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The FAIR model: A tool to analyse environmental and costs implications of regimes of future commitments

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This article describes the policy decision-support tool, FAIR, to assess the environmental and abatement costs implications of international regimes for differentiation of future commitments. The model links long-term climate targets and global reduction objectives with regional emission allowances and abatement costs, accounting for the Kyoto Mechanisms used. FAIR consists of three sub-models: a simple climate model, an emission-allocation model and a cost model. The article also analyses ten different rule-based emission allocation schemes for two long-term concentration stabilisation targets for greenhouse gases. This analysis shows that evaluating regimes requires not only an assessment of the initial allocation, but also of the distribution of abatement costs and the impacts from emissions trading. The Multi-Stage approach (with a gradual increase of Parties adopting emission intensity or reductions targets) and the Triptych approach (with sectoral targets for all Parties) seem to provide the best prospects for most of the Parties when compared to the other allocation schemes analysed.

1. Introduction

Climate change resulting from human-induced emissions of greenhouse gases (GHGs) is increasingly noted to constitute a major threat to ecosystems, food supply and human health [58]. Without substantially reducing these emissions, there is also an increasing risk of extreme climate events and large-scale discontinuities. Some of the major driving forces for emissions are closely related to development objectives such as economic growth and increased food production. GHG emission projections of the IPCC SRES baseline scenarios for the next hundred years range from emissions returning to approximately current levels to a seven-fold increase in the absence of climate mitigation actions [57], leading to a continuing rise in the GHG concentrations throughout the 21st century. Therefore, in order to meet the long-term objective of the United Nations Framework Convention on Climate Change (UNFCCC) for stabilising atmospheric GHG levels at non-dangerous levels (Article 2) [72], substantial reductions of global GHG emissions will be necessary [47].

The Kyoto Protocol, which has entered into force since February 2005, is the first step of departure towards achieving the long-term objective of the UNFCCC. According to the Kyoto Protocol (Article 9.2), international negotiations on the design of a post-2012 climate agreement are to start by 2005. One of the most contentious issues is the issue of (international) burden sharing or differentiation of post-2012 commitments. In this paper we will describe the policy decision-support tool, FAIR 2.0 (Framework to Assess International Regimes for the differentiation of commitments) [29]. This model has been developed to explore and evaluate the environmental and abatement cost implications of various international regimes for differentiation of future commitments for meeting such long-term climate targets as stabilisation of the atmospheric GHG concentrations. The model description is supplemented with an analysis of ten different post-2012 regimes compatible with stabilising atmospheric greenhouse gases concentrations at 550 and 650 ppmv CO_2-equivalent in 2100 and 2150, respectively.

There have been many proposals for differentiating commitments among countries, both from the literature and from Parties to the UNFCCC (see [1,9,51,71] for an overview). The FAIR 2.0 model includes about ten approaches, all defining the differentiation of commitments based on criteria and rules for the distribution of emission allowances[1] (i.e. allocation-based approaches, see also section 2). The model does not comprise approaches for differentiation of commitments in terms of outcomes, such as equal mitigation costs [3], as these are dependent on a macro-economic model (not included in the FAIR model). Also Policies and Measures approaches, like technology and performance standards, such as energy-efficiency standards (e.g., [4,35]); financial measures (e.g., [68]) and carbon taxes [11] (see [9,24] for an overview) are not implemented, as this requires more detailed, aggregated, sectoral energy modelling. The model focuses on multi-lateral regimes based on the UNFCCC and the Kyoto Protocol, and not on regimes based on smaller coalitions between like-minded parties, the most important players or collaboration being at the regional level.

[1] In the literature also referred to as assigned amounts, emission permits, or emission endowments; from this point on we will use the term ‘emission allowances’.

This approach is often combined with a pledge-based approach, with countries' commitments based on their "willingness to pay". While the model allows for simulating such an approach, its focus is on evaluation of rule-based approaches to defining international commitments.

