KP implementation.

The stability of the MS regime seems secured by the advantages offered by emission trading, which also limit the implementation costs of countries with stringent targets. Including both fixed and dynamic targets, linked by one international emission trading system, results in an inconsistency that may lead to enhancing carbon leakage via the emission trading market. This might be prevented if countries with intensity targets can only trade ex-post (after the commitment period). The MS approach does not offer clear links to national policy concerns, but the intensity targets could be linked with energy efficiency improvement or more rational land-use practises.

10.2.3 Per Capita Convergence approach

The environmental effectiveness of the Per Capita Convergence approach is well assured as it is based on global emission targets, and all countries participate in binding quantitative emission limitations. The approach also provides incentives for developing countries to take action to limit GHG emissions because this creates emission allowances that can be sold on the market. However, in the case of large amounts of surplus emission allowances, this incentive may be weak. The PCC regime can be easily adjusted to more stringent future targets; however, this may affect the perceived fairness of the regime, since it will particularly affect the (cumulative) emission space when the convergence year is fixed. Revenues from emission trading could be reinvested in further emission control and used to enhance sustainable development, but this has not been secured. If the regime does provide for a high level of transparency in long-term emissions reductions, which in practice may be less certain (as the global emission level will be subject of continuous review and negotiation), it could allow for long-term business investments in technological change. Likewise, if developing-country revenues were to be spent in a proper way, this could lend much support to their sustainable economic development.

The PCC does not cover the various equity principles well, in particular, (historical) responsibility. On the other hand, the PCC does takes into account both sovereignty and the egalitarian principles. The political support for the PCC approach has grown over the years, mainly in developing countries (African Group), but also in developed countries (see the GCI website: http://www.gci.org.uk/). There seems to be a particularly open mind for the PCC approach in some European countries. However, it is expected that the approach will meet resistance from the USA and other regions with high per capita emission levels (Oceania, Middle East & Turkey and FSU) and from China. On the one hand, this resistance will be based on economic concerns related to the large resource transfers resulting from the redistribution of emission allowances and surplus emissions for the least developed countries. On the other, there are also political reasons for opposing the approach: resistance against the global commons concept underlying the approach and concerns that the climate issue is too much linked to the issue of unequal development. Nevertheless, the approach, being transparent and comprehensive, could help much in building trust between developed and developing countries. In principle, the approach does not leave much room for negotiation apart from the convergence year and overall emission target. However, this could be enhanced if allowance factors were added.

In principle, universal participation and world-wide emission trading make the PCC approach a very cost-effective regime. However, in practice, cost-effectiveness is likely to be hampered by an improper functioning of the international emissions trading market (Baumert et al., 2003). Many developing countries will not be able to meet illegibility requirements for (fully) engaging in emission trading. This will limit supply from developing countries while the demand for emissions reductions from developed countries may be large due to the large redistribution of emission rights. In addition, market instability may further result in price fluctuations that could be detrimental to both developed (buyers) and developing countries (sellers). Along with the fact that the PCC approach takes neither economic developments, nor national circumstances into account, it results in a high level of uncertainty about mitigation costs and can also yield disproportional burdens for some countries or regions. The PCC approach would be a strong shift away from the KP approach, but would not be incompatible with it or with the UNFCCC. Given the clear concept and limited number of policy parameters, the negotiation process would be rather simple. However, implementing the approach is likely to be very complicated due to the involvement of many developing countries with very limited - if any - capacity to do so and related problems in the area of monitoring, verification and reporting. As indicated, this will also directly affect their ability to engage in emission trading.
More than under some regimes the PCC regime stability could be compromised when countries change from being large gainers to losers when their per capita emission levels rise. The PCC could be linked to national development targets if revenues from emission trading are channelled to supporting sustainable development.

10.2.4 Preference Score

Like the PCC approach, the environmental effectiveness of the PS approach is, in principle, well assured because it is also based on global emission targets, and all countries participate in binding quantitative emission limitations. The approach also provides incentives for developing countries to take action to limit GHG emissions, because this creates emission allowances that can be sold on the market. However, compared to the PCC approach, here there are even larger amounts of surplus emission allowances that may weaken the incentive to take real action. The PS regime can be easily adjusted to more stringent future targets. Under the PS approach revenues from emission trading could also be reinvested in further emission control and used to enhance sustainable development, but this remains uncertain.

The PS does not cover the various equity principles well. In particular, (historical) responsibility and capability are ignored. On the other hand, the PS does takes into account both sovereignty and the egalitarian principles. The latter principle is now also translated into procedural equity (population-weighted voting). The PS approach is expected to find much support among the least developed countries. However, it seems even less acceptable to Annex I countries than the PCC approach because of its radical implications. The procedure for voting based on population numbers, contrasts strongly with all United

Nations' and Bretton Woods' bodies, where voting is either based on one-country one-vote (UN General Assembly), on a country's financial contribution (IMF) or on its military capabilities (veto power in the UN Security Council). Accepting the population-weighted voting procedure for legally binding commitments would imply a revolutionary change from present international politics (highly unlikely), in particular, given the USA's opposition against a prominent role of the UN in global governance. Apart from political opposition, there will also be resistance on economic grounds related to the large resource transfers resulting from the redistribution of emission allowances and surplus emissions for the least developed countries.

With respect to the economic criteria, the PS approach is comparable to the PCC approach. However, since the redistribution of emission rights is much greater, the problems related to the PCC approach are even more pronounced. The PS approach leaves more uncertainty about costs, and is even more likely to result in a disproportional burden for some countries or regions.

The PS approach is not compatible with the UNFCCC and KP. For the proposed voting approach to be binding, it would require a major revision of the decision-making structure, which presently is based on consensus and one-country one-vote.. If the proposed voting procedure were to adopted, the negotiations would of course be very simple, as only the global emission target would have to be negotiated. At the same time, implementation of the regime would be confronted with the same institutional problems as the PCC regime.

More than under the other regimes, the PS regime stability could be endangered when countries change from being large gainers to losers when their per capita emission levels rise. Once voting rules have been adopted, it will be difficult to change them. This may affect the stability of the regime when some countries feel decisions do not allow for taking their circumstances into account. The PS approach has no direct link to national policy concerns, but like the PCC approach revenues from emission trading the approach could be channelled to support sustainable development.

10.2.5 Jacoby Rule

The Jacoby Rule approach is originally a bottom-up approach that has been implemented here in a top-down way to make it comparable with the other approaches. The environmental effectiveness of the approach is not as certain as in the top-down approaches, as it is dependent on the income threshold levels and emissions reduction rate parameters. The JR approach does not provide an incentive for early action by developing countries, because both the participation and burden-sharing keys are related to per capita income only and not to (per capita) emission levels. The approach has the ability to change the parameters affecting the overall stringency of the regime if needed. However, as in the BP and MS approaches, the difficulty of changing the income threshold may limit the flexibility of the JR approach in case more stringent global emission control is needed. The approach does not contain any specific incentives for technological change or sustainable development.

The JR approach is, in principle, only based on the capability criterion. Nevertheless, it could well be acceptable for key countries, because it does not penalise countries with (relatively) high per capita emissions (USA, FSU), while sparing poor countries at the same time (India). However, it is generally unfavourable for LA and China. By providing an objective system for defining developing countries' participation, it would also help in

establishing trust between North and South. The various parameters do leave room for negotiation, but are too abstract to guide negotiations on efforts.
When combined with the KMs the cost-effectiveness of the JR approach could be fairly high. As under the BP and the MS approaches, the cost-effectiveness is limited by the fact that not all developing countries participate immediately. In linking the emissions reduction rate to per capita income, the JR should result in a rather balanced distribution of mitigation costs or at least avoid disproportional or abnormal costs. However, the approach does not take into account national circumstances.
The JR approach is well compatible with the UNFCCC and KP approach, but the abstract and non-transparent nature of the parameters used for defining the emissions reduction efforts poses a problem for the negotiation process. The implementation of the JR approach, on the other hand, does not have to be more complex as any other approach, since it defines fixed national emissions reduction targets for relatively well-developed countries are able to implement these.
With per capita income of developing countries increasing over time, the JR regime is unlikely to produce extreme future outcomes for some countries that could endanger the regime's stability. The JR approach does not provide any link to national policy concerns.

The results of the evaluation are summarised in Table 10.1.

Table 10.1: Multi-criteria evaluation of the regime approaches (reference cases)

Regime / Criteria	Brazilian Proposal	Multi-Stage	Conver-gence	Preference Score	Jacoby Rule
Environmental criteria	+	+	+/++	+/++	**0**
Environmental effectiveness	+/0	+	++	++	0
Incentives for developing country action	0/+	- / +	-	-	-
Ability to adjust stringency regime	*0*	*0/+*	*0*	+	+
Promoting technological change	-	*0*	*0*	*0*	-
Promoting sustainable development	0	0	0/+	0/+	0
Political criteria	**-**	+/++	**0**	**-**	**0**
Comprehensiveness equity principles	*0*	++	+	+	0
Acceptability for key countries	-	0/+	-	--	0
Supportive to building trust	+	+	++	++	+
Room for negotiation	--	++	--	--	-
Economic criteria	**--**	**0**	**-**	**--**	**0**
Cost-effectiveness	*0*	+	++/+	++/+	+
Certainty about costs	--	0	--	--	0
Accounting for different national circumstances	--	0	--	--	--
Avoidance of disproportional / abnormal burdens	--	0	-	--	0
Technical and Institutional criteria	**0**	+	**0/-**	**--**	**0**
Compatibility with the KP and UNFCCC	+	++	-	--	+
Simplicity of the negotiation process	-	0	++	+	-
Ease of implementation	0	0/-	--	--	0
General policy criteria	**--**	**0**	**0**	**-**	**0**
Stability of regime	--	+	-	--	+
Consistency of regime	+	0	+	+	+
Link with national policy concerns	--	-	(+)	(+)	--

Legend: ++: fully satisfied; +: generally satisfied; 0: partly satisfied; - poorly satisfied; --: not satisfied at all

10.3 Strengths and weakness of the regime approaches

The results of the multi-criteria evaluation can be used to identify the relative strengths and weaknesses of the approaches under review. These have been summarised in Table 10.2. This table also includes possible remedies that could be thought of in order to overcome or reduce the weaknesses of each approach.

