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Exploring Climate Regimes for Differentiation of Future Commitments to Stabilise Greenhouse Gas Concentrations

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ABSTRACT

This paper aims at exploring the implications of various international climate regimes for differentiating future commitments compatible with Article 2 of the Climate Change Convention, i.e., stabilising the greenhouse gas concentration at a 'non-dangerous' level. Three climate regimes explored are: (1) the Multi-stage approach, with a gradual increase in the number of Parties involved and their level of commitment according to participation and differentiation rules; (2) the Convergence approach, with universal participation and a convergence of per capita emissions and (3) the Triptych sector and technology-oriented approach, with universal participation in which the emission allowances are determined by applying differentiation rules according to sector, e.g., convergence of per capita emissions in the domestic sector, and efficiency and de-carbonisation targets in the energy-intensive industrial and power-producing sectors. The FAIR (Framework to Assess International Regimes for the differentiation of commitments) model is used to explore the implications of these regimes for future emission allowances. It was not the objective to reach any conclusions about what type of regime would be preferred. Analysis of the three approaches shows that substantive reductions of Annex I emissions will be needed for stabilising CO_2 concentration at 450 ppmv by 2100, as well as timely participation of the non-Annex I regions in global emissions control.

Keywords: climate policy, Contraction & Convergence, Triptych, differentiation of future commitments, burden sharing.

1. INTRODUCTION

The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) (Article 2) is to 'stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' [1]. The UNFCCC has not yet quantified this objective. One of the most crucial issues for the development of an effective international climate regime is the issue of the differentiation of future commitments for both Annex I and non-Annex I countries. While the greenhouse gas emissions of non-Annex I at present are smaller than the emissions of Annex I countries, it is expected that within a few decades these emissions will overtake those of Annex I countries. However, already in 1992, during the negotiations on the UNFCCC, non-Annex I countries stressed that given their historical emissions the Annex I countries would bear the primary responsibility for the climate change problem and should take the lead in climate change mitigation actions. This is formally recognised in the UNFCCC, which states that Annex I and non-Annex I countries have ‘‘common but differentiated responsibilities’’ (Article 3.1) [1]. This was re-acknowledged in the so-called Berlin Mandate [2], in which additional commitments were limited to developed countries only. During COP-3 in 1997, the industrialised countries agreed in Kyoto (Japan) to reduce their GHG emissions in the 2008–2012 period by an average of 5.2%, compared to base-year levels [3]. At meetings in Bonn and Marrakech in 2001, the Parties agreed on a number of key implementation issues of the Kyoto Protocol, leading to the Marrakech Accords, notwithstanding the US decision to withdraw from the Kyoto Protocol earlier the same year. The Kyoto Protocol (KP) does not include new commitments for the non-Annex I regions for the first commitment period, but it will be a major issue in discussions about subsequent commitment periods.

In the light of the need to broaden the participation of developing (non-Annex I) countries in future emission control, the international climate regime might develop in different directions [4]:

1. incremental regime evolution, i.e., a gradual expansion of the Annex I group of countries, adopting binding

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quantified emission limitation or reduction objectives under the UNFCCC;
2. structural regime change, i.e., defining the evolution of emission allowances for all Parties over a longer period.

The first approach would mean a gradual extension of the present KP approach to differentiate the obligations of various Parties under the Convention (sometimes referred to as 'graduation'). It could either be based on ad-hoc criteria, or on pre-defined rules for both participation and differentiation of commitments. An example of such an approach is the '*increasing participation*' or '*Multi-stage*' approach [4–6]. In this approach, the levels and the type of commitments are differentiated among Parties on the basis of (alternative) participation and burden-sharing rules. This approach entails gradual extension of the climate regime to include non-Annex I regions with different types of obligations.

The second approach would mean a major shift away from the present Protocol approach towards defining commitments for all Parties and their evolution over the long-term. A clear case of the latter is the so-called 'Contraction & Convergence' approach [7], which defines emission permits on the basis of a convergence of per capita emissions under a contracting global emission profile. In such a *Convergence* regime all Parties participate in the climate regime with emission allowances converging to equal per capita levels over time.

A quite different approach would be in a regime with a sector- and/or technology-oriented approach in differentiating commitments, such as the *Triptych* approach [8]. The Triptych approach is a sectoral approach taking into account national circumstances and, hence, is more bottom-up in character. Originally, the approach was used within the EU to help define its internal differentiation of targets for the KP [8, 9]. It was applied on a global level in two studies [6, 10].

Both prior and subsequent to the negotiations on the KP, many proposals for differentiating mitigation commitments among countries were made, both by academic circles and Parties to the UNFCCC [11–13]. This paper focuses only on three approaches for of differentiation of future commitments: Multi-stage, Convergence and Triptych, which, as indicated above, represent quite distinctive directions for the development of a post-Kyoto climate regime. The paper also presents an updated Triptych approach, which deals with a number of shortcomings in two earlier global applications [6, 10]. This updated approach is based on recent work of Groenenberg [14]. The framework for the analysis is formed by the decision-support model, FAIR (Framework to Assess International Regimes for differentiation of future commitments). This model is designed to quantitatively explore a range of alternative differentiation schemes of future commitments under the UNFCCC (post-Kyoto) in the context of stabilising greenhouse gas concentrations [15], as briefly described in Section 3. An illustrative differentiation of commitments is put forward in Section 4 for each of the three approaches. This differentiation aims at reaching the relatively low atmospheric carbon dioxide (CO_2) concentration stabilisation level of 450 ppmv (approximately 550 ppmv CO_2-equivalent concentration and a global temperature of less than 2 degrees above pre-historical levels [4]) by 2100 (Section 3). Section 4 also presents a sensitivity analysis to assess the impact of different parameter settings for each of the three approaches. In Section 5 the various cases are compared for all three approaches. The paper ends with a number of conclusions (Section 6). However, we will start with a short overview on various equity principles of differentiation of (future) commitments relevant for understanding the approaches evaluated (Section 2).

2. EQUITY PRINCIPLES FOR DIFFERENTIATION OF COMMITMENTS

The Climate Convention requires Annex I countries to take the lead in climate change mitigation and national priorities, objectives and circumstances to be taken into account (Article 3.1), in particular, the needs and circumstances of developing countries (Article 3.2) [1]. Here is where the debate on equity or fairness comes in. Different categorisations of equity principles can be found in the literature [16–18]. In reviewing the most relevant elements for a widely accepted approach to burden differentiation in future international climate negotiations in recent studies, the most salient equity and fairness principles in distributing efforts are summarised by Ringius et al. [19]:

- *Responsibility*: costs should be distributed in proportion to a country's share of responsibility for causing the problem;
- *Capacity*: costs should be distributed in proportion to a country's ability to pay;
- *Need*: all individuals have equal rights to pollution permits, with a minimum necessary to secure basis human rights, including a reasonable standard of living.

The three approaches in differentiation of future commitments analysed in this article combine different principles of equity discussed above (see also Berk & den Elzen [4]). The Multi-stage and Triptych approaches are based on more than one equity principle. The main equity principle behind the Multi-stage approach is the responsibility principle, but by defining one or more thresholds for different levels of participation, the approach also accounts for the considerations of need (for development) and capacity to act. The Convergence approach is based mainly on the egalitarian equity/need principle, although to some extent it also partially accounts for considerations of capacities by allowing for a transition period, in which the distribution of per capita emission allowances change from status quo levels to equal per capita levels. The Triptych approach is a mixed one, encompassing both the principle of capacity through its technological orientation and the principle of need by adopting a per capita convergence approach for domestic-sector emissions (see also Ringius et al. [19]).

3. THE FAIR MODEL

The FAIR model is designed to quantitatively explore a range of alternative options for differentiation of future commitments in international climate policy and link these to targets for climate protection [15]. The FAIR model is a simulation tool with a graphic interface allowing for changing and viewing model input and output in an interactive way. Here, version 1.1 of FAIR is used, which differs from FAIR 1.0 [15] by including the climate model meta-IMAGE 2.2 [20], an updated methodology of the Triptych approach and the cost model [21]. The baseline emission scenarios are based on the new IMAGE 2.2 IPCC SRES emission scenarios [22]. Finally, the number of world regions has been extended to seventeen, i.e., Canada, USA, Central America, South America, North, West, East and South Africa, OECD Europe, Eastern Europe, Former Soviet Union (FSU), Middle East (incl. Turkey), South Asia (incl. India), East Asia (incl. China), South East Asia, Oceania and Japan.