The FAIR model can be used for a consistent and quantitative comparison of various allocation-based, multi-lateral regime proposals, as we have done, for example, for the EU DG Environment project "Greenhouse gas reduction pathways in the UNFCC post-Kyoto process up to 2025" [14,26,79]. The model has also been used to evaluate the Kyoto Protocol under the Bonn and Marrakesh agreements in terms of environmental effectiveness and costs [27,28,53], the Bush Climate Change Initiative [78] and the Brazilian Proposal [26,32,34]. The model was also used to support dialogues between scientists, NGOs and policy makers (e.g., [7]). To this end the model is set up as an interactive tool with a graphical interface, allowing for interactive changing and viewing model input and output.[2] Other scientific applications of the FAIR 2.0 model are, in combination with the integrated assessment model IMAGE[3] and the energy model TIMER[4], the analysis of multi-gas mitigation scenarios in the Emission Modelling Forum (EMF 21) [80].

The FAIR model consists of three linked models (figure 1): (1) A *climate model* to calculate the climate impacts of global emission profiles and emission scenarios, and to determine the global emission reduction objective (based on the difference between the global emissions scenario (without climate policy) and a global emission profile); (2) An *emission allocation model* to calculate the regional emission allowances for different regimes for the differentiation of future commitments within the context of this global reduction objective (from climate model); (3) A *costs model* to calculate the emission targets after emissions trading and regional abatement costs on the basis of the emission allowances (from emission allocation model) following a least-cost approach, making full use of the flexible Kyoto Mechanisms as emissions trading and substitution of reductions between the different gasses and sources. Furthermore, various data sets of historical emissions, baseline scenarios, emission profiles and costs curves are included in the model framework to assess the sensitivity of the outcomes towards these key inputs.

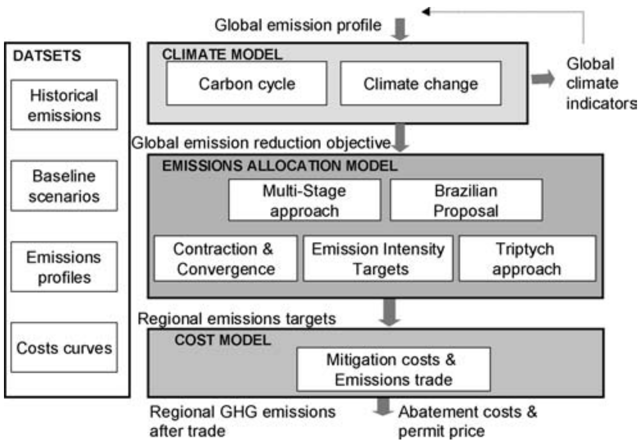

Figure 1. Schematic diagram of the FAIR model showing its framework and linkages [29].

[2] A demonstration version of FAIR 2.0 can be downloaded from: http://www.mnp.nl/fair.

[3] The IMAGE 2.2 model is an integrated assessment model, consisting of a set of integrated models that together describe important elements of the long-term dynamics of global environmental change, such as agriculture and energy use, atmospheric emissions of greenhouse gases and air pollutants, climate change, land-use change and environmental impacts [38].

[4] The global energy model TIMER 1.0, as part IMAGE, describes the primary and secondary demand and production of energy and the related emissions of greenhouse gasses and regional air pollutants [19].

The first part of this article gives a brief overview of the regimes (section 2), and a description of the model (section 3). The second part presents a model analysis of the ten regimes included in the model (section 4) and the conclusions with respect to this analysis (section 5).

2. International regimes and their main characteristics

The international regimes included currently in the FAIR model (table 1) can be characterised on the basis of a number of regime dimensions, such as equity principles.