Brazilian Proposal: This proposal's only strengths seem to be its origin and status under the UNFCCC as a proposal for formal review. It main weaknesses are its potentially extreme results (negative emissions) under stringent global emission constraints and the need for a relatively high participation threshold. This may be remedied by taking another 'responsibility' indicator, such as cumulative emissions since 1990 (Blanchard, 2002; den Elzen et al., (2003). This would also avoid discussions about whether developed countries can be held responsible for historical emissions when these were not known to be harmful.

Multi-Stage: The strengths of the MS approach are its flexible concept (striking a balance between structure and leaving room for negotiation) and its compatibility to the present regime. Its main weaknesses are the high reductions for Annex I countries with high per capita emissions (particularly under stringent emission profiles), the limited ability to adjust to more stringent targets over time and the complications resulting from the use of intensity targets. Adopting another burden-sharing key (like per capita income), or even a mix of criteria, could reduce the first weakness. The second weakness could be reduced by adopting a low-(income) threshold for intensity targets, although this could run both against equity concerns and enhance implementation problems. The implementation problems related to the adoption of intensity targets might be remedied by allowing developing countries to trade only after the commitment period (ex-post) and by adopting a dual-intensity target approach (Kim and Baumert., 2002) that would reduce economic uncertainty.

Per Capita Convergence: The main strengths of the PCC approach are its clear concept, the certainty that it provides regarding the environmental effectiveness of the regime and developing country participation, and its 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, while the approach is likely to result in surplus emissions that increase the mitigation costs for Annex I and more advanced developing regions. Furthermore, it does not take any national circumstances into account. The approach is also likely to meet principal policy objections from some key countries. Possible options for remedying these problems are the inclusion of national adjustment factors and/or a regional allocation of emissions (allowing for regional redistribution under emission bubbles), and restricting the illegibility of emission trading of the least developed countries in relation to the certainty about emission levels (to avoid overselling).

Preference Score approach: The Preference Score method has comparable strengths and weaknesses to the PCC approach, but its weaknesses are greater. The approach produces more extreme results and is also not compatible with the UNFCCC structure. The extreme results could be remedied by extending the policy delay (as explored in the alternative cases) or – more structurally – by giving more weight to emissions than populations in the allocation of emissions. As in the PCC approach, the national adjustment factors could also be included. The compatibility problem does not seem one to be easily remedied because adjusting the voting element would affect the core of the approach.

Jacoby Rule approach: The strength of this approach seems its fairly balanced distribution of mitigation efforts. Its weaknesses are its focus on capability only, disregarding responsibility or national circumstances, and its abstract parameters. However, a simplification of the approach – avoiding these parameters - does seem highly possible.

Table 10.2: Strengths and weaknesses of the regime approaches and possible remedies

	Strengths	Weaknesses	Possible remedies
Brazilian Proposal (RIVM)	• Origin in developing country • Formal status under UNFCCC	• Focus on responsibility only • Extreme results (negative emissions for some Annex I regions) • Relatively complex approach • Inflexibility (in original form)	• Use of other responsibility indicator (e.g. cumulative emissions from 1950 or 1990)
Multi-Stage (RIVM)	• Different equity principles covered • Flexible concept offering room for negotiation • Compatibility with KP/UNFCCC	• Intensity targets that reduce certainty about environmental effectiveness and complicate implementation • Large reductions for Annex countries with high PC emissions	• Dual targets concept • Ex-post trading for DC with intensity targets • Use of other BS key than per capita emissions or multi-criteria key
Per Capita Convergence (GCI)	• Certainty about DC participation • Certainty about environmental effectiveness • Clear concept • Allows for full ET • Funds for LDCs	• Implementation problems for DCs • Extra costs for Annex I / middle-income DCs due to surplus emissions • No accounting for nat. circumstances • Large reductions for countries with high PC emissions	• Inclusion of adjustment factors • Adjustment of convergence year to avoid surplus emissions • Restriction of ET in ratio to certainty about emissions • Increase in flexibility by a regional PCC approach
Preference score method (Müller)	• Certainty about participation • Certainty about environmental effectiveness • Simple concept • Allows for full ET • Funds for LDCs	• Extreme results (drastic instant re-allocation) • Large extra costs for Annex I / middle-income DCs • Implementation problems for DCs • Non-compatibility with UNFCCC	• Extending the policy delay • Giving more weight to emissions than population in voting • Inclusion of adjustment factors for nat. circumstances
Jacoby Rule (MIT)	• Gives balanced distribution of costs	• Based on capability only Abstract parameters	• Simplification of approach

10.4 Conclusions

On the basis of the multi-criteria evaluation, and the strengths and weaknesses identified, we will draw up a few overall conclusions on the analyses of the regime approaches.

- The Brazilian Proposal does not score well on either political or economic criteria, mainly due to its main focus on responsibility and its extreme outcomes for some regions. In order to better satisfy the political and economic criteria it might be simplified to burden sharing based on cumulative emissions since 1950 or 1990.
- The MS approach scores relatively well on political, economic, and technical and institutional criteria, and overall seems to satisfy most criteria. Still, it could do even better, particularly if the burden-sharing key were to be changed from per capita emissions to per capita income or even a mix of keys.
- The PCC scores high on the environmental criteria, but does much worse on the political, and technical and institutional criteria. While the cost-effectiveness is high, the overall score on the economic criteria is fairly low, mainly due to a lack of consideration of national circumstances and baseline developments. Including adjustment factors and /or a regional approach, as well as provisions for emission trading, may enhance its performance. Institutional requirements from developing countries remain a major bottleneck.
- The Preference Score approach scores even lower that the PCC approach on political, and the technical and institutional criteria, due to the extreme re-distribution of emissions and the incompatibility of the PS approach with the UNFCCC.
- The Jacoby Rule approach scores are balanced for most criteria, but the approach does not have any particular strengths. To overcome its academic focus and to increase its political appeal it would seem to need simplification.

Overall, the Multi-Stage approach seems, in principle, to best satisfy the various types of criteria. The strength of the Multi-Stage approach is its flexible concept, striking a balance between providing structure and leaving room for negotiation. The concept thus allows for an incremental, but rule-based broadening and deepening of mitigation commitments, while it is sufficiently flexible to avoid unacceptable outcomes or economic risks. At the same time, the approach will have to better accommodate national circumstances to be acceptable to all countries. The problems related to the use of emission intensity targets too require further analysis and additional provisions.
Moreover, the other approaches could improve their performance as well by making adjustments in their design; there may be alternative approaches not explored here that could also meet the criteria.

11 Conclusions

In this study, we have explored the implications of several possible international climate regimes for differentiating future commitments on the basis of two alternative global emission profiles for long-term stabilisation of greenhouse gas concentrations in the atmosphere at 550 and 650 ppmv CO_2 equivalents. These profiles were found to be congruent with a stabilisation of the CO_2 concentrations at 450 (S450c) and 550ppmv (S550c), respectively.

Meeting the long-term target of the European Union for limiting global average temperature increase to 2 degrees Celsius above pre-industrial levels would, at least, require a stabilisation of CO_2 equivalent concentration at 550 ppmv under a median value of the climate sensitivity. For stabilisation at 650ppmv, the EU target would only be met when the climate sensitivity is at the low end of the uncertainty range. Consequently, this profile is unlikely to meet the EU-target. At the same time it is clear that stabilising at 550 ppmv will require much earlier and deeper reductions of GHG emission than stabilising at 650 ppmv. Stabilising at 550 ppmv will require a stabilisation of global GHG emissions within the next two decades followed by substantial emissions reductions afterwards. This is also clearly reflected in the emissions reductions for the Annex I regions after 2010 and the timing and contribution of non-Annex I regions to global emission control, irrespective of the climate regime adopted. At the same time it is obvious that the more a stringent global GHG emission control is needed, the more prominent the issue of designing an effective and fair climate regime becomes.

For the Post-Kyoto period, the following five climate regimes for differentiation of future commitments were explored using the emission profile for stabilising the CO_2 concentration at 450 ppmv (S450c profile): Brazilian Proposal (BP), Multi-Stage (MS), Per Capita Convergence (PCC), Preference Score (PS), and Jacoby Rule (JR).

For each approach, we developed reference cases for comparing results. In addition alternative cases were defined to explore the sensitivity of the results for the policy settings adopted in the reference cases. The alternative cases were also used to explore the robustness of the findings of the comparison of results among the different approaches. Finally, the robustness of the findings was explored by comparing the results of the different regimes using the S450c emission profile with those when a CO_2 emission profile for stabilising the CO_2 concentrations at 550 ppmv (by 2150) is used (S550c profile).

In addition to the quantitative analysis, we also performed a qualitative assessment on the basis of a multi-criteria evaluation, using a set of environmental, economic, political, technical-institution and general-policy criteria. Below the main findings from both the quantitative and qualitative assessments are summarised.

11.1 Quantitative evaluation of the regime approaches

1. The need for further action: S450c and S550c profiles

- For both stabilisation at 450 and 550 CO_2 concentrations, substantial CO_2 emissions reductions from the CPI baseline will be needed, particularly in the long term.
- In 2025 and under the S450c profile, global emission levels can still increase to about 20% above 1990 levels but this already implies a substantial emissions reduction of 35% compared to baseline levels. The reduction compared to the baseline is lower (10%) for the S550c profile.
- In 2050 and for the S450c profile, CO_2 emissions will have to be reduced sharply, not only in comparison to baseline level (75%), but also to 1990 levels (about 35%).

However, for S550c, the CO_2 emissions levels in 2050 still exceed 60% of the 1990 levels. However, compared to the baseline, global emissions need to be reduced by about 35%.