The FAIR model integrates three models: a simple integrated climate model, a burden-sharing model for calculating regional emission allowances or permits for various options for the differentiation of future commitments and a cost model for the calculation of emission trading and abatement costs. More specifically:

1. *Scenario construction and evaluation*: The climate impacts in terms of the global climate indicators: greenhouse gas concentrations, temperature increase, rate of temperature increase and sea level rise of global emission profiles for greenhouse gases are calculated using the simple climate model meta-IMAGE 2.2 [20]. This climate model reproduces the IMAGE 2.2 projections of these climate indicators [22]. The meta-IMAGE 2.2 model is supplemented with a climate 'attribution' module to calculate the regional contributions to various categories of emissions, concentrations of greenhouse gases, and temperature and sea-level rise (especially developed for the evaluation of the Brazilian Proposal) [23].
2. *Differentiation of future commitments*: Next, the burden-sharing model calculates regional emission allowances or permits on the basis of the three different commitment regime approaches [4, 15]:

   a. Multi-stage approach, with 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, per capita emissions, or contribution to global warming (including the Brazilian Proposal) [6].
   b. Convergence approach, in which all Parties participate in the regime, with emission allowances converging to equal per capita levels over time. Three types of convergence methodologies are included: (i) per capita Convergence approach, convergence towards equal per capita emission allowances. (ii) Per capita Convergence approach with basic sustainable emission rights as suggested by the Centre of Science and Environment (CSE) [24]. (iii) Convergence of emission intensities of the economy (emissions per unit of economic activity expressed in GDP (Gross Domestic Product) terms).
   c. 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 decarbonisation targets for the industrial and the power generation sector).

   The calculated emission allowances (without emissions trading) of a selected climate regime form the input for the cost module [21], i.e.:
3. *Emissions trading and abatement costs*: this model calculates the tradable emission permits, international permit price and abatement costs for the first commitment period, i.e., 2008–2012 and the post-Kyoto period till 2030 with or without emissions trading. Marginal Abatement Curves (MACs), which reflect the additional mitigation costs of reducing the last unit of carbon, are used to this end [21]. The calculations make use of the properties of the permit supply and demand curves, derived from MAC curves, so as to calculate the market equilibrium permit price under different regulation schemes. These schemes could include constraints on imports and exports of emission permits, non-competitive behaviour, transaction costs associated with the use of emissions trading and less than completely efficient supply (related to the operational availability of viable CDM projects). The analysis in the present study will only focus on emission allowances (without emissions trading), and does not include an economic evaluation, i.e., calculation of emissions trading and abatement costs.

4. THREE CLIMATE REGIMES UNDER A GLOBAL FOSSIL CO_2 EMISSION PROFILE FOR STABILISING AT 450 ppmv

The following sections describe the methodology of the three regime approaches, Multi-stage, per capita Convergence and Triptych, in more detail. In addition, each of the three approaches is illustrated with a reference case, indicating how commitments may be differentiated if a long-term stabilisation of the atmospheric CO_2 concentration of 450 ppmv is to be achieved. The IMAGE 2.1 A1B scenario [22] is used as the baseline scenario for the fossil CO_2 emissions, population and economic growth. The analysis of the differentiation of future commitments focuses

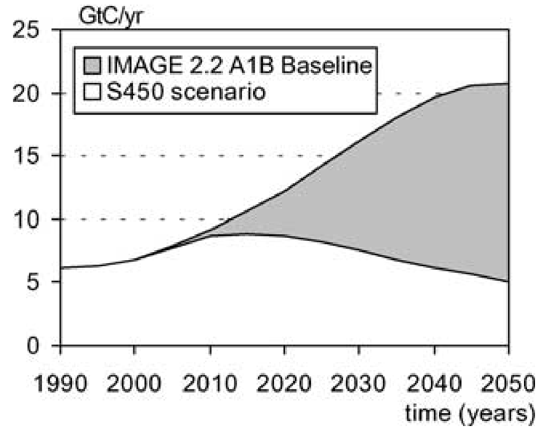

Fig. 1. The fossil CO_2 emission reduction burden is shown (in the grey area) to be the difference between the IMAGE 2.2 A1B baseline scenario and the fossil CO_2 emission profile for stabilising CO_2 concentration at 450 ppmv (S450 scenario).

on the fossil CO_2 emissions only (CO_2 emissions from fossil fuel combustion and industrial sources). The global fossil CO_2 emission ceiling aiming at 450 ppmv is described by the IPCC delayed response to the global anthropogenic CO_2 emission profile leading to a 450 ppmv CO_2 concentration stabilisation target [25],[1] adjusted with a global land-use emission profile based on per capita convergence towards a zero-level by 2050. This global land-use emission profile is comparable to the IMAGE 2.2 A1B land-use emission scenario [22]. In 1990 the global fossil CO_2 emissions amounted to 6.1 GtC. The global fossil CO_2 emission profile leads to the highest global emissions of about 8.7 GtC by 2015, while the emissions start to decline to 6.0 GtC by 2025 (30% reduction compared to A1B emissions), 5.1 GtC by 2050 (67% reduction) and 2.6 GtC by 2100 (80% reduction) (Fig. 1). The global emission reduction burden between 1990 and 2100 for stabilising CO_2 concentration at 450 ppmv by 2100 is defined by the difference between the fossil CO_2 emission profile, leading to 450 ppmv (hereafter referred to as S450 scenario), and the IMAGE 2.1 A1B reference emission scenario.

The analysis of the differentiation of future commitments focuses on the emission allowances for the post-Kyoto period (after the first commitment period) up to 2050. All three regimes assume similar regional emission allowances in the short term, up to the middle of the first commitment period (2010). More specifically, all Annex I regions participating in the Kyoto Protocol (i.e., all Annex I regions except the USA) agreed to an immediate start (2000) for meeting the Kyoto targets for 2010. The US emissions follow an emission profile that differs only marginally (about −5%) from the baseline emissions of the reference scenario, consistent with the greenhouse gas intensity target of the recent Bush Climate Change Initiative. The non-Annex I regions follow their baseline reference emissions.

[1] More specifically, we refer to the delayed response curve of the IPCC Second Assessment Report (SAR) in Figure 2.6 [25], which was not updated in the IPCC-2001 Third Assessment Report (TAR).

4.1. The Multi-Stage Approach

In the Multi-stage approach the number of Parties involved and the level and type of commitments is differentiated amongst Parties on the basis of (alternative) participation and burden-sharing rules [5, 6].

This 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 responsibilities/ commitments under the climate regime. Moreover, the system defines when their level of commitment changes arising from a change in circumstances. The Multi-stage approach was originally developed as a global application of the Brazilian proposal to relate Parties' relative contribution to emission control to their relative contribution to (realised) global temperature increase. Here, the Brazilian approach was combined with a threshold for participation [4, 6, 26]. Later, the approach was extended to a Multi-stage approach, fitting the ideas from Gupta [5].

4.1.1. Methodology

In its basic form the regime starts with the selection of a long-term emission profile, which aims at stabilising the CO_2 concentration at target level (in the illustrative case 450 ppmv). For each 5-year time-period, the participation rules 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 de-carbonisation threshold.
- *Stage 2. Adoption of intensity targets*: The Non-Annex I regions then enter a stage in which their 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). Participation is based on income and/or emission thresholds, or by a selected starting year. A region moves to stage 3 when it reaches any of the selected 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 emission reduction regime.

Table 1. Model parameters in the Multi-stage approach for the reference case, and the Annex I favourable* and non-Annex I favourable cases.

Model parameters	Reference case	Annex I favourable case	Non-Annex I favourable case
Stage 1 No quantitative commitments			
Stage 2 The adoption of intensity targets			
Participation threshold	2010	2010	2050
De-carbonisation rate			
High-income non-Annex I regions	2.5% after 2010	3% after 2010	0.5% after 2010
Middle-income non-Annex I regions	1% 2010–2.5% 2030	3% after 2010	0.5% after 2010
Low-income non-Annex I regions	0.5% 2010–2.5% 2050	3% after 2010	0.5% after 2010
Stage 3 Stabilisation of emissions			
Participation threshold	world average per capita fossil emission	30% ’90 Annex I per cap. Income	world average per capita fossil emis.
Stabilisation period	10 years	0 year	15 years
Stage 4 Sharing in the efforts of absolute emission reductions.			
Annex I (incl. USA) enter Stage 4	2010		
Burden-sharing key	Per capita fossil CO_2 emissions	Fossil CO_2 emissions	Per capita income (in PPP$/cap)

Note. *Annex I favourable case corresponds to parameter settings leading to ‘loose’ Annex I commitments relative to the Annex I commitments under the reference case. A similar definition holds for the non-Annex I favourable case.
**De-carbonisation rate is the change in emission intensity (emissions per unit of economic activity expressed in PPP$ terms). Economic activity in US$ terms would increase the de-carbonisation rate: High-income NA-I: 3% after 2010; Middle-income NA-I : 2% in 2010 – 3% in 2030; Low-income NA-I: 1% in 2010 – 3% in 2050.

- *Stage 4. Sharing in the efforts of absolute emission reductions*: In the emission reduction regime the burden-sharing rules then determine the emission reductions for each of the participating regions (Annex I and non-Annex I). More specifically, the required emission reduction effort is determined by subtracting the sum of the emissions of non-participating regions in stages (1), (2) and (3) from the global emission profile. The contribution of each participating region to the overall emission reduction effort is determined by the burden-sharing rule selected (e.g., contribution to CO_2 emissions) [15].