There is no common accepted definition of equity. Equity principles refer to general concepts of distributive justice or fairness [66]. Many different categorisations of these principles can be found in the literature (e.g., [64–66]). Equity principles refer to more general notions or concepts of distributive justice or fairness. Rose et al. [66] distinguish three types of alternative equity criteria for global warming regimes:

(1) *allocation based criteria*, defining equitable differentiation of commitments in terms of principles for the distribution of emission allowances or the allocation of emission burdens;

(2) *outcome based criteria*, defining equitable differentiation of commitments in terms of outcome, in particular, the distribution of economic effects, and

(3) *process based criteria*, defining equitable differentiation of commitments in terms of the process for arriving at a distribution of emission burdens.

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 (as we will show in section 4). Process-based criteria are generally less suitable for ex ante evaluation because their outcomes are less predictable.

In den Elzen et al. [26] a typology of four key equity principles was developed to characterise the various differentiation approaches of post-2012 commitments that have been

Table 1
Short description of the ten different regimes implemented in the FAIR model.

Approach	Abbr.	Operational rule for allocation of emission allowances
Multi-Stage approach	MS	A gradual increase in the number of Parties involved adopting either emission intensity or reduction targets [6].
Brazilian Proposal	BP	Reduction targets based on countries' contribution to temperature increase [73], participation based on a per capita income threshold [26].
Ability to Pay	AP	Emission reduction allocation and participation based on per capita income thresholds [49].
Contraction & Convergence	C&C	Emission targets based on a convergence of per capita emission levels of all Parties under a contraction of the global emission profile [55].
CSE convergence	CSE	Per capita emission convergence (C&C) combined with basic sustainable emission rights, by Centre of Science and Environment (CSE) [17].
Global Compromise	GC	Allocation of the global emission allowances based on a population-weighted preference score voting for either emission (grandfathering) or per capita allocation [56].
Grandfathering	GF	Allocation of the global emission allowances proportional to their present emission share, with participation based on an income threshold [66].
Multi-Criteria Convergence	MCC	Allocation of the global emission allowances based on different weighting of criteria, i.e. emissions, population and GDP.
Emission Intensity Targets	EIT	Emission reductions related to improvements in the emission per unit GDP output [23].
Triptych	TT	Emission allowances based on various differentiation rules to different sectors for all Parties [61].

proposed in the literature and international climate negotiation:

(1) *Egalitarian*: i.e. all human beings have equal rights in the 'use' of the atmosphere.

(2) *Sovereignty and acquired rights*: all countries have a right to use the atmosphere, and current emissions constitute a 'status quo right'.

(3) *Responsibility/polluter pays*: the greater the contribution to the problem, the greater the share of the user in the mitigation/economic burden.

(4) *Capability*: the greater the capacity to act or ability to pay, the greater the share in the mitigation/economic burden.

Capability, here, refers to countries' ability to pay as well as to their mitigation opportunities. Mitigation *opportunities* are not identical to mitigation *capabilities*: while a country may posses many opportunities for taking relatively cost-effective abatement measures, its actual capability to take these measures may be severely limited due to technological, institutional and financial constraints (see [5]). It is also not likely that developing countries such as China and India would be willing to pay for the mitigation measures themselves at such an early stage, although they have good opportunities to abate. Moreover, the flexibility provided by the Kyoto Mechanisms allows countries access to these low cost opportunities. This makes the issue of opportunity less relevant. The principle of opportunity (see [10]) is thus not included here as main principle.

The basic needs principle [65] often referred to is included here as a special expression of the capability principle. The least capable countries should be exempted from the obligation to share in the reduction effort so as to secure their basic needs.

Many regimes have their basis in a combination of different guiding principles. For example, the C&C, CSE, GC and MCC approaches are ultimately based on a combination of the egalitarian and sovereignty principles. The Multi-Stage approach is based on a combination of responsibility and capability principles, but may also include elements related to the egalitarian principle in the use of per capita-related burden-sharing keys. The Triptych approach is based mainly on the capability to act but also encompasses elements of the egalitarian principle. Other regimes are based mainly on one principle (see table 2).