2. Implications for Annex I action

- In 2025 for S450c all regimes explored (reference cases) resulted in reductions in emission allowances for all Annex-I regions of at least 20-60% compared to the 1990 levels. For S550c this range is much wider, from –30% to 50%, indicating a larger sensitivity to the choice of burden-sharing keys for the higher stabilisation level.
- In 2050, apart from the Brazilian Proposal cases, the reductions in 2050 are 70-90% (S450c), while the reductions for S450c are 70-90% and for S550c, 15-70%.
- For Europe the reductions compared to 1990 levels are 40-60% in 2025 and 80-90% in 2050, apart from the Brazilian Proposal cases.

3. Implications for non-Annex I action

- The major non-Annex I regions (East Asia and South Asia) at significant lower per capita income and emission levels than Annex I under the Kyoto Protocol need to reduce their emissions before 2025 (S450c) and 2050 (S550c).
- The low-income non-Annex I regions, i.e. Africa and South Asia, are shown in all cases to have much lower required reductions, while the other middle- and high income non-Annex I regions, Latin America, the Middle East and the SE & East Asia regions are found in an intermediate position, between low-income non-Annex I and Annex I regions.

4. Brazilian Proposal (BP)

- The BP approach, i.e. the allocation of the emissions reduction based on region's contribution in realised global temperature increase, combined with an income threshold leads to high emissions reductions for the Annex I regions.
- The BP is particularly unattractive for OECD-Europe and Japan due to their high contribution to temperature increase as a result of the historical CO_2 emissions. The BP may even lead to negative emission allowances for these regions.
- The BP can result in lower per capita emission allowances for Annex I regions than non-Annex I regions due to their larger contribution in realised global temperature increase than per capita emissions.
- Some non-Annex I regions with large land-use emissions (i.e. Latin-America) are also faced with high emissions reductions.
- The threshold level for participation has a large influence on the level of emissions reductions. Low threshold levels work to the advantage of Annex I regions and Latin-America.

5. Multi-Stage (MS)

- In a MS regime, applying burden-sharing keys based on per capita emissions or per capita income results in the long term (by 2050 for the S450c profile) in a convergence of per capita emissions amongst Annex I and non-Annex I regions
- Dynamic thresholds (like percentage of world average per capita emissions) may be interesting for both Annex I and non-Annex I, since Annex I action is rewarded and non-Annex I countries are provided with an incentive to keep below this threshold.

The regime is made more robust for adjustment to stringent climate targets. Participation of the non-Annex I regions (notably SE & E. Asia , South Asia and Africa) takes place earlier in the process.

- In the short-term the burden-sharing key affects mainly the distribution of Annex I emissions reductions as most non-Annex I regions do not yet participate in the emissions reductions.
- Using per capita income (PPP$) as a burden-sharing key is favourable for EEUR&FSU and low-income non-Annex I regions, but less favourable for OECD.
- Using emission intensity as a burden-sharing key is to the advantage of the OECD, but to the strong disadvantage of Eastern Europe and FSU. Using emission intensity is generally also less favourable for the Middle East /Turkey, Latin America, and SE & East Asia.

6. Per Capita Convergence (PCC)

- For the S450c profile, a convergence of per capita emissions by 2050 not only implies (large) emissions reduction efforts from Annex I regions, but also from most non-Annex I regions long before 2025. Only for the least developed regions, notably Africa, will emission allowances exceed baseline emission levels.
- A convergence regime leads to high reductions for both profiles for especially China but also for the Middle East, since their per capita emissions are close to the world average, and therefore do not gain from converging per capita emissions.
- The occurrence and level of surplus emission allowances is dependent on the stringency of the climate target and the convergence year chosen. For S450c this applies only to the least developed regions, notably surplus emissions for West and East Africa, whereas there are many more surplus emissions for S550c in other regions as well, in particular, South Asia; these also persist in the long term.
- The convergence year has the greatest impact on the distribution of emission allowances. An early convergence year results in much higher reductions in Annex I emissions in both the short and longer term. It also creates substantial amounts of surplus emission allowances for low-income non-Annex I regions (Africa, South Asia).
- The convergence year and the convergence rate have the greatest impact on the distribution of emission allowances. The impact of the population cut-off year is limited.

7. Preference Score (PS)

- The PS approach results in a quick initial change in the allocation of emission allowances due to an initial reshuffle of the regional emission allowances on the basis of the weighted mean of shares in emissions (grandfathering) and global population (per capita distribution). Since, initially, the largest share of the world population is in favour of a per capita division, regional per capita emission allowances show strong convergence
- In the short term, the PS approach is favourable to non-Annex I regions (except the Middle East) due to the drastic reshuffle, while in the long term, per capita emissions show convergence. However, in the long-term, per capita emissions of the Annex I regions remain slightly above the per capita emissions of the non-Annex I regions.

- The PS results in large amounts of surplus emission allowances in the short term for most Annex I regions, even in the case of a stringent climate target (stabilisation of the CO_2 concentration at 450 ppmv).

8. Jacoby Rule (JR)

- The JR approach is, in the short term, relatively attractive for Annex I regions with high energy intensities and per capita emissions, like the EEUR& FSU and Canada & USA, but not for Latin America (due to its relative wealth and the late participation of other non-Annex I regions). In the long-term, the JR approach becomes attractive for Annex I regions (due to their low emission intensities), and unattractive for more developed non-Annex I regions, such as Latin America, the Middle East & Turkey and SE & East Asia, because of their relatively high emission intensities.
- The regional emission allowances under the Jacoby rule approach are highly dependent on the welfare threshold selected, as well as on three attuned parameters. The main lack of these attuned parameters is an actual representation in real life.
- A low welfare threshold is unattractive to non-Annex I regions and attractive to the Annex I regions, while the high-income non-Annex I regions prefer a low welfare trigger, resulting in earlier participation of the low-income non-Annex I regions.
- A high welfare trigger leads to moderate non-Annex I emissions reductions, and high emissions reductions for the Annex I regions.

9. Approaches compared

The following fairly robust results on the implications and relative attractiveness of the various approaches for stabilising the CO_2 concentrations at 450 ppmv were found for the different regions upon comparison of the approaches for the differentiation of commitments under the global emission profile:

- The PS regime is generally the least attractive in the short term for all Annex I regions, while the BP approach is the least attractive in the long term. Apart from the BP approach, the differences in Annex I reductions between the approaches in the long term are small.
- For the middle- and high-income non-Annex I regions (Latin America, ME & Turkey and SE & East Asia) Multi-Stage is more attractive in the short term than PCC and PS cases, since their per capita emissions are higher than those of the low-income non-Annex I regions and closer to the world average. The differences between these three approaches in the long term are small. Moreover, the BP in general then becomes more favourable, and JR (burden-sharing based on PPP$ income) turns out to be less favourable.
- For the least developed non-Annex I countries participation is more attractive than non-participation if their allowable emission levels are larger than their baseline emissions, as for the PS and PCC approaches. Therefore, for these regions, short-term PCC and even more, PS, are more attractive than Multi-stage, while, in the long-term, this situation is reversed.
- In general, all reference cases (including the PS approach) result in a convergence in the per capita emissions for Annex I and non-Annex I countries (because of the assumptions). However, in the BP case, Annex I per capita emission allowances decrease below non-Annex I per capita emission allowances. Full convergence is not reached for PS, however.

10. Comparison of results of the S450c and S550c profiles
The relative attractiveness of the approaches to the various regions (under the assumptions made) in some cases is found to be hardly affected by changing the global emissions profile from S450c to the S550c. For example:

- The PS approach remains the least attractive for Annex I and the Middle East in the short term, and the most attractive for most other non-Annex I regions;
- The Jacoby Rule approach remains the least attractive for Latin America in the short term;
- The PCC approach still remains unattractive for SE & East Asia and the Middle East, with their per capita emissions close to the world average.

At the same time, there are also some remarkable changes:

- Due to the less stringent profile, the BP approach is no longer the least attractive approach for Annex I the long-term one, as it does not result in negative emission allowances.
- The PS and PCC approaches have become more attractive for South Asia than the approaches with an income threshold, because it now receives surplus emissions.
- In general, for Annex I and Middle East countries under S550c, a Multi-stage regime is more favourable than a convergence regime (2050); this is the other way around for the more stringent S450c profile. This conclusion is drawn mainly from the fact that under S550c and the convergence regime, there are many much more surplus emissions for the low-income non-Annex I regions, and this has to be compensated through more reductions for the Annex I regions.

11. Sensitivity analysis, uncertainties and robustness

- Using a (relatively) high threshold for participation results in non-Annex I regions experiencing a strong shift from their baseline toward emissions reductions once entering the burden-sharing regime. This can be problematic as it may result in non-compliance.
- The attractiveness of a regime also depends on the time horizon chosen. For example, for the least developed regions, PCC can be more attractive than an approach with an income threshold in the short term, although not in the long term.
- Regionally assigned reductions depend just as much on the different regimes chosen as on the parameter settings chosen. The most important policy parameters are threshold levels, burden-sharing key and convergence dates.
- Therefore it is difficult to draw general conclusions about the implications of the approaches for different regions. However, it is clear that regions that rank much higher than average on burden-sharing indicators like per capita emissions are particularly affected if such an indicator is chosen.

11.2 Qualitative evaluation of the approaches

In addition to the quantitative analysis, we evaluated the strengths and weaknesses of the regimes explored on the basis of a (qualitative) multi-criteria evaluation. Different types of criteria (environmental, political, economic, technical and institutional and general policy) were identified. Based on the multi-criteria evaluation and the strengths and weaknesses identified, several overall conclusions about the analyses of the various regime approaches can be drawn.