4.1.2. *Illustrative Case: CO_2 Concentration Stabilisation at 450 ppmv*

4.1.2.1. Reference Case In the case of stringent climate goals, non-Annex I regions have to participate early (e.g., Berk & den Elzen [4]). To stimulate early participation, while leaving room for an increase in emission for economic development, the following Multi-stage regime (reference case) is evaluated (Table 1):

- Non-Annex I regions first adopt income-differentiated de-carbonisation targets (Stage 2). More specifically, a constant de-carbonisation target of 2.5% per year is assumed for the high-income regions (more than 5000 [PPP-corrected] 1995 US$ per cap)[2]. The middle-income regions (2500–5000 US$ per cap) start with a target of 1% per year after 2010, which increases linearly up to 2.5% per year by 2030. The low-income regions (less than 2500 US$ per cap) start with a target of 0.5% per year after 2010, which increases up to 2.5% per year by 2050. In the following sensitivity analysis we analyse 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 emission reduction regime stage 4.
- All Annex I and non-Annex I regions participating in stage 4 share the efforts of overall emission reduction needed to stay below the fossil CO_2 emission ceiling for stabilising the CO_2 concentration at 450 ppmv (S450 scenario) on the basis of the burden-sharing key of per capita fossil CO_2 emissions (Stage 4).

Figure 2 shows the total and per capita fossil CO_2 emission allowances for the multi-stage regime (reference case) for eight aggregated regions: Canada & the USA, OECD Europe, Eastern Europe & FSU, Japan, Latin America (LAM), Africa, South Asia and South East & East Asia. The regions Oceania and Middle East are not shown here. The choice of a participation threshold in the emission reduction regime (Stage 4) on the basis of the world average per capita fossil CO_2 emissions rewards both emission reductions by the industrialised (Annex I) regions and efforts by developing (non-Annex I) regions to control the growth in their emissions (e.g., by improving their energy efficiencies).

[2] The Purchase Power Parity (PPP) is an alternative indicator for GDP per capita, based on relative purchase power of individuals in various regions.

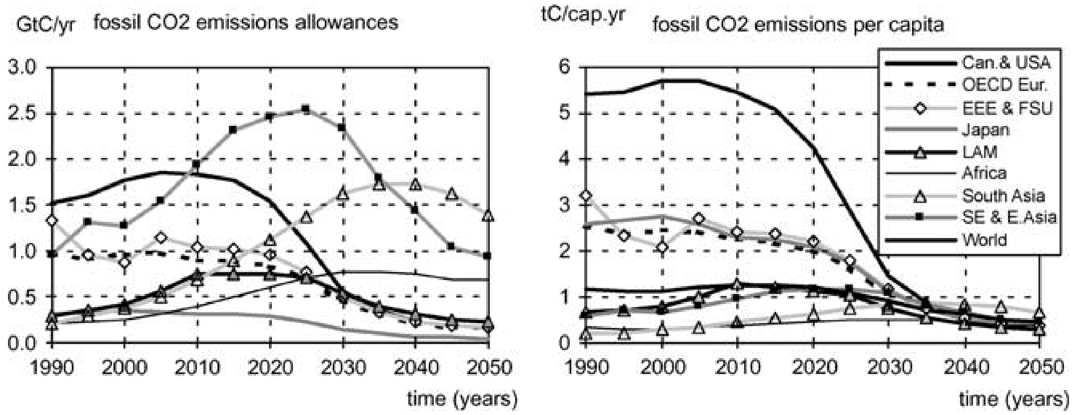

Fig. 2. Regional absolute and per capita emission allowances for the eight aggregated regions the Multi-stage regime (reference case) for the S450 scenario.

As a rule, the per capita (CO_2) emissions are selected (Stage 4) for the differentiation of emission reduction efforts (burden-sharing key). This tends to result in a convergence of per capita fossil CO_2 emissions in Annex I and non-Annex I regions by 2050. This case would imply that to meet the 450 ppmv target the non-Annex I regions, Latin America and Middle East, would have to stabilise their emissions after 2010, since they reach the average per capita level by that date. SE Asia and East Asia would first be allowed to continue to increase their emissions (Stage 2) until 2015, and South Asia and South Africa even until 2030, before reaching this world average per capita threshold. East & West Africa, in fact, remain in stage 2 with only intensity target commitments up to 2050. At the same time, the emission allowances for OECD Europe, Japan and, in particular the USA, would diminish sharply (Fig. 2). However, the emission profile and resulting allocation of total emissions will not only demand substantial efforts from all Annex I regions (about 70–80% compared to their baseline emissions), but also from non-Annex I regions, in particular, for Latin America, SE Asia, East Asia, and the Middle East (about 40–60% compared to their baseline emissions).

4.1.2.2. Sensitivity Analysis A sensitivity analysis is performed to assess the impact of a change in assumptions for the key policy parameters on the emission allowances.[3] The analysis focuses on variants of the reference case, in which the key parameters are similar, as in the reference case, with the exception of one key parameter. In this way, the results can be compared with the reference case outcomes. This single parameter is set according to its value in either the Annex I favourable (AF) case or the non-Annex I favourable (NAF) case. The AF case corresponds to parameter settings leading to 'loose' Annex I commitments relative to the Annex I commitments under the reference case. In other words, the AF case leads to relatively fewer Annex I emission reductions compared to those for the reference case. The NAF case corresponds to parameter settings leading to 'loose' non-Annex I commitments relative to the non-Annex I commitments under the reference case.

The key parameters analysed are the de-carbonisation rate (Stage 2), participation threshold (Stage 3), stabilisation period (Stage 3) and burden-sharing key (Stage 4), as described in Table 1. The target scenario is again the S450 scenario. Figure 3 shows the results of the analysis for the Multi-stage reference case and variants of this reference case in terms of the change in the emission allowances compared to the actual 1990 emission level for the target year 2025. The broad bars on the bar chart in Figure 3 indicate the outcome of the reference case. The line bars in this figure indicate the range of outcomes resulting from the AF and NAF cases. More specifically, the strips at the end of each line bar represent the outcome of the AF case (upper strips: left and lower strips: right) and the NAF case (lower strips: left and upper strips: right). Here, the model is run by setting only the value of the parameter associated with the line bar for the Annex I or non-Annex I favourable case, while fixing the other parameters at their central estimates (value for the reference case)

Figure 3 shows the de-carbonisation targets and participation thresholds to have the strongest impact on the outcomes. The first broad bar in the figure represents the impacts of the choice of de-carbonisation targets on the allowable emissions. When the emissions of non-Annex I regions up to the target year 2025 increase less rapidly due to higher adopted de-carbonisation targets in the de-carbonisation stage (3% after 2010) (AF case), fewer emission reduction efforts of the Annex I regions are needed to remain below the global emission profile. Conversely, low de-carbonisation targets as in the NAF case will lead to high emission reduction efforts for the Annex I regions.

[3] The analysis focuses on the key policy parameters. There are also other model parameters influencing the outcomes (like the emission scenario or historical emissions), but these are not analysed here.

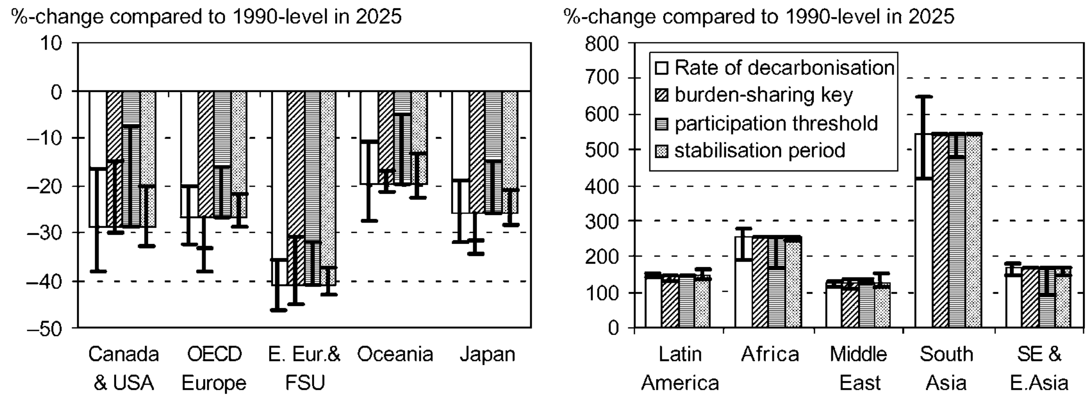

Fig. 3. Model parameter and choices with their impact on the percentage change in the emission allowances relative to the actual 1990 emission level (shown at the line bar) compared to the reference case (shown at the broad bar) in the target year 2025 for the S450 scenario.