Next to the equity principles, there are a number of other dimensions related to regimes for future commitments as sited below [7]:

1. *Problem definition*. the climate change problem can be defined either as a pollution problem or as a property-sharing issue. In the first approach, '*burden-sharing*', the differentiation of commitments will focus on defining who should reduce or limit pollution and by how much. In the second approach, '*resource-sharing*', the problem is defined as an allocation of emission *rights*; the reduction of emissions will be in line with the user rights.

2. *Emission limit*. One can define the regional emission reduction *top-down* by first defining globally allowed emissions (global emission profile) and then applying certain participation and differentiation rules for allocating the global reduction effort needed. In a *bottom-up* approach the emission allowances are allocated among regions without a predefined global reduction effort.

3. *Participation level*. There are approaches assuming a *gradual* extension of the number of countries participating in global greenhouse gas emission abatement, while there are also approaches assuming *full* participation, so that all countries participate from the start.

4. *Type of commitment*. The form of the quantified commitments for the participating Parties may be defined in a differentiated manner (e.g., [8,59,60]), that is, as (i) binding absolute emission or fixed targets, such as in the Kyoto targets for the Annex I Parties, or (ii) relative or dynamic tar-

Table 2
The characteristics of the ten regimes for future commitments included in the FAIR model [7,26].

		MS	BP	AP	C&C	CSE	GC	MCC	GF	EIT	TT
Equity principles											
1. Responsibility		X	X								
2. Capability		X		X		(X)[a]				X	X
3. Egalitarian		X			X	X	X	X			X
4. Sovereignty		(X)			X	X	X	X	X		
Dimensions											
Problem definition	• Burden sharing	X	X	X					X	X	X
	• Resource sharing				X	X	X	X			
Emissions limit	• Top down	X	X	(X)	X	X	X	X	X	(X)[b]	(X)
	• Bottom up			X						X	X
Participation level	• Gradual	X	X	X					X	X	
	• Full				X	X	X	X			X
Type of commitment	• Non-binding targets	X	X	X						X	
	• Binding or fixed targets	X	X	X	X	X	X	X	X		X
	• Dynamic or index targets	X								X	

[a] Related to the basic need principle; [b] X = applicable; (X) = partly applicable.

gets (reduction in energy and/or carbon intensity levels) and (iii) non-binding targets.[5]

Only the AP, Triptych and EIT are bottom-up approaches; for reasons of comparability, these regimes can also be implemented in a top-down way, as will be illustrated in the analysis. The Multi-Stage approach is the only approach that incorporates all three forms of quantified commitments (see table 2).

Finally, it should be noted that this article does not evaluate the regimes on the basis of a set of assessment criteria, as has been done by: [23,24,26,42,71].

3. The FAIR model

This section describes the methodologies of the three submodels of the FAIR model, i.e. the climate model, emission allocation model and the abatement costs model, along with the different data sets included. The GHG emissions are calculated as CO_2-equivalent emissions, similar to those in the Kyoto Protocol, i.e. the sum of the Global Warming Potential (GWP-100 year)-weighted emissions of the six GHGs or groups of GHGs specified in the Kyoto Protocol (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride). It should be noted that there are limitations of the GWP concept [54,69,70], for example, the rather arbitrary time horizon. However, despite its limitations, the GWP concept is convenient and has been widely used in policy documents such as the Kyoto Protocol. To date, no alternative measure has attained a comparable status in policy documents. The model calculations are carried out for 17 world regions [46]. For reporting reasons different aggregates of these 17 regions have been used, as presented in table 3.