- The Brazilian Proposal does not score well on either political or economic criteria, mainly due to its main focus on responsibility only and its extreme outcomes for some regions. In order to better satisfy the political and economic criteria, the proposal could be simplified to burden-sharing based on cumulative emissions since 1950 or 1990.
- The MS approach scores relatively well on political, economic and technical and institutional criteria, and overall seems to satisfy most criteria. Still it may do even better, particularly if the burden-sharing key were to be changed from per capita emissions to per capita income or even a mix of keys.
- The PCC scores high on the environmental criteria, but does much worse on the political, and technical and institutional criteria. While the cost-effectiveness is high, the overall scores on the economic criteria is fairly low, mainly due to a lack of consideration of national circumstances and baseline developments. Including adjustment factors and /or a regional approach, and provisions for emission trading, may enhance the PCC performance.
- The Preference Score approach scores even lower that the PCC approach on political, and the technical and institutional criteria due to its extreme re-distribution of emissions and incompatibility with the UNFCCC.
- The Jacoby Rule approach score is fairly balanced for most types of criteria but does not have any particular strengths. To overcome it academic nature and to increase its political appeal, the approach may need to be simplified.

Overall, the MS approach seems, in principle, to best satisfy the various types of criteria. However, other approaches could improve the performance by making adjustments in their design.

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Appendix I 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 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 (Eickhout et al., 2002) 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, 2002a) (ACCC-TOR)), or the IRF functions based on simulation experiments with various Atmosphere-Ocean General Circulation Models can be used (AOGCMs) (e.g., den Elzen et al. (1999) and den Elzen and Schaeffer (2002)). 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 (den Elzen, 2002; den Elzen et al., 2001):
   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; den Elzen, 2002; den Elzen et al., 1999).
   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 and Schaeffer, 2002; 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) (Agarwal and Narain, 1991; Agarwal et al., 1999; 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) (den Elzen, 2002).

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 (1998) and Criqui et al. (2001; 1999). 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).

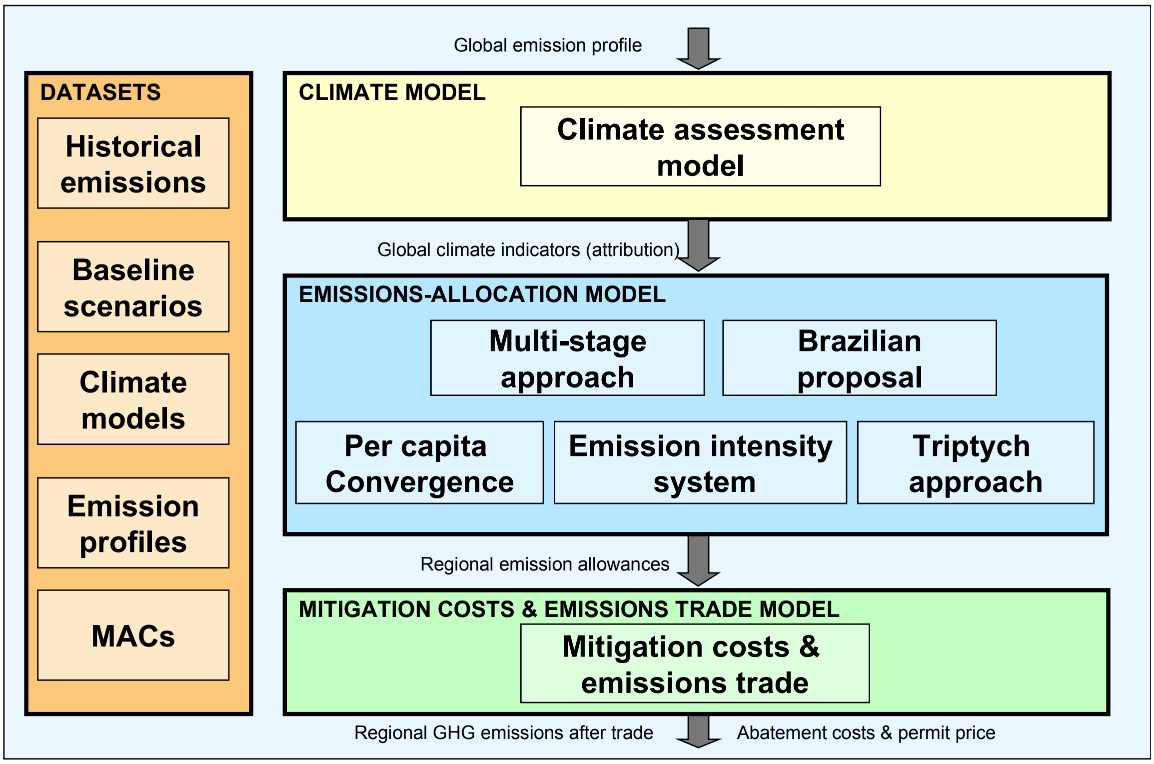

Figure I.1 Schematic diagram of FAIR 2.0 showing its framework and linkages (den Elzen, 2002; den Elzen and Lucas, 2003).

New elements of FAIR 2.0

The FAIR 2.0 model differs to FAIR 1.0 with respect to the following major elements:

1. The number of world regions has been extended to the seventeen IMAGE 2.2 world regions, i.e. Canada, USA, Central America, South America, Northern Africa, Western Africa, Eastern Africa, Southern Africa, OECD Europe, Eastern Europe, Former USSR

(FSU), Middle East, South Asia (incl. India), East Asia (incl. China), South East Asia, Oceania and Japan.

2. All emissions allocation and costs calculations are now at the level of CO_2-equivalent emissions instead of (fossil) CO_2-only. The CO_2-equivalent emissions are calculated as the sum of the 100-year GWP-weighted emissions of the six greenhouse gases or groups of gases as included in the Kyoto Protocol.[23]
3. The historical emissions of the GHGs can now based on the latest EDGAR-HYDE 1.4 historical emissions database (Olivier and Berdowski, 2001; van Aardenne et al., 2001), the energy and industry related CO_2 emissions on the latest CDIAC-ORNL database (Andres et al., 1998; Marland et al., 1999), and the land-use related CO_2 emissions on Houghton (1999). The bunker CO_2 emissions can be treated as a separate group/country, but can also be included in the regional emissions. All historical emissions are at the level of the 17 IMAGE 2.2 regions.[24]
4. The set of baseline emission is updated with the new IMAGE 2.2 IPCC SRES emission scenarios (IMAGE team, 2001), as well as the original IPCC SRES scenarios (Nakicenovic et al., 2002). Furthermore, the recently developed Common POLES-IMAGE (CPI) baseline is included (this report).
5. New IMAGE 2.2 emission profiles (Eickhout et al., 2003), have been included, stabilising the atmospheric CO_2-equivalent concentration at different levels (550, 650 and 750 ppmv).
6. The climate model has been replaced by the stand-alone version of the Atmosphere-Ocean System (AOS) of IMAGE 2.2 (Eickhout et al., 2002). This climate model calculates the CO_2 and CO_2-equivalent concentrations, global temperature increase, rate of temperature increase and sea-level rise for the different emissions scenarios.
7. An improved climate 'attribution' module is included, for the calculation of the regional contributions to emissions, concentrations of greenhouse gases, and temperature and sea-level rise (especially developed for the evaluation of the Brazilian Proposal). The climate attribution model also includes more alternative simple carbon cycle and climate models as described in the Terms of Reference (UNFCCC, 2002a) (ACCC-TOR), and the improved ACCC-TOR methodology for the attribution calculations (e.g., den Elzen et al. (2002), den Elzen et al. (1999) and den Elzen and Schaeffer (2002)).
8. The methodology of the Triptych approach is updated (as described in den Elzen, 2002), as well as other improvements in the convergence and multi-stage climate regimes. Also new climate regimes are included, i.e. the Preference Score (Bartsch and Müller, 2002) and the Jacoby rule (Jacoby et al., 1999).
9. The mitigation cost & emission trade model, which can be used to analyse the economic implications of the Kyoto Protocol and the different future commitment regimes (den Elzen and Both, 2002).
10. The inclusion of the Kyoto Protocol and its flexibilities (den Elzen and de Moor, 2001) and the Climate Change Initiative proposed by the Bush administration (van Vuuren et al., 2002; White-House, 2002a).

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[23] The set of greenhouse gases includes the fossil carbon dioxide (CO_2) emissions and the anthropogenic emissions of methane (CH_4), nitrous dioxide (N_2O), the hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF_6).

[24] To this end, only the regional CO_2 emissions from land-use changes of Houghton had to disaggregate at the level of our IMAGE 2.2 regions using historical population data.

Appendix II Detailed model results of Brazilian Proposal cases

Brazilian Proposal reference case
- participation threshold of 40% of 1990 Annex I per capita income;
- burden sharing based on contribution to temperature increase

Table II.1: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990	Reference	Target	Target per capita	Baseline level	1990 level	1990 per capita
	$MtCO_2$	$MtCO_2$	$MtCO_2$	tCO_2/cap.yr	%	%	%
USA	5143	6342	4065	12.5	-36	-21	-38
Canada	438	589	246	6.6	-58	-44	-58
OECD Europe	3503	3568	1442	3.8	-60	-59	-59
Eastern Europe	1021	928	522	4.4	-44	-49	-47
FSU	3849	3516	1917	6.4	-45	-50	-52
Oceania	310	626	247	6.2	-61	-20	-47
Japan	1161	1321	687	5.7	-48	-41	-39
Central America	426	1061	661	2.8	-38	55	-4
South America	614	1944	1239	2.7	-36	102	30
North Africa	246	716	680	3.3	-5	177	59
sub-Saharan Africa	484	1066	1719	1.5	61	255	59
ME & Turkey	897	2948	1864	4.9	-37	108	6
South Asia	788	4398	4054	2.2	-8	414	212
SE & E. Asia	3489	10558	8208	3.6	-22	135	73
World	22368	39581	27551	3.5	-30	23	-17