Participation based on 75% of 1990 Annex I per capita income (ca. PPPS$12,500, an income level which is close to the present level of per capita PPP-income in Portugal, Czech Republic and Slovenia) would delay the participation of the major developing regions like East Asia and South Asia. These regions would only start participating after the middle of this century. This would result in non-Annex I CO_2 emissions that are too high, Annex I emission allowances would go down to zero and the 450 ppmv target is not reached. This is the reason for not analysing this case here. A participation threshold of 50% of 1990 Annex I per capita (ca. PPPS$8,300, about the income level of South Africa and Mexico) (leads to results similar to the world average per capita emission threshold (reference case). Therefore it is this emission threshold that is also used in the non-Annex I favourable case. This implies that major non-Annex I regions like East Asia and South Asia will have to participate within a number of decades at much lower levels of per capita income than the average 1990 Annex I income (see also Berk & den Elzen [4]). A participation threshold of 30% of the1990 Annex I per capita income (ca. PPPS$5,000, about the income level of Poland, Bulgaria, Romania and Turkey), instead of the per capita emission threshold (reference case), tends to be less favourable for South Asia, SE Asia, East Asia, and Africa, since these regions have to participate earlier.

The impact of the stabilisation time period and the burden-sharing key is less important, in particular, for the non-Annex I regions. Due to the participation threshold of world average per capita emissions and the ten-year stabilisation period, changing the burden-sharing key mainly affects the distribution amongst the Annex I regions up to 2025. Using per capita income instead of contribution to per capita fossil CO_2 emissions (reference case) as a burden-sharing key is to the disadvantage of the OECD regions, in particular the USA, OECD Europe and Japan. It is much more favourable for Eastern Europe and FSU; in fact, their emission reductions are even lower than those found in the reference case. Using total emissions as burden-sharing would only favour Annex I regions with high per capita emissions such as the USA and Canada, but such a burden-sharing key is less favourable for the other Annex I regions: Japan, OECD Europe, Eastern Europe and FSU, and the non-Annex I regions in the long term (2050). Changing the stabilisation period only affects the emission allowances of the regions participating in the reduction regime in the short term (before 2050), i.e., the Annex I regions and the middle-income non-Annex I regions Latin America, Middle East and SE & East Asia.

4.2. Per Capita Convergence Approach

An alternative approach that would represent a major shift from the present Protocol approach is the so-called ‘Contraction and Convergence’ approach of the Global Common Institute (GCI) [7]. Instead of focusing on the question of how to share the emission reduction burden, it starts from the assumption that the atmosphere is a global common to which all are equally entitled. It defines emission rights on the basis of a convergence of per capita emissions under a contracting global emission profile. In the per capita Convergence approach all Parties immediately participate in the emission-control regime (in the post-Kyoto period), with per capita emission rights/permits converging towards equal levels over time.

4.2.1. Methodology

The regime uses the following format: Similar to the Multi-stage approach, a global atmospheric GHG concentration target is first selected; this creates a long-term global emission profile or global GHG emission contraction budget (like the IPCC stabilisation scenarios). This budget is then allocated to the regions/countries, so as to have the per capita emissions converge from their individual values to a global average [7]. More specifically, all shares converge from actual proportions in emissions to shares based on the distribution of population in the convergence year. The actual degree of convergence in per capita emissions

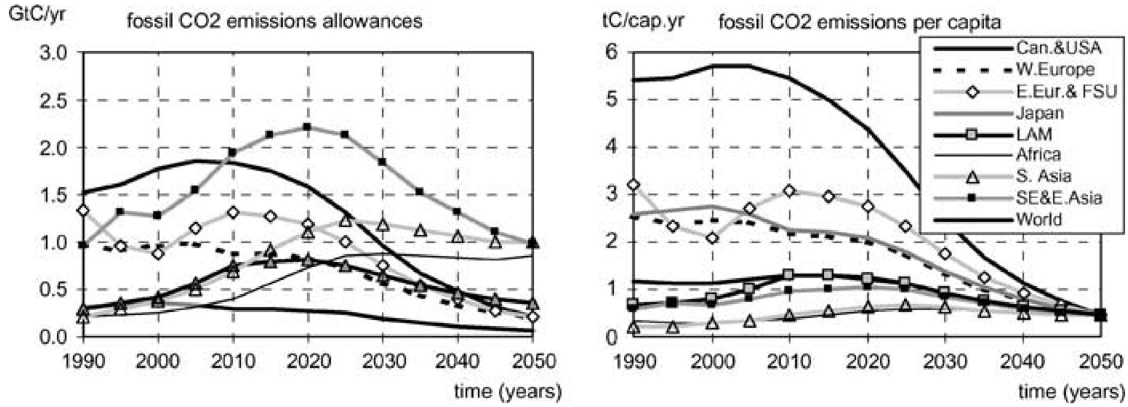

Fig. 4. Regional absolute and per capita emission allowances for the Convergence regime (reference case) with a linear per capita convergence between 2010 and 2050 for the S450 scenario.

allocated each year depends for the original convergence approach[4] of the GCI [7], a non-linear convergence, on the rate of convergence selected. The rate of convergence determines whether most of the per capita convergence takes place at the beginning or near the end of the convergence period. The higher the value for the rate of convergence, the more the convergence takes place towards the end of the convergence period and vice-versa. The default value in the GCI contraction and convergence cases is 4, leading to an balance in the convergence. The reference case assumes a linear convergence corresponding with an equal per capita convergence over time.[5]

Another key parameter in the approach is accounting for population growth, which could discourage population control. For this reason, the approach may be combined with the option of applying a cut-off year after which population growth is no longer accounted for. Applying a cut-off year for population means that the population share in calculating convergence is kept constant after this year. Note that there is no assumption made about what populations will or should be beyond the cut-off year; merely that population growth after that year should not accrue additional emission rights. In our case, the approach is applied without a cut-off year and with population projections of the baseline A1B scenario.

4.2.2. *An Illustrative Case: CO_2 Concentration Stabilisation at 450 ppmv*

4.2.2.1. Reference Case The FAIR model is used to analyse the regional distribution of emission allowances resulting from a convergence regime (reference case), defined by a linear convergence of per capita fossil CO_2 emissions between 2010 and 2050 for the S450 scenario (Fig. 4). Convergence in per capita emission allowances will imply a strong reduction in allowable emissions after the Kyoto Protocol for Annex I regions, in particular for the USA, Japan and OECD Europe (around 60–65% compared to actual 1990 emission levels by 2040). At the same time, there is only limited space for non-Annex regions to increase their capital emissions. In fact, per capita emission allowances for Central and South America already decrease after 2010. East Asia has to stabilise its per capita emissions in the second and third commitment periods (up to 2020), after which it starts to decline. South Asia is allowed to increase its per capita emissions, although these remain below the per capita baseline emissions. In some of the developing regions, i.e., East and West Africa, permitted emission levels exceed the baseline levels, resulting in excess emission permits (hot air).

4.2.2.2. Sensitivity Analysis A similar sensitivity analysis as for the Multi-stage approach is conducted here for the Convergence regime to assess the impact of the key assumptions for the key policy parameters (Table 2) on the emission allowances as in Figure 5. This figure shows the outcome of the convergence reference case in the broad bars

Table 2. Model parameters in the Convergence approach for the reference case, and Annex I favourable and non-Annex I favourable cases.

Model parameters	Reference case	Annex I favourable case	Non-Annex I favourable case
General			
Cut-off year population	Non-applicable	Cut-off (2000)	Non-applicable
Convergence			
Year of convergence	2050	2075	2030
Rate of convergence	Linear	Linear	Non-linear rate = 4

[4] The equation for non-linear convergence is: $S_r(t) = S_r(t-1) - [S_r(t-1) - P_r(t-1)].\exp[-\alpha.(1-\tau)]$, 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).

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

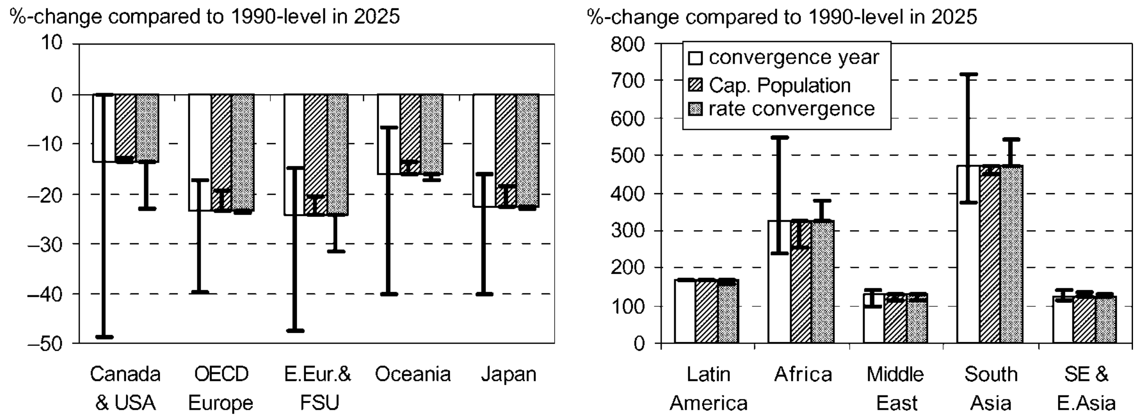

Fig. 5. Model parameter and choices with their impact on the percentage change in the emission allowances relative to the actual 1990 level (shown on the line bar) compared to the reference case (shown on the broad bar) in the target year 2025 under a Convergence regime for the S450 scenario.

and the range of outcomes for the Annex I favourable (AF) and non-Annex I favourable (NAF) cases in the line bars for the S450 scenario. These cases are all variants of the reference case, with all key parameters similar to the reference case, except for one, which is set at the value of the Annex I favourable or non-Annex I favourable case. Figure 5 shows the convergence year (duration of transition period) and the rate of convergence to have the largest impact on the outcomes. A long transition period (late date of convergence) is favourable for the Annex I regions since it results in less (cumulative) emission permits over a defined period of time. Shifting the convergence year from 2050 to 2030 strongly decreases the emission allowances for the Annex I regions and the Middle East. It creates substantial amounts of hot air in the low-income non-Annex I regions (Africa, South Asia).