3.1. Data sets

The FAIR model includes various data sets based on regional emissions, global emission profiles and costs curves, i.e.:

Historical emissions – The historical regional emissions are based on the CDIAC-ORNL database (http://cdiac.esd.ornl.gov/trends/) and the EDGAR database [76]. The CDIAC-ORNL database includes the CO_2 emissions from fossil fuel combustion and cement production (for the time period of 1751–2000), and the CO_2 emissions from land-use changes are based on Houghton [44] (1890–2000). The EDGAR database includes the emissions of the Kyoto GHGs (CO_2, CH_4, N_2O and the HCFCs, HFCs, PFCs and SF_6), other halocarbons (e.g., CFCs, HCFCs), sulphur dioxide (SO_2) and the ozone precursors (NO_x, CO and VOC) from fossil fuel combustion, industrial and agricultural sources, biomass burning and land-use changes (1890–1995).

Baseline scenarios – Baseline scenarios are used for future (1995–2100) projections of the regional population and GDP, and the anthropogenic baseline emissions of the Kyoto GHGs, SO_2 and the ozone precursors. The different baseline scenarios included are the IMAGE implementation of the six IPCC SRES scenarios [46,57] and the Common POLES-IMAGE baseline emission scenario [79].

Global emission profiles – The global CO_2-equivalent emission profiles included result in a stabilisation of the GHGs concentrations at 550 and 650 ppmv CO_2-equivalent[6] in 2100 and 2150, respectively (S550e and S650e). An early action and a delayed response variant of the 650 profile are also included [36]. The IMAGE 2.2 and IPCC CO_2-only emission profiles [43] are included for alternative calculations at the level of CO_2 only.

Costs curves – Marginal Abatement Costs (MAC) curves that reflect the costs of abating the last ton of CO_2-equivalent

[5] Other quantified targets, such as price-cap or safety valve [48], "dual-targets" [52], "positively binding targets", and other alternatives, such as policies and measures, technology agreements, sectoral targets and carbon taxes, are not included in the model.

[6] The CO_2-equivalent concentration is a measure of radiative forcing of the set of the six greenhouse gases covered under the Kyoto Protocol expressed in terms of the CO_2 concentration that would result in the same level of (additional) radiative forcing.

Table 3
World regions and the different aggregated levels.

Annexes	Income classes*	Aggregated regions	World regions
Annex I	High income	North America	Canada
			USA
		EU plus	OECD-Europe
			Eastern Europe
		Japan	Japan
		Oceania	Oceania
	Lower middle income	Former Soviet Union (FSU)	FSU
Non-Annex I	Middle income (lower middle to upper middle income)	Latin America	Central America
			South America
		Middle East & Turkey	Middle East & Turkey
	Low to lower middle income	South-East & East Asia	East Asia (incl. China)
			South-East Asia
		Africa	Northern Africa
			Southern Africa
	Low income		Western Africa
			Eastern Africa
		South Asia	South Asia (incl. India)

* High-income ($9266 or more), Upper middle income ($2996–9265), lower middle ($756–2995) and low income ($755 or less) [83].

Table 4
Sectoral non-CO_2 MAC curves and their sources.

Gas	Sector	EMF21 sources [45]	GECS sources [13]
CH_4	Industry	–	–
	Energy	Losses/leakage from oil, gas and coal production	Losses/leakage from oil, gas and coal production
	Agriculture	Landfills, animal waste, wetland rice and animals	Landfills and domestic sewage
N_2O	Industry	Adipic and nitric acid production	Adipic and nitric acid production
	Energy	–	Transport
	Agriculture	Fertiliser use	
HFCs	All	All	All
PFCs	All	All	All
SF_6	All	All	All

emissions and, in this way, describe the potential and costs of the different abatement options considered are used here. For the energy and industry-related CO_2 emissions, MAC curves derived from the energy models TIMER [77] and POLES [16] and from the macro-economic model World-Scan [12] are used here. For CO_2 sequestration MAC curves derived from the IMAGE 2.2 model [38] can be used, while for the non-CO_2 gases, two sets of MACs are incorporated: one from the GECS study [13] and one from EMF21 [20,21,67]. These MACs for the non-CO_2 gases are mostly constructed on the basis of detailed abatement options for different sectors and sources, as presented in table 4.

3.2. Climate model

Climate model