2050	Absolute emissions level				Reduction compared to		
Regions	1990	Reference	Target	Target per capita	Baseline level	1990 level	1990 per capita
	$MtCO_2$	$MtCO_2$	$MtCO_2$	tCO_2/cap.yr	%	%	%
USA	5143	6369	-110	-0.3	-102	-102	-102
Canada	438	560	-31	-0.8	-106	-107	-105
OECD Europe	3503	3324	-1409	-4.1	-142	-140	-144
Eastern Europe	1021	1044	-103	-1.0	-110	-110	-112
FSU	3849	3976	160	0.6	-96	-96	-96
Oceania	310	668	93	2.0	-86	-70	-83
Japan	1161	1194	-12	-0.1	-101	-101	-101
Central America	426	1615	373	1.4	-77	-12	-54
South America	614	3279	866	1.6	-74	41	-22
North Africa	246	1240	638	2.5	-48	160	23
Africa	484	2206	3540	2.2	61	632	137
ME & Turkey	897	4341	1088	2.3	-75	21	-52
South Asia	788	8712	4994	2.3	-43	533	232
SE & E. Asia	3489	14619	5281	2.2	-64	51	5
World	22368	53146	15367	1.7	-71	-31	-59

Brazilian Proposal no participation threshold

- no participation threshold: all region participate after 2010
- burden sharing based on contribution to temperature increase

Table II.2: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990	Reference	Target	Target per capita	Baseline level	1990 level	1990 per capita
	$MtCO_2$	$MtCO_2$	$MtCO_2$	tCO_2/cap.yr	%	%	%
USA	5143	6342	4504	13.9	-29	-12	-32
Canada	438	589	347	9.3	-41	-21	-41
OECD Europe	3503	3568	2605	6.8	-27	-26	-27
Eastern Europe	1021	928	779	6.6	-16	-24	-20
FSU	3849	3516	2519	8.4	-28	-35	-36
Oceania	310	626	307	7.7	-51	-1	-34
Japan	1161	1321	983	8.2	-26	-15	-13
Central America	426	1061	830	3.5	-22	95	20
South America	614	1944	1308	2.9	-33	113	37
North Africa	246	716	555	2.7	-23	126	30
Sub-Saharan Africa	484	1066	757	0.7	-29	57	-30
ME & Turkey	897	2948	1984	5.3	-33	121	13
South Asia	788	4398	2775	1.5	-37	252	114
SE & E. Asia	3489	10558	8136	3.5	-23	133	72
World	22368	39581	28388	3.6	-28	27	-15

2050	Absolute emissions level				Reduction compared to		
Regions	1990	Reference	Target	Target per capita	Baseline level	1990 level	1990 per capita
	$MtCO_2$	$MtCO_2$	$MtCO_2$	tCO_2/cap.yr	%	%	%
USA	5143	6369	74	0.2	-99	-99	-99
Canada	438	560	36	0.9	-94	-92	-94
OECD Europe	3503	3324	130	0.4	-96	-96	-96
Eastern Europe	1021	1044	119	2.0	-89	-88	-86
FSU	3849	3976	409	1.5	-90	-89	-89
Oceania	310	668	110	2.4	-84	-65	-80
Japan	1161	1194	178	1.6	-85	-85	-83
Central America	426	1615	627	2.3	-61	47	-22
South America	614	3279	1104	2.1	-66	80	0
North Africa	246	1240	466	1.9	-62	90	-11
Sub-Saharan Africa	484	2206	684	0.4	-69	41	-54
ME & Turkey	897	4341	1368	2.8	-68	53	-39
South Asia	788	8712	2583	1.2	-70	228	72
SE & E. Asia	3489	14619	6215	2.5	-57	78	23
World	22368	53146	14102	1.6	-73	-37	-63

Brazilian Proposal: burden-sharing key temperature increase per capita

- participation threshold of 40% of 1990 Annex I per capita income;
- burden sharing based on contribution to temperature increase per capita

Table II.3: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990	Reference	Target	Target per capita	Baseline level	1990 level	1990 per capita
	$MtCO_2$	$MtCO_2$	$MtCO_2$	tCO_2/cap.yr	%	%	%
USA	5143	6342	2627	8.1	-59	-49	-60
Canada	438	589	242	6.5	-59	-45	-59
OECD Europe	3503	3568	1882	4.9	-47	-46	-47
Eastern Europe	1021	928	622	5.3	-33	-39	-36
FSU	3849	3516	1975	6.6	-44	-49	-50
Oceania	310	626	256	6.5	-59	-17	-45
Japan	1161	1321	744	6.2	-44	-36	-34
Central America	426	1061	735	3.1	-31	73	7
South America	614	1944	1333	2.9	-31	117	40
North Africa	246	716	680	3.3	-5	177	59
Sub-Saharan Africa	484	1066	1719	1.5	61	255	59
ME & Turkey	897	2948	1958	5.2	-34	118	11
South Asia	788	4398	4054	2.2	-8	414	212
SE & E. Asia	3489	10558	8722	3.8	-17	150	84
World	22368	39581	27551	3.5	-30	23	-17

2050	Absolute emissions level				Reduction compared to		
Regions	1990	Reference	Target	Target per capita	Baseline level	1990 level	1990 per capita
	$MtCO_2$	$MtCO_2$	$MtCO_2$	tCO_2/cap.yr	%	%	%
USA	5143	6369	3	0.0	-100	-100	-100
Canada	438	560	6	0.1	-99	-99	-99
OECD Europe	3503	3324	28	0.1	-99	-99	-99
Eastern Europe	1021	1044	31	0.3	-97	-97	-96
FSU	3849	3976	79	0.3	-98	-98	-98
Oceania	310	668	41	0.9	-94	-87	-92
Japan	1161	1194	30	0.3	-97	-97	-97
Central America	426	1615	405	1.5	-75	-5	-49
South America	614	3279	895	1.7	-73	46	-19
North Africa	246	1240	521	2.1	-58	112	0
Sub-Saharan Africa	484	2206	3540	2.2	61	632	137
ME & Turkey	897	4341	764	1.6	-82	-15	-66
South Asia	788	8712	4603	2.1	-47	484	206
SE & E. Asia	3489	14619	4419	1.8	-70	27	-12
World	22368	53146	15367	1.7	-71	-31	-59

Brazilian Proposal burden-sharing key: CO_2 concentration

- participation threshold of 40% of 1990 Annex I per capita income;
- burden sharing based on contribution to CO_2 concentration

Table II.4: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990	Reference	Target	Target per capita	Baseline level	1990 level	1990 per capita
	$MtCO_2$	$MtCO_2$	$MtCO_2$	tCO_2/cap.yr	%	%	%
USA	5143	6342	4141	12.7	-35	-19	-37
Canada	438	589	253	6.8	-57	-42	-57
OECD Europe	3503	3568	1603	4.2	-55	-54	-55
Eastern Europe	1021	928	542	4.6	-42	-47	-45
FSU	3849	3516	1950	6.5	-45	-49	-51
Oceania	310	626	246	6.2	-61	-21	-47
Japan	1161	1321	688	5.7	-48	-41	-39
Central America	426	1061	649	2.8	-39	52	-6
South America	614	1944	1220	2.7	-37	99	28
North Africa	246	716	680	3.3	-5	177	59
Sub-Saharan Africa	484	1066	1719	1.5	61	255	59
ME & Turkey	897	2948	1815	4.8	-38	102	3
South Asia	788	4398	4054	2.2	-8	414	212
SE & E. Asia	3489	10558	7992	3.5	-24	129	69
World	22368	39581	27551	3.5	-30	23	-17

2050	Absolute emissions level				Reduction compared to		
Regions	1990	Reference	Target	Target per capita	Baseline level	1990 level	1990 per capita
	$MtCO_2$	$MtCO_2$	$MtCO_2$	tCO_2/cap.yr	%	%	%
USA	5143	6369	158	0.5	-98	-97	-98
Canada	438	560	-8	-0.2	-102	-102	-101
OECD Europe	3503	3324	-975	-2.8	-129	-128	-130
Eastern Europe	1021	1044	-45	-0.4	-104	-104	-105
FSU	3849	3976	259	1.0	-93	-93	-93
Oceania	310	668	94	2.1	-86	-70	-83
Japan	1161	1194	11	0.1	-99	-99	-99
Central America	426	1615	342	1.2	-79	-20	-57
South America	614	3279	810	1.5	-75	32	-27
North Africa	246	1240	617	2.5	-50	151	18
Sub-Saharan Africa	484	2206	3540	2.2	61	632	137
ME & Turkey	897	4341	974	2.0	-78	9	-57
South Asia	788	8712	4877	2.3	-44	519	224
SE & E. Asia	3489	14619	4713	1.9	-68	35	-6
World	22368	53146	15367	1.7	-71	-31	-59

Appendix III Detailed model results of Multi-Stage cases

Multi-Stage reference case

- participation threshold of de-carbonisation stage 2: 30% of 1990 Annex I per capita income;
- Stabilisation period (stage 3): 10-years
- participation threshold of burden-sharing stage 40% of 1990 Annex I per capita income;
- burden sharing based on contribution to per capita fossil CO_2 emissions

Table III.1: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels for the Multi-Stage reference case

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	2601	8.0	-64	-49	-60
Canada	438	613	226	6.0	-63	-48	-62
OECD Europe	3503	3921	2010	5.3	-49	-43	-43
Eastern Europe	1021	998	582	5.0	-42	-43	-41
FSU	3849	3770	1722	5.8	-54	-55	-57
Oceania	310	550	204	5.1	-63	-34	-56
Japan	1161	1441	665	5.5	-54	-43	-41
Central America	426	1095	773	3.3	-29	82	12
South America	614	2007	1379	3.0	-31	124	45
North Africa	246	680	652	3.2	-4	165	53
Sub-Saharan Africa	484	1719	1719	1.5	0	255	59
ME & Turkey	897	3200	2108	5.6	-34	135	20
South Asia	788	4054	4054	2.2	0	414	212
SE & E. Asia	3489	11843	9029	3.9	-24	159	91
World	22368	43120	27725	3.5	-36	24	-17