The rate of convergence, the other main factor, has an effect similar to an earlier convergence. A non-linear convergence at a rate of 4 (NAF case) would imply that most of the convergence takes places at the beginning of the convergence period. A non-linear convergence is therefore also to the advantage of the non-Annex I regions, except for Middle East and Latin America, but not as much as in the early 2030 convergence. It leads to high emission reductions for the USA.

Accounting for a cap on population growth (population cut-off year) for the calculation of the emission allowances also slightly affects the outcomes (Fig. 5). The introductions of a population cap is a disadvantage for regions with a population growth over the period 2000–2025, such as the Africa and South Asia, but is favourable for East Asia and also the OECD regions.

4.3. Triptych Approach

The Triptych approach is a sector- and technology-oriented approach to the differentiation of future commitments, which allows different national circumstances to be taken into account. The approach has been used for supporting decision-making on internal target differentiation in the European Union both prior to and after Kyoto (COP-3) [8, 9, 27]. In principle, the Triptych approach is bottom-up in character, but it can also be combined with specific emission targets (as illustrated below). A global application of the Triptych approach has been explored in two studies (Groenenberg et al. [10]; den Elzen et al. [6]). Here an updated Triptych approach is presented, which deals with a number of shortcomings in both initial global applications. For example, the growth in industrial production now accounts for structural economic sector changes. This updated approach tries, in particular, to incorporate some widely supported notions in the climate debate, especially the necessity of technological improvement, the transition to low carbon energy and the desirability of narrowing per capita emission differences. The design of the regime aims at defining criteria and rules for differentiation future commitments for all regions in a consistent and transparent way.

4.3.1. Methodology

In the Triptych approach three categories or sectors of emission sources are distinguished in the Triptych approach:

1. the internationally-oriented energy-intensive industry;
2. the domestic sectors;
3. the power-production sector.

The emissions of the domestic sector compromise only those related to fossil fuel use. The emissions associated with electricity use in this sector are included in the power-production sector. The selection of the Triptych categories is based on two considerations: (i) different parts of national economies require different approaches to achieve a fair distribution of efforts, and (ii) national circumstances (standards of living, resources and economic structure) vary widely. Different criteria are used for the different sectors to calculate partial emission allowances. These add up to binding national emission allowances. In the following the three sectors in the Triptych approach are described in more detail, including the scenario (baseline) assumptions and criteria for the calculation of emission allowances.

4.3.1.1. The Internationally Oriented Energy-Intensive Industry

a. *Description of the sector.* The internationally oriented energy-intensive industry covers internationally oriented industries, where competitiveness is determined by the costs of energy and energy efficiency. In the Triptych approach the sector covers the following six sub-sectors: iron and steel, chemicals, pulp and paper, non-metallic minerals, non-ferrous metals and the energy transformation sector. The energy transformation sector includes petroleum-refining, manufacture of solid fuels, coal mining, oil and gas extraction and any energy transformation other than power production. Compared to other economic sectors, this part of industry generally has a relatively high-energy use per value added and in most regions also high CO_2 per value added ratio. Countries with a high share of heavy industry will therefore have relatively higher CO_2 emissions/units of GDP than countries that focus primarily on light industry and services. The international character of this sector implies that countries lacking sizeable energy-intensive industries themselves import goods from other countries and thus indirectly benefit from other countries' efforts in this sector. Apart from international specialisation, the share of heavy industry in the overall economy is generally related to a country's levels of development. Initially, at a low level of development its share is low, but with increasing development its share tends to increase at the expense of primary sectors (agriculture, mining). Only at later stages of development does the share of energy-intensive industry in total economy tend to decrease again with the growth of the share of the service sector in the economy. For these reasons, countries should not necessarily be penalised for relatively high emissions from this sector.

b. *Calculation of emission allowances.* The regional allowable CO_2 emissions are calculated on the basis of (i) a realistic growth of production in the energy-intensive industry, (ii) a convergence of energy intensity (energy used per unit of production) and (iii) an achievable reduction of carbon intensity of the energy consumption (carbon emissions per unit of energy use).

(i) *Growth in production.* Projections of future physical growth in the energy-intensive industry are estimated on the basis on a detailed study of recent (mid-1980s to mid-1990s) historical trends in per capita physical production in various countries [28]. Growth rates are differentiated amongst countries on the basis of five income groups. Based on these data a continuous curve is composed, which represents differentiated growth rates of per capita physical production in the energy-intensive industry as a function of per capita PPP income (in PPP-corrected 1995 US$ per cap), as used here for the calculations of the future growth (see Fig. 6). Growth rates of per capita production in the energy-intensive industry are high for the low-income regions. For the middle-income regions, the growth-rates show a decreasing trend in future when income increases. For the high-income regions, growth rates are already low, and these converge to even lower growth rates when income increases.

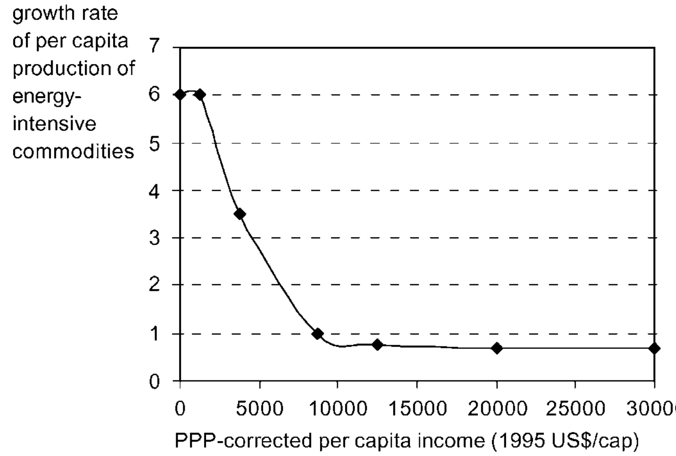

Fig. 6. The overall annual growth rates of per capita commodity production for the energy intensive industry as a function of the per capita income (1995 US$ PPP).

(ii) *Energy intensity of production.* For the energy-intensity levels a worldwide convergence in energy-efficiency levels of all regions over time is assumed. A convenient indicator for energy efficiency is the Energy Efficiency Indicator (EEI) [8]. This index is defined as the ratio between the specific energy consumption (SEC) (energy consumption per tonne of product) for each region, divided by a reference SEC level. The reference SEC is equal to the SEC of the best current practices or the best available technologies. For example, an EEI of 105 in a region means that the SEC on average is 5% higher than the reference level, so that 5% of energy could be saved at the given sector structure[6] by implementing the reference level technology. Here, instead of a single product, the SEC of a package of energy-intensive commodities is used. This results in aggregated EEIs for all regions, each representing a relative measure of

[6] The sector structure can be defined as being determined by the mix of activities or products within a sector. This mix may well influence the reference specific energy consumption level [8].

the average efficiency of the energy-intensive industry in that specific region [28, 29].[7]

If aggregated EEIs for all regions converge at the same level, the required rate of energy efficiency improvement (*eff*) (in %/year) can be calculated from the regional actual EEI (EEI_{act}), the convergence level of the EEI (EEI_{conv}) and convergence time-period (tp_{conv}). In formulas:

$$eff = 100.0 * \left[1.0 - (EEI_{conv}/EEI_{act})^{tp_{conv}}\right] \quad (1)$$

(iii) *Carbon intensity of energy use*. This indictor represents two different dimensions of a change in the energy supply side: the shift in the relative use of different fossil fuel types (coal, oil, natural gas), and the change in the share of non-fossil fuels (nuclear, hydro-power, wind, solar, biomass). Here, a constant de-carbonisation rate (reduction of carbon intensity of the energy consumption) is assumed, which is the same for all regions.

4.3.1.2. The Domestic Sector

a. *Description of the sector*. The domestic sector includes the residential sector (households), the commercial sector, transportation, light industry and agriculture.
b. *Calculation of emission allowances*. The allowable CO_2 emissions in the domestic sectors are assumed to be primarily related to population size, as they are determined by the number of people in dwellings, at workplaces and needing transport, etc. Therefore a per capita convergence approach is assumed to be appropriate here. For the domestic sectors no baseline growth assumptions are made. Instead, the regional domestic CO_2 emission allowance per capita converges to the worldwide average, consistent with a specific stabilisation level.