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	572	1.6	-92	-89	-92
Canada	438	650	62	1.5	-90	-86	-90
OECD Europe	3503	4012	573	1.7	-86	-84	-82
Eastern Europe	1021	1121	170	1.6	-85	-83	-80
FSU	3849	4179	457	1.7	-89	-88	-87
Oceania	310	653	64	1.4	-90	-79	-88
Japan	1161	1374	182	1.6	-87	-84	-83
Central America	426	1823	325	1.2	-82	-24	-59
South America	614	3668	606	2.0	-83	-1	-45
North Africa	246	1122	580	2.3	-48	136	11
Sub-Saharan Africa	484	3540	3516	2.2	-1	627	135
ME & Turkey	897	4895	649	1.3	-87	-28	-71
South Asia	788	7975	4443	2.1	-44	464	195
SE & E. Asia	3489	16820	3342	1.4	-80	-4	-34
World	22368	59318	15542	1.7	-74	-31	-59

Multi-Stage case: burden-sharing key per capita income

- participation threshold of de-carbonisation stage 2: 30% of 1990 Annex I per capita income;
- Stabilisation period (stage 3): 10-years
- participation threshold of burden-sharing stage 40% of 1990 Annex I per capita income;
- burden sharing based on contribution to per capita income

Table III.2: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	2451	7.5	-66	-52	-63
Canada	438	613	185	4.9	-70	-58	-69
OECD Europe	3503	3921	1524	4.0	-61	-56	-57
Eastern Europe	1021	998	655	5.6	-34	-36	-33
FSU	3849	3770	2339	7.8	-38	-39	-41
Oceania	310	550	182	4.6	-67	-41	-61
Japan	1161	1441	506	4.2	-65	-56	-55
Central America	426	1095	777	3.3	-29	83	13
South America	614	2007	1378	3.0	-31	124	44
North Africa	246	680	652	3.2	-4	165	53
Sub-Saharan Africa	484	1719	1719	1.5	0	255	59
ME & Turkey	897	3200	2171	5.7	-32	142	23
South Asia	788	4054	4054	2.2	0	414	212
SE & E. Asia	3489	11843	9133	4.0	-23	162	93
World	22368	43120	27725	3.5	-36	24	-17

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	66	0.2	-99	-99	-99
Canada	438	650	10	0.2	-98	-98	-98
OECD Europe	3503	4012	83	0.2	-98	-98	-97
Eastern Europe	1021	1121	153	1.5	-86	-85	-82
FSU	3849	4179	771	2.8	-82	-80	-79
Oceania	310	653	16	0.4	-98	-95	-97
Japan	1161	1374	23	0.2	-98	-98	-98
Central America	426	1823	349	1.3	-81	-18	-57
South America	614	3668	553	1.0	-85	-10	-50
North Africa	246	1122	629	2.5	-44	156	21
Sub-Saharan Africa	484	3540	3516	2.2	-1	627	135
ME & Turkey	897	4895	1013	2.1	-79	13	-55
South Asia	788	7975	4503	2.1	-44	471	199
SE & E. Asia	3489	16820	3858	1.6	-77	11	-23
World	22368	59318	15542	1.7	-74	-31	-59

Multi-Stage case: burden-sharing key based fossil CO_2 emissions intensity

- participation threshold of de-carbonisation stage 2: 30% of 1990 Annex I per capita income;
- Stabilisation period (stage 3): 10-years
- participation threshold of burden-sharing stage 40% of 1990 Annex I per capita income;
- burden sharing based on contribution to fossil CO_2 emissions intensity

Table III.3: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	3590	11.0	-50	-30	-45
Canada	438	613	253	6.8	-59	-42	-57
OECD Europe	3503	3921	2384	6.2	-39	-32	-33
Eastern Europe	1021	998	350	3.0	-65	-66	-64
FSU	3849	3770	614	2.1	-84	-84	-85
Oceania	310	550	218	5.5	-60	-30	-53
Japan	1161	1441	878	7.3	-39	-24	-23
Central America	426	1095	747	3.2	-32	75	8
South America	614	2007	1356	3.0	-32	121	42
North Africa	246	680	652	3.2	-4	165	53
Sub-Saharan Africa	484	1719	1719	1.5	0	255	59
ME & Turkey	897	3200	2009	5.3	-37	124	14
South Asia	788	4054	4054	2.2	0	414	212
SE & E. Asia	3489	11843	8902	3.9	-25	155	88
World	22368	43120	27725	3.5	-36	24	-17

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	1368	3.9	-82	-73	-81
Canada	438	650	104	2.6	-84	-76	-84
OECD Europe	3503	4012	1207	3.5	-70	-66	-62
Eastern Europe	1021	1121	131	1.3	-88	-87	-85
FSU	3849	4179	206	0.8	-95	-95	-94
Oceania	310	653	108	2.4	-84	-65	-80
Japan	1161	1374	512	4.6	-63	-56	-51
Central America	426	1823	180	0.7	-90	-58	-78
South America	614	3668	421	0.8	-89	-31	-62
North Africa	246	1122	461	1.8	-59	88	-11
Sub-Saharan Africa	484	3540	3516	2.2	-1	627	135
ME & Turkey	897	4895	393	0.8	-92	-56	-83
South Asia	788	7975	4349	2.0	-45	452	189
SE & E. Asia	3489	16820	2587	2.0	-85	-26	-49
World	22368	59318	15542	1.7	-74	-31	-59

Multi-Stage case: participation threshold: world average per capita emissions

- participation threshold of de-carbonisation stage 2: 30% of 1990 Annex I per capita income;
- Stabilisation period (stage 3): 10-years
- participation threshold of burden-sharing stage per capita world-average fossil CO_2 emissions;
- burden sharing based on contribution to per capita fossil CO_2 emissions

Table III.4: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	2427	7.5	-66	-53	-63
Canada	438	613	215	5.7	-65	-51	-64
OECD Europe	3503	3921	1926	5.0	-51	-45	-46
Eastern Europe	1021	998	559	4.8	-44	-45	-43
FSU	3849	3770	1643	5.5	-56	-57	-59
Oceania	310	550	196	4.9	-64	-37	-58
Japan	1161	1441	636	5.3	-56	-45	-44
Central America	426	1095	856	3.6	-22	101	24
South America	614	2007	1514	3.3	-25	146	59
North Africa	246	680	652	3.2	-4	165	53
Sub-Saharan Africa	484	1719	1688	1.5	-2	249	56
ME & Turkey	897	3200	2093	5.5	-35	133	19
South Asia	788	4054	4054	2.2	0	414	212
SE & E. Asia	3489	11843	9230	4.0	-22	165	95
World	22368	43120	27688	3.5	-36	24	-17

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	525	1.5	-93	-90	-93
Canada	438	650	57	1.4	-91	-87	-91
OECD Europe	3503	4012	534	1.5	-87	-85	-83
Eastern Europe	1021	1121	158	1.5	-86	-84	-82
FSU	3849	4179	424	1.6	-90	-89	-88
Oceania	310	653	60	1.3	-91	-81	-89
Japan	1161	1374	169	1.5	-88	-85	-84
Central America	426	1823	466	1.7	-74	9	-42
South America	614	3668	1111	2.1	-70	81	0
North Africa	246	1122	573	2.3	-49	133	10
Sub-Saharan Africa	484	3540	2111	1.3	-40	336	41
ME & Turkey	897	4895	604	1.3	-88	-33	-73
South Asia	788	7975	4576	2.1	-43	480	204
SE & E. Asia	3489	16820	4135	1.7	-75	18	-18
World	22368	59318	15504	1.7	-74	-31	-59

Appendix IV Detailed model results of Convergence cases

Per capita convergence reference case

- Linear Per Capita Convergence by 2050;

Table IV.1: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	3887	12.0	-46	-24	-41
Canada	438	613	268	7.2	-56	-39	-55
OECD Europe	3503	3921	2209	5.8	-44	-37	-38
Eastern Europe	1021	998	630	5.4	-37	-38	-36
FSU	3849	3770	1960	6.6	-48	-49	-51
Oceania	310	550	228	5.7	-59	-26	-51
Japan	1161	1441	737	6.1	-49	-37	-35
Central America	426	1095	697	3.0	-36	64	1
South America	614	2007	1271	2.8	-37	107	33
North Africa	246	680	531	2.6	-22	116	25
Sub-Saharan Africa	484	1719	1961	1.7	14	305	82
ME & Turkey	897	3200	1574	4.2	-51	76	-11
South Asia	788	4054	3566	1.9	-12	352	175
SE & E. Asia	3489	11843	7368	3.2	-38	111	56
World	22368	43120	26888	3.4	-38	20	-19

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	573	1.6	-92	-89	-92
Canada	438	650	66	1.6	-90	-85	-90
OECD Europe	3503	4012	566	1.6	-86	-84	-82
Eastern Europe	1021	1121	170	1.6	-85	-83	-80
FSU	3849	4179	447	1.6	-89	-88	-88
Oceania	310	653	75	1.6	-89	-76	-86
Japan	1161	1374	182	1.6	-87	-84	-83
Central America	426	1823	447	1.6	-75	5	-44
South America	614	3668	863	1.6	-76	41	-22
North Africa	246	1122	410	1.6	-63	67	-21
Sub-Saharan Africa	484	3540	2586	1.6	-27	434	73
ME & Turkey	897	4895	791	1.6	-84	-12	-65
South Asia	788	7975	3535	1.6	-56	348	135
SE & E. Asia	3489	16820	3992	1.6	-76	14	-21
World	22368	59318	14704	1.6	-75	-34	-61

1. Early convergence 2030

- linear Per Capita Convergence by 2030;

Table IV.2: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	2220	6.8	-69	-57	-66
Canada	438	613	184	4.9	-70	-58	-69
OECD Europe	3503	3921	1664	4.4	-58	-52	-53
Eastern Europe	1021	998	492	4.2	-51	-52	-50
FSU	3849	3770	1394	4.7	-63	-64	-65
Oceania	310	550	172	4.3	-69	-44	-63
Japan	1161	1441	541	4.5	-62	-53	-52
Central America	426	1095	759	3.2	-31	78	10
South America	614	2007	1438	3.2	-28	134	51
North Africa	246	680	632	3.1	-7	157	48
Sub-Saharan Africa	484	1719	3116	2.7	81	544	189
ME & Turkey	897	3200	1402	3.7	-56	56	-20
South Asia	788	4054	5238	2.8	29	564	303
SE & E. Asia	3489	11843	7635	3.3	-36	119	61
World	22368	43120	26888	3.4	-38	20	-19

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	573	1.6	-92	-89	-92
Canada	438	650	66	1.6	-90	-85	-90
OECD Europe	3503	4012	566	1.6	-86	-84	-82
Eastern Europe	1021	1121	170	1.6	-85	-83	-80
FSU	3849	4179	447	1.6	-89	-88	-88
Oceania	310	653	75	1.6	-89	-76	-86
Japan	1161	1374	182	1.6	-87	-84	-83
Central America	426	1823	447	1.6	-75	5	-44
South America	614	3668	863	1.6	-76	41	-22
North Africa	246	1122	410	1.6	-63	67	-21
Sub-Saharan Africa	484	3540	2586	1.6	-27	434	73
ME & Turkey	897	4895	791	1.6	-84	-12	-65
South Asia	788	7975	3535	1.6	-56	348	135
SE & E. Asia	3489	16820	3992	1.6	-76	14	-21
World	22368	59318	14704	1.6	-75	-34	-61

2. Non-linear convergence

- non-linear Per Capita Convergence by 2050;

Table IV.3: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	3390	10.4	-53	-34	-48
Canada	438	613	251	6.7	-59	-43	-57
OECD Europe	3503	3921	2108	5.5	-46	-40	-41
Eastern Europe	1021	998	598	5.1	-40	-41	-39
FSU	3849	3770	1792	6.0	-52	-53	-55
Oceania	310	550	217	5.5	-60	-30	-53
Japan	1161	1441	703	5.8	-51	-39	-38
Central America	426	1095	713	3.0	-35	68	3
South America	614	2007	1316	2.9	-34	114	38
North Africa	246	680	558	2.7	-18	127	31
Sub-Saharan Africa	484	1719	2241	2.0	30	363	108
ME & Turkey	897	3200	1492	4.0	-53	66	-15
South Asia	788	4054	4056	2.2	0	414	212
SE & E. Asia	3489	11843	7453	3.3	-37	114	57
World	22368	43120	26888	3.4	-38	20	-19

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	573	1.6	-92	-89	-92
Canada	438	650	66	1.6	-90	-85	-90
OECD Europe	3503	4012	566	1.6	-86	-84	-82
Eastern Europe	1021	1121	170	1.6	-85	-83	-80
FSU	3849	4179	447	1.6	-89	-88	-88
Oceania	310	653	75	1.6	-89	-76	-86
Japan	1161	1374	182	1.6	-87	-84	-83
Central America	426	1823	447	1.6	-75	5	-44
South America	614	3668	863	1.6	-76	41	-22
North Africa	246	1122	410	1.6	-63	67	-21
Sub-Saharan Africa	484	3540	2586	1.6	-27	434	73
ME & Turkey	897	4895	791	1.6	-84	-12	-65
South Asia	788	7975	3535	1.6	-56	348	135
SE & E. Asia	3489	16820	3992	1.6	-76	14	-21
World	22368	59318	14704	1.6	-75	-34	-61

3. Cap population case

- Linear Per Capita Convergence by 2050 with population cut-off year 2010.

Table IV.4: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	3909	12.0	-46	-24	-41
Canada	438	613	269	7.2	-56	-39	-54
OECD Europe	3503	3921	2294	6.0	-42	-35	-35
Eastern Europe	1021	998	657	5.6	-34	-36	-33
FSU	3849	3770	2014	6.8	-47	-48	-49
Oceania	310	550	228	5.7	-59	-27	-51
Japan	1161	1441	769	6.4	-47	-34	-32
Central America	426	1095	690	2.9	-37	62	0
South America	614	2007	1263	2.8	-37	106	32
North Africa	246	680	520	2.5	-23	112	22
Sub-Saharan Africa	484	1719	1741	1.5	1	260	61
ME & Turkey	897	3200	1528	4.0	-52	70	-13
South Asia	788	4054	3498	1.9	-14	344	169
SE & E. Asia	3489	11843	7505	3.3	-37	115	58
World	22368	43120	26888	3.4	-38	20	-19

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	638	1.8	-91	-88	-91
Canada	438	650	72	1.8	-89	-84	-89
OECD Europe	3503	4012	835	2.4	-79	-76	-74
Eastern Europe	1021	1121	259	2.5	-77	-75	-70
FSU	3849	4179	635	2.3	-85	-83	-82
Oceania	310	653	73	1.6	-89	-76	-86
Japan	1161	1374	271	2.4	-80	-77	-74
Central America	426	1823	427	1.6	-77	0	-47
South America	614	3668	836	1.6	-77	36	-24
North Africa	246	1122	367	1.5	-67	49	-30
Sub-Saharan Africa	484	3540	1804	2.0	-49	273	21
ME & Turkey	897	4895	637	1.3	-87	-29	-72
South Asia	788	7975	3376	1.6	-58	328	124
SE & E. Asia	3489	16820	4473	1.8	-73	28	-11
World	22368	59318	14704	1.6	-75	-34	-61

Appendix V Detailed model results of Preference Score cases

Preference Score reference case

- policy delay: ten years

Table V.1: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	1704	5.2	-76	-67	-74
Canada	438	613	171	4.6	-72	-61	-71
OECD Europe	3503	3921	1735	4.5	-56	-50	-51
Eastern Europe	1021	998	509	4.3	-49	-50	-48
FSU	3849	3770	1316	4.4	-65	-66	-67
Oceania	310	550	163	4.1	-70	-47	-65
Japan	1161	1441	574	4.8	-60	-51	-49
Central America	426	1095	761	3.2	-31	79	10
South America	614	2007	1472	3.2	-27	140	54
North Africa	246	680	639	3.1	-6	160	50
Sub-Saharan Africa	484	1719	3017	2.6	75	524	180
ME & Turkey	897	3200	1215	3.2	-62	36	-31
South Asia	788	4054	5652	3.0	39	617	335
SE & E. Asia	3489	11843	7960	3.5	-33	128	68
World	22368	43120	26888	3.4	-38	20	-19

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	628	1.8	-92	-88	-91
Canada	438	650	71	1.7	-89	-84	-89
OECD Europe	3503	4012	676	2.0	-83	-81	-79
Eastern Europe	1021	1121	202	2.0	-82	-80	-77
FSU	3849	4179	525	1.9	-87	-86	-86
Oceania	310	653	76	1.7	-88	-75	-86
Japan	1161	1374	213	1.9	-84	-82	-80
Central America	426	1823	440	1.6	-76	3	-45
South America	614	3668	850	1.6	-77	38	-23
North Africa	246	1122	390	1.6	-65	59	-25
Sub-Saharan Africa	484	3540	2270	1.4	-36	369	52
ME & Turkey	897	4895	738	1.5	-85	-18	-67
South Asia	788	7975	3463	1.6	-57	339	130
SE & E. Asia	3489	16820	4162	1.7	-75	19	-17
World	22368	59318	14704	1.6	-75	-34	-61

1. No policy delay Preference Score

- policy delay: zero years

Table V.2: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	1110	3.4	-85	-78	-83
Canada	438	613	128	3.4	-79	-71	-78
OECD Europe	3503	3921	1311	3.4	-67	-63	-63
Eastern Europe	1021	998	403	3.4	-60	-61	-59
FSU	3849	3770	1023	3.4	-73	-73	-74
Oceania	310	550	135	3.4	-75	-56	-71
Japan	1161	1441	415	3.4	-71	-64	-63
Central America	426	1095	800	3.4	-27	88	16
South America	614	2007	1549	3.4	-23	152	62
North Africa	246	680	698	3.4	3	184	64
Sub-Saharan Africa	484	1719	3855	3.4	124	697	257
ME & Turkey	897	3200	1282	3.4	-60	43	-27
South Asia	788	4054	6345	3.4	57	705	389
SE & E. Asia	3489	11843	7834	3.4	-34	125	65
World	22368	43120	26888	3.4	-38	20	-19

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	573	1.6	-92	-89	-92
Canada	438	650	67	1.6	-90	-85	-90
OECD Europe	3503	4012	570	1.6	-86	-84	-82
Eastern Europe	1021	1121	171	1.6	-85	-83	-80
FSU	3849	4179	449	1.6	-89	-88	-88
Oceania	310	653	75	1.6	-89	-76	-86
Japan	1161	1374	183	1.6	-87	-84	-83
Central America	426	1823	447	1.6	-75	5	-44
South America	614	3668	863	1.6	-76	40	-22
North Africa	246	1122	410	1.6	-64	67	-21
Sub-Saharan Africa	484	3540	2574	1.6	-27	432	72
ME & Turkey	897	4895	789	1.6	-84	-12	-65
South Asia	788	7975	3534	1.6	-56	348	135
SE & E. Asia	3489	16820	4000	1.6	-76	15	-21
World	22368	59318	14704	1.6	-75	-34	-61

2. Twenty year policy delay Preference Score

- policy delay: twenty years

Table V.3: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	2370	7.3	-67	-54	-64
Canada	438	613	217	5.8	-65	-50	-63
OECD Europe	3503	3921	2041	5.3	-48	-42	-42
Eastern Europe	1021	998	575	4.9	-42	-44	-41
FSU	3849	3770	1547	5.2	-59	-60	-61
Oceania	310	550	199	5.0	-64	-36	-57
Japan	1161	1441	685	5.7	-52	-41	-40
Central America	426	1095	730	3.1	-33	72	6
South America	614	2007	1395	3.1	-30	127	46
North Africa	246	680	594	2.9	-13	142	39
Sub-Saharan Africa	484	1719	2502	2.2	46	417	132
ME & Turkey	897	3200	1242	3.3	-61	39	-29
South Asia	788	4054	4965	2.7	22	530	282
SE & E. Asia	3489	11843	7825	3.4	-34	124	65
World	22368	43120	26888	3.4	-38	20	-19

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	827	2.4	-89	-84	-88
Canada	438	650	83	2.0	-87	-81	-87
OECD Europe	3503	4012	809	2.3	-80	-77	-75
Eastern Europe	1021	1121	243	2.3	-78	-76	-72
FSU	3849	4179	640	2.3	-85	-83	-82
Oceania	310	653	86	1.9	-87	-72	-84
Japan	1161	1374	260	2.3	-81	-78	-75
Central America	426	1823	427	1.6	-77	0	-47
South America	614	3668	823	1.6	-78	34	-26
North Africa	246	1122	367	1.5	-67	49	-30
Sub-Saharan Africa	484	3540	1934	1.2	-45	300	29
ME & Turkey	897	4895	712	1.5	-85	-21	-68
South Asia	788	7975	3241	1.5	-59	311	115
SE & E. Asia	3489	16820	4253	1.7	-75	22	-16
World	22368	59318	14704	1.6	-75	-34	-61

3. Cap population case

- Preference Score with population cut-off year 2010.