4.3.1.3. The power-producing sector

a. *Description of the sector*. The power-producing sector is treated separately because specific CO_2 emissions from power production vary to a large extent due to large differences in the share of nuclear power and renewables and in the fuel mix in fossil-fuel-fired power plants. The potential for cutting CO_2 emissions emanating from this sector differs accordingly. Therefore fuel mix in power generation is an important national circumstance to take account of in a differentiation of commitments. In the analysis this sector includes both centralised and decentralised electricity production.
b. *Calculation of emission allowances*. The allowable CO_2 emissions from the power sector are defined by (i) a realistic growth in the electricity consumption and (ii) a convergence in the carbon intensity of energy consumption (CO_2 emissions per unit of energy consumption).

(i) *Growth in energy consumption*. The growth in the energy supply of the power sector can be assumed to be estimated by the weighted sum of the emission growth in the energy-intensive industry and the domestic sectors. Furthermore, the share of the two sectors in power consumption is assumed to remain constant in future; it is based on their present (1995) share in total final energy consumption [30, 31]. This is a rather simplistic assumption, which may need improvement.

(ii) *Carbon intensity of energy consumption.* A convergence of carbon intensities of the electricity produced to low carbon intensity levels is assumed for the change in the carbon intensity of electricity. This low intensity level is calculated on the basis of share of renewables and gas-based capacity, with high conversion efficiency in total electricity production in the convergence year.

4.3.2. Illustrative Case: CO_2 Concentration Stabilisation at 450 ppmv

4.3.2.1. Reference case The FAIR 1.1 model is used to explore the implications of stabilising CO_2 concentrations at 450 ppmv. Table 3 lists the parameter values for the Triptych regime (reference case), as used in the quantitative illustration of the Triptych approach. A single convergence end-year, 2050, is used here for the three above-mentioned types of convergence, i.e., convergence in energy efficiency in energy-intensive industry, convergence in the per capita domestic emissions and convergence in carbon intensity of the power producing sector. The starting-year of convergence differs per region. For the Annex I regions (excluding the USA) the convergence starts immediately in 2000 and aims at achieving the Kyoto targets, whereas for the non-Annex I regions and the USA, the convergence starts ten years later (2010). Up to this point, they follow baseline trends for sectoral emissions.

The energy-intensive industry. The illustrative calculations for the reference case assume that the aggregated EEI index of all regions will ultimately converge at a level of 0.7 by the year 2050 (see Fig. 7). This final convergence level means that energy-intensive commodities will be produced at two-thirds of the current reference, specific energy consumption levels (the energy consumption levels under best practices). Indications are that for a set of energy-intensive commodities energy requirements could, theoretically (i.e., down to thermodynamic minimal energy requirements), be lowered by almost two-thirds [14]. The yearly rates of energy efficiency improvements (in per cent per year) over the convergence period are calculated on the basis of Equation 1, as summarised in the legend of Figure 7. These improvement rates vary from 1.0–1.2% for OECD

[7] These EEI_{act} are calculated as: $En_{act}/\Sigma_i\ m_i.SEC_{ref,i}$, where En_{act} is the energy consumption in the energy-intensive industry, m_i the production quantity of sub-sector i (six sub-sectors) and $SEC_{ref,i}$ the reference SEC for sub-sector i [29].

Table 3. Model parameters in the Triptych approach with a set of possible choices for the reference case, and Annex I favourable and non-Annex I favourable cases.

Model parameters	Reference case	Annex I favourable case	Non-Annex I favourable case
Energy-intensive industry sector			
Growth rates of per capita production of energy-intensive commodities	See Figure 6	Figure 6	Figure 6
Year of convergence Energy Efficiency Index	2050	2075	2030
Level of convergence Energy Efficiency Index	0.7	0.9	0.5
Domestic sectors			
Year of convergence of per capita emissions	2050	2075	2030
Power-production sector			
Year of convergence emission intensity	2050	2075	2030
Level of convergence emission intensity	31 gC/kWh	100 gC/kWh	15 gC/kWh

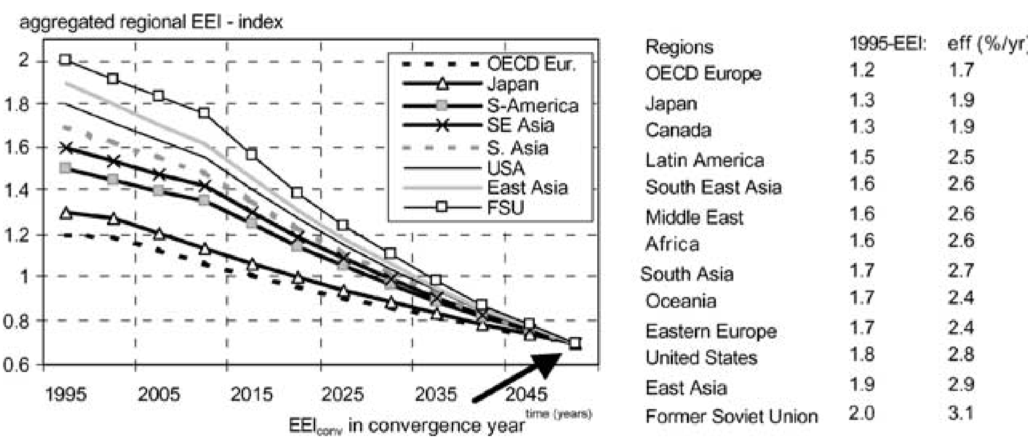

Fig. 7. The convergence in the aggregated Energy Efficiency Indices (EEIs) by 2050 (reference case) to half the current reference level. The legend shows the 1995 Aggregated Energy Efficiency Indices (EEIs) at the regional level (based on Groenenberg [2002 #1114]) and the calculated yearly energy efficiency improvements in per cent per year for the convergence period.

Europe and Japan, from about 1.6–1.8% for Latin America, South Asia, Eastern Europe and the African regions up to 2.0–2.3% for East Asia, the Former Soviet Union and USA. In addition to this improvement in energy efficiency, a de-carbonisation rate of the industrial energy consumption of 0.25% per year for all regions is assumed here.

The resulting emissions in the energy-intensive industry show a decreasing trend in all Annex-I regions after 2000, mainly as a result of the technological convergence in the energy efficiency. For most of the non-Annex I regions (except for South Asia and Africa) the emissions first increase up to 2020 (up to about 3–4 times the 1995 emission levels), but then also start to decline. This decline in the emissions results from the decrease per capita growth rates in the energy-intensive industry with increasing income, in combination with the high-energy efficiency improvements after 2020. For South Asia, North and South Africa, the decline starts after 2030, whereas for West and East Africa, the emissions may even increase up to 2050.

Power production sector. The convergence level of the carbon intensity in the power sector (CO_2 emissions per unit of electricity production) is based on a 60% share of renewables in power generation in the convergence year 2050 (as in projections by Johansson [32]), complemented with gas-based capacity with a high conversion efficiency (i.e., 70%). This leads to a final carbon intensity level of 31 gC/kWh in 2050. This convergence implies high yearly de-carbonisation rates of 3 to 4% in East Asia and South Asia, but also in the USA (3%). Lower de-carbonisation rates are found in OECD Europe, Japan (about 2%) and Canada (about 1%). In this sector emissions start to decline after 2000 for most of the Annex I regions, whereas for the non-Annex I regions this decrease starts 10 to 20 years later.

Domestic sectors. Linear convergence in the per capita domestic emissions between 2000 and 2050 (Annex I regions without the USA), or 2010 and 2050 (non-Annex I regions and the USA) is assumed for this reference case. This is combined with a 50% reduction of the global domestic per capita emissions in the convergence year compared to 2000 levels.

From bottom-up to top-down approach. The assumptions made for the three sectors result in total CO_2 emissions that remain below the global CO_2 emission ceiling, leading to the 450 ppmv CO_2 concentration target. Therefore, the bottom-up approach for the domestic sector is adjusted here to a top-down approach. In this case the convergence in domestic per capita emissions by 2050 accommodates the emission space available for domestic emissions under the global domestic emission ceiling. This domestic emission ceiling is equal to the difference between the ceiling for global CO_2 emissions for stabilisation at 450 ppmv and the sum of the emissions allocated to the power and energy-intensive industry sector (see Fig. 8). This top-down approach results in more domestic emission allowances up to 2030 compared to domestic allowances under the bottom-up approach. Furthermore, the top-down approach provides a better guarantee for environmental effectiveness (the total emissions are equal to the emission ceiling aiming at the 450 ppmv target), and also enables us here to compare the results of the Triptych approach to the other top-down approaches (Fig. 9).