Table V.4: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	1454	4.5	-80	-72	-78
Canada	438	613	153	4.1	-75	-65	-74
OECD Europe	3503	3921	1655	4.3	-58	-53	-53
Eastern Europe	1021	998	498	4.2	-50	-51	-49
FSU	3849	3770	1255	4.2	-67	-67	-68
Oceania	310	550	150	3.8	-73	-52	-68
Japan	1161	1441	543	4.5	-62	-53	-52
Central America	426	1095	768	3.3	-30	80	11
South America	614	2007	1497	3.3	-25	144	57
North Africa	246	680	652	3.2	-4	165	53
Sub-Saharan Africa	484	1719	3106	2.7	81	542	188
ME & Turkey	897	3200	1182	3.1	-63	32	-33
South Asia	788	4054	5884	3.2	45	646	353
SE & E. Asia	3489	11843	8091	3.5	-32	132	71
World	22368	43120	26888	3.4	-38	20	-19

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	646	1.8	-91	-87	-91
Canada	438	650	72	1.8	-89	-83	-89
OECD Europe	3503	4012	838	2.4	-79	-76	-74
Eastern Europe	1021	1121	259	2.5	-77	-75	-70
FSU	3849	4179	638	2.3	-85	-83	-82
Oceania	310	653	74	1.6	-89	-76	-86
Japan	1161	1374	272	2.4	-80	-77	-74
Central America	426	1823	427	1.6	-77	0	-47
South America	614	3668	836	1.6	-77	36	-24
North Africa	246	1122	366	1.5	-67	49	-30
Sub-Saharan Africa	484	3540	1799	2.0	-49	272	20
ME & Turkey	897	4895	638	1.3	-87	-29	-72
South Asia	788	7975	3368	1.6	-58	327	124
SE & E. Asia	3489	16820	4471	1.8	-73	28	-11
World	22368	59318	14704	1.6	-75	-34	-61

Appendix VI Detailed model results of Jacoby rule cases

Jacoby Rule Reference case

- 40% '90 Annex I PPP-per capita income
- $\alpha = 0.050$; $\beta = 0.040$; and $\gamma = 0.040$

Table VI.1: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	4108	12.6	-43	-20	-38
Canada	438	613	263	7.0	-57	-40	-55
OECD Europe	3503	3921	2070	5.4	-47	-41	-42
Eastern Europe	1021	998	614	5.2	-39	-40	-37
FSU	3849	3770	2103	7.1	-44	-45	-47
Oceania	310	550	216	5.4	-61	-30	-54
Japan	1161	1441	700	5.8	-51	-40	-38
Central America	426	1095	536	2.3	-51	26	-22
South America	614	2007	911	2.0	-55	48	-5
North Africa	246	680	680	3.3	0	177	59
Sub-Saharan Africa	484	1719	1719	1.5	0	255	59
ME & Turkey	897	3200	1713	4.5	-46	91	-3
South Asia	788	4054	4054	2.2	0	414	212
SE & E. Asia	3489	11843	7201	3.1	-39	106	52
World	22368	43120	26888	3.4	-38	20	-19

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	1356	3.9	-82	-74	-81
Canada	438	650	88	2.2	-86	-80	-86
OECD Europe	3503	4012	696	2.0	-83	-80	-78
Eastern Europe	1021	1121	220	2.1	-80	-78	-75
FSU	3849	4179	777	2.8	-81	-80	-79
Oceania	310	653	74	1.6	-89	-76	-86
Japan	1161	1374	234	2.1	-83	-80	-78
Central America	426	1823	207	0.8	-89	-51	-74
South America	614	3668	345	0.7	-91	-44	-69
North Africa	246	1122	438	1.7	-61	78	-16
Sub-Saharan Africa	484	3540	3540	2.2	0	632	137
ME & Turkey	897	4895	668	1.4	-86	-25	-70
South Asia	788	7975	3313	1.5	-58	320	120
SE & E. Asia	3489	16820	2746	2.0	-84	-21	-45
World	22368	59318	14704	1.6	-75	-34	-61

1. JR low welfare trigger

- 30% ‘90 Annex I PPP-per capita income
- $\alpha = 0.050$; $\beta = 0.040$; and $\gamma = 0.050$

Table VI.2: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	4488	13.8	-38	-13	-32
Canada	438	613	287	7.7	-53	-34	-51
OECD Europe	3503	3921	2259	5.9	-42	-36	-36
Eastern Europe	1021	998	664	5.7	-33	-35	-32
FSU	3849	3770	2245	7.5	-40	-42	-43
Oceania	310	550	236	5.9	-57	-24	-49
Japan	1161	1441	764	6.3	-47	-34	-33
Central America	426	1095	569	2.4	-48	34	-17
South America	614	2007	977	2.1	-51	59	2
North Africa	246	680	535	2.6	-21	118	25
Sub-Saharan Africa	484	1719	1719	1.5	0	255	59
ME & Turkey	897	3200	1588	4.2	-50	77	-10
South Asia	788	4054	4054	2.2	0	414	212
SE & E. Asia	3489	11843	6503	2.8	-45	86	37
World	22368	43120	26888	3.4	-38	20	-19

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	1839	5.3	-75	-64	-74
Canada	438	650	120	3.0	-82	-73	-81
OECD Europe	3503	4012	942	2.7	-77	-73	-71
Eastern Europe	1021	1121	294	2.8	-74	-71	-66
FSU	3849	4179	1020	3.7	-76	-73	-72
Oceania	310	653	100	2.2	-85	-68	-81
Japan	1161	1374	317	2.9	-77	-73	-70
Central America	426	1823	268	1.0	-85	-37	-67
South America	614	3668	454	0.9	-88	-26	-59
North Africa	246	1122	274	2.0	-76	11	-47
Sub-Saharan Africa	484	3540	3116	2.0	-12	544	108
ME & Turkey	897	4895	754	1.6	-85	-16	-67
South Asia	788	7975	2182	1.0	-73	177	45
SE & E. Asia	3489	16820	3024	1.2	-82	-13	-40
World	22368	59318	14704	1.6	-75	-34	-61

2. JR high welfare trigger

- 40% ‘90 Annex I PPP-per capita income
- $\alpha = 0.050$; $\beta = 0.040$; and $\gamma = 0.020$

Table VI.3: Overview of the total and per capita emission allowances, as well as the changes compared to 1990 and baseline emissions levels.

2025	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7228	2937	9.0	-59	-43	-55
Canada	438	613	188	5.0	-69	-57	-68
OECD Europe	3503	3921	1482	3.9	-62	-58	-58
Eastern Europe	1021	998	445	3.8	-55	-56	-55
FSU	3849	3770	1880	6.3	-50	-51	-53
Oceania	310	550	155	3.9	-72	-50	-67
Japan	1161	1441	501	4.2	-65	-57	-56
Central America	426	1095	624	2.7	-43	46	-10
South America	614	2007	680	1.5	-66	11	-29
North Africa	246	680	680	3.3	0	177	59
Sub-Saharan Africa	484	1719	1719	1.5	0	255	59
ME & Turkey	897	3200	2788	7.4	-13	211	58
South Asia	788	4054	4054	2.2	0	414	212
SE & E. Asia	3489	11843	8755	3.8	-26	151	85
World	22368	43120	26888	3.4	-38	20	-19

2050	Absolute emissions level				Reduction compared to		
Regions	1990 $MtCO_2$	Reference $MtCO_2$	Target $MtCO_2$	Target per capita tCO_2/cap.yr	Baseline level %	1990 level %	1990 per capita %
USA	5143	7486	661	1.9	-91	-87	-91
Canada	438	650	43	2.0	-93	-90	-93
OECD Europe	3503	4012	340	1.0	-92	-90	-89
Eastern Europe	1021	1121	110	2.0	-90	-89	-87
FSU	3849	4179	481	1.8	-88	-88	-87
Oceania	310	653	36	0.8	-94	-88	-93
Japan	1161	1374	115	1.0	-92	-90	-89
Central America	426	1823	169	0.6	-91	-60	-79
South America	614	3668	180	0.3	-95	-71	-84
North Africa	246	1122	666	2.7	-41	171	28
Sub-Saharan Africa	484	3540	3540	2.2	0	632	137
ME & Turkey	897	4895	769	1.6	-84	-14	-66
South Asia	788	7975	5150	2.4	-35	553	242
SE & E. Asia	3489	16820	2445	1.0	-85	-30	-51
World	22368	59318	14704	1.6	-75	-34	-61

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