Concluding, a comparison of the global emission level in this quantitative illustration of the Triptych approach with the reference scenarios seems to indicate that strict measures will be needed to ultimately reduce emissions to a sufficiently low level. The distribution of efforts over the sectors depends a lot on the precise specification of the parameters in the approach (see Table 3). High (1.7–3%) but not unfeasible rates of energy efficiency improvement are required in the energy-intensive industry, together with sharp decreases in the carbon intensity of electricity production (1–4%). These rates are comparable to what global energy models assume to be feasible [33, 34]. Domestic per capita emission reduction required for a 450 ppmv stabilisation scenario is also significant (−50% by 2050 compared to present levels), but this order of magnitude is also achievable technically and economically achievable according to existing model calculations (see also van Vuuren & de Vries [34]).

4.3.2.2. Sensitivity Analysis A sensitivity analysis is performed to assess the impact of changing key policy parameters (Table 3) on the percentage change in the emission allowances relative to the 1990 emission level in the target-year 2025 for the S450 scenario (Figure 10). The broad bars show the outcome for the triptych reference case, whereas the line bars (with strips at the ends) indicate the range of outcomes resulting from varying the value of one model parameter (associated with the line bar) for the Annex I favourable and non-Annex I favourable cases (see Table 3). The other parameters are fixed at their central estimates (reference case). The methodology is similar to the one described in the sensitivity analysis of section 4.1. The figure

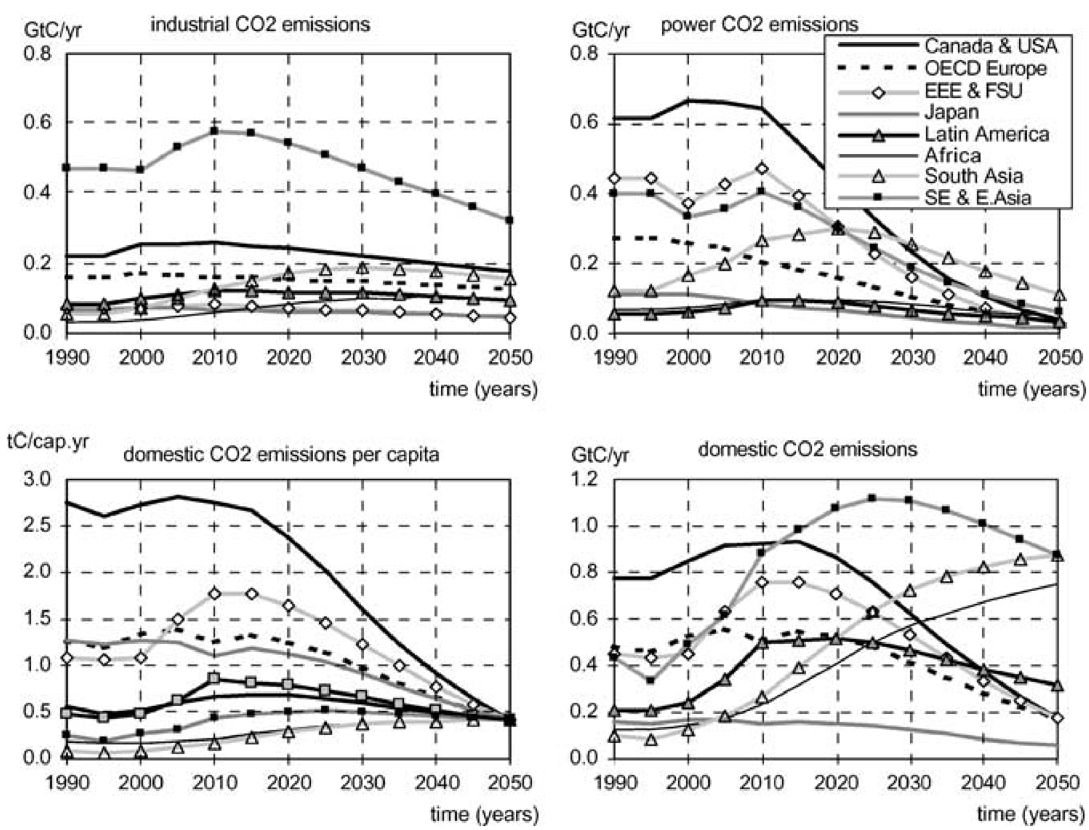

Fig. 8. Regional sector emissions (domestic, industrial and power-production sector) and the per capita domestic emissions for the Triptych regime (reference case) aimed at stabilising CO_2 concentrations at 450 ppmv (S450 scenario).

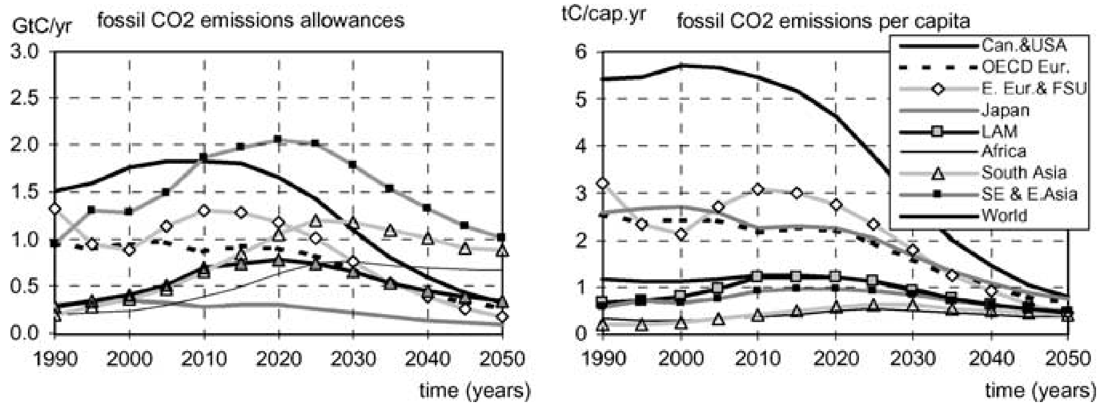

Fig. 9. Regional total and per capita CO_2 emission allowances for the Triptych regime (reference case) for the S450 scenario.

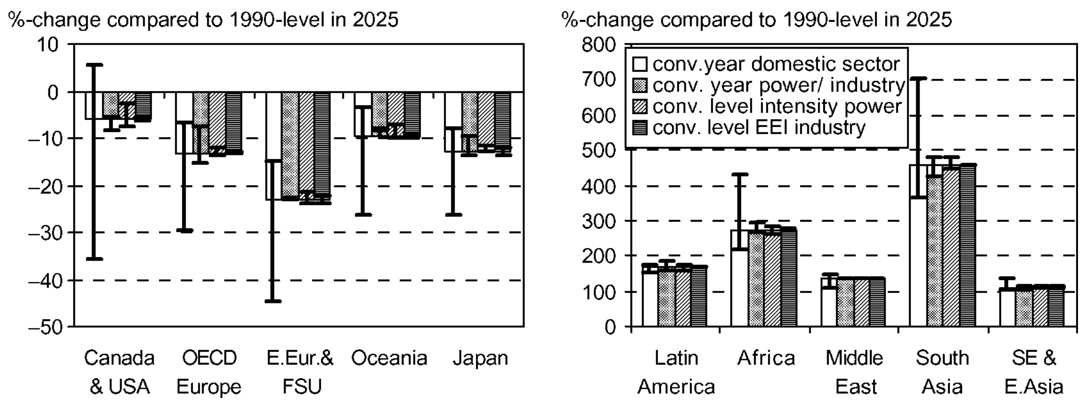

Fig. 10. Model parameter and choices with their impact on the percentage change in the emission allowances relative to the actual 1990 level (shown on the line bar) compared to the reference case (shown on the broad bar) in the target year 2025 under a Triptych regime for the S450 scenario.

shows the sensitivity of the outcome for the various parameters. In particular, column 1 in the Figure shows that the emission allowances in the target year 2025 depend a lot on the assumptions with respect to the convergence year of per capita domestic emissions.

The range of outcomes for the Canada & USA region, for example, varies from a 5% rise compared to the 1990 emission levels (convergence year of domestic sector is 2075) to an almost 40% reduction (convergence year is 2030). A similar wide range of outcomes is also found for other OECD regions. Shifting the convergence year in the energy efficiency index (EEI) in the industrial sector and the emission intensity of the power sector also affects the outcomes, but its impact on the emissions is less in comparison to the impact of the convergence year of the domestic sector.

The impact of the convergence level of the EEI index in the energy-intensive industry and the emission intensity for the power sector on the emission allowance in the target-year 2025 seems small compared to the impact of the convergence year. Groenenberg [14] analyses the impact of various assumptions for these parameters on the emission allowances in more detail.

5. OVERALL ANALYSIS OF THE CLIMATE REGIMES EXPLORED

This section presents a comparison of the emission allowances in 2025 for the reference and alternative cases for the S450 scenario across the three approaches. Figure 11 summarises the emission allowances as a percentage change compared to the actual 1990 emission levels for the three approaches for the target year 2025. This figure presents the outcomes for the reference case in the broad bars. The uncertainty ranges resulting from the outcomes of the overall Annex I favourable and non-Annex I favourable cases (now all key parameters set at values for the Annex I favourable and non-Annex I favourable case) are indicated with line bars. The figure also shows the change for the reference A1B scenario (broad bar) compared to the 1990 emission levels and the range of emission scenarios (line bar). This information is needed to compare the results with the baseline emissions. Figure 11 is primarily meant to illustrate the methodologies. It is not the objective to reach any conclusions about what type of regime would be preferred. The outcomes are dependent on the choice of the target year,

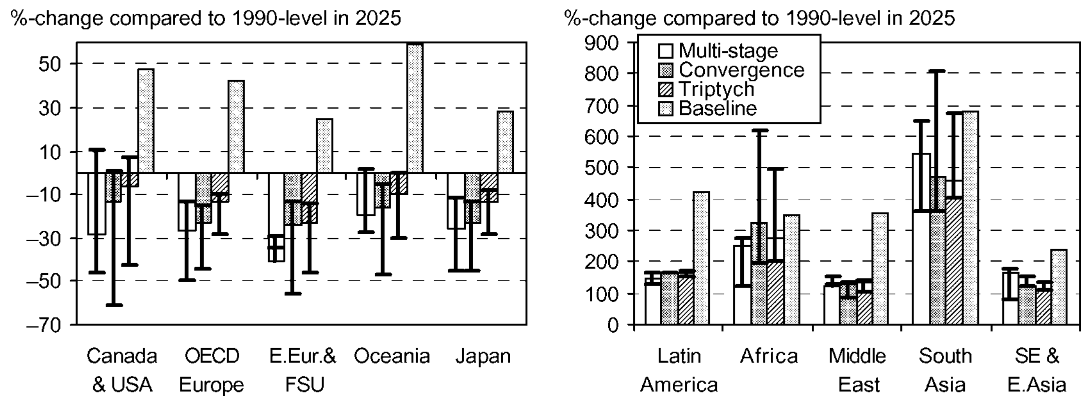

Fig. 11. Percentage change in emission allowances compared to the 1990 emission levels for the reference cases and the uncertainty range (resulting from the Annex I favourable and non-Annex I favourable cases) of the three climate regimes: Multi-stage, Convergence and Triptych, and the baseline emission scenario for the target year 2025 and S450 scenario for Annex I and non-Annex I regions.

2025 (medium long-term) and the selected CO_2 concentration stabilisation level of 450 ppmv (stringent climate target). Any conclusion drawn in this section should therefore be seen in the context of these conditions.

Figure 11 clearly shows the broad range of possible outcomes for the three climate regimes as a consequence of the basic assumptions on model parameters and of the precise quantification of some more-or-less subjective choices in the approaches.

The Multi-stage approach (reference case) gives the highest emission reductions in comparison to the baseline emissions for the Annex I regions and the non-Annex I regions Latin America and Middle East in 2025, compared to the reductions of the reference cases of the other two regimes. The Multi-stage reference case is the most attractive approach only for South Asia and SE & East Asia. In the target year 2025 most of the non-Annex I regions only have de-carbonisation or stabilisation commitments (Stage 2 or 3). Other assumptions for the key parameters can change the attractiveness of this regime, as illustrated by the Annex I and non-Annex I favourable cases. For the Annex I favourable case with high de-carbonisation targets and a low participation income threshold for the non-Annex I regions, the multi-stage regime becomes relatively favourable for most Annex I regions (except Eastern Europe and FSU), and relatively unfavourable for most non-Annex I regions. The non-Annex I favourable case with lower de-carbonisation commitments for the non-Annex I regions leads in 2025 to high emission reductions of about 40–50% below 1990 emission levels for Canada & the USA, OECD Europe and Japan. For Eastern Europe and FSU, the AF and NAF cases both lead to lower emission reductions compared to the reductions in the multi-stage reference case. A burden-sharing key based on per capita income is to the advantage of Eastern Europe and FSU (see also Fig. 3).

The per capita Convergence approach (reference case) is especially attractive for the least developed regions, i.e., West and East Africa, where allowed emission levels exceed baseline emission levels, resulting in surplus emissions (hot air). The level of surplus allowances is dependent on baseline emission projections, with stringent stabilisation targets (e.g., 450 ppmv) likely to occur only for a limited time period (here only up to 2040). The total emission allowances for Africa do not exceed its baseline emissions due to the emission reductions in North and South Africa. For the reference case, the Convergence approach results in 20–35% emission reduction compared to 1990 emission levels for the Annex I regions in the target year 2025, while non-Annex I regions may still increase their emissions. For the Annex I favourable case with a convergence year of 2075, the emission reductions in the Annex I regions are much smaller. However, the early convergence (2030) in the Annex I favourable case leads to low emission reductions in the non-Annex I and hot air for Africa and South Asia. Both cases can lead to a wide range of outcomes; for Eastern Europe and FSU, the per capita Convergence regime may be the most favourable (2075 convergence) and the least favourable regime (2030 convergence).

The Triptych approach (reference case) is favourable for all OECD regions, in particular, Japan and OECD Europe, with relatively low energy intensities, but also for Latin America and Middle East. For Eastern Europe and FSU, the Triptych reference case leads to the same emission reductions (25–35% compared to 1990 emission level) as those found for the Convergence reference case. For East Asia and South Asia, the Triptych approach results in somewhat smaller growth objectives, especially for the regions with high emission intensities such as East Asia. The Annex I favourable case leads to the lowest emission reductions for most Annex I regions. The non-Annex I favourable case even leads to hot air for Africa due to the early convergence in the per capita domestic emissions.

In conclusion then, the Multi-stage approach is the most unattractive regime for all Annex I regions in this short-term (2025) for the reference cases due to the world average per capita emission threshold and per capita-emission burden-sharing key, whereas the Triptych regime is the most attractive regime. For Africa, Convergence is the most attractive regime (hot air). For Latin America and Middle East the Convergence and Triptych regimes are both favourable, showing the same emission allowances by 2025. For SE and East Asia, and South Asia, the multi-stage regime is the most favourable. The alternative cases clearly show the results found to be sensitive to the assumptions of the key parameters. This is particularly the case for the burden-sharing key, participation thresholds and convergence year applying to each of the approaches. Other parameters may have an even larger impact than another climate regime for differentiation of future commitments.

6. CONCLUSIONS

This paper explores three approaches to the differentiation of future commitments: the '*Multi-stage*' approach, the '*Convergence*' approach, and the '*Triptych*' approach under a global fossil CO_2 emission profile that aims at a CO_2 concentration stabilisation at 450 ppmv using the FAIR model.

The analysis using the reference cases for the 450 ppmv target shows the Multi-stage approach to result in the highest emission reduction commitments for the Annex I regions in the target year 2025, as most non-Annex I regions only have de-carbonisation or stabilisation commitments. The per capita Convergence approach is especially attractive for the least developed regions, i.e., West and East Africa, where the emissions even exceed the baseline emission levels. These excesses in emission allowances (hot air) can be sold on the emission trading market. The Triptych approach results in moderate emission reductions for the FSU and Eastern Europe; however, in general, the approach is more favourable for the OECD regions with relatively low energy intensities, especially OECD Europe and Japan. For the non-Annex I regions, the Triptych approach results in lower allowances for emission growth, especially for the regions with high emission intensity, such as East Asia. In general, all reference cases tend to result in a convergence in per capita emissions for Annex I and non-Annex I before 2050, although for the Triptych approach no full convergence is reached.

A sensitivity analysis has been made to assess the impact of different assumptions for the key policy parameters on the outcomes. The analysis shows that the de-carbonisation rates and the participation rules have the strongest impact on the outcomes for the Multi-stage approach. In the short term, the participation threshold used implies that the parameter burden-sharing key used has its main effect on the distribution of emission reductions in the Annex I regions. The key parameters for the Convergence approach are the convergence year (duration of transition period) and the rate of convergence. A long transition period (late date of convergence) works to the disadvantage of non-Annex I regions. Results for the Triptych approach are especially sensitive to the assumptions in the various convergence approaches for the convergence year. Different assumptions in the parameters made for each of the approaches have a major impact on the outcomes of the various regimes. Other assumptions for key parameters in an approach may have an even larger impact than another approach. It is therefore difficult to draw general conclusions on the implications of the approaches for different regions. On the other hand, it is clear that regions ranking much higher than average on burden-sharing indicators like per capita emissions, emission intensity or per capita income are particularly affected if such an indicator is chosen.

In general, the analysis shows that substantive reductions of Annex I emissions are needed for stabilising the CO_2 concentration at 450 ppmv in 2100, as well as participation of the major non-Annex I regions (East Asia and South Asia) in the global emission control before 2050, regardless of their level of economic development. Non-Annex I regions thus have to start participation in the global emission reductions at significant lower per capita income and emission levels than Annex I regions under Kyoto if they are to meet the 450 ppmv target.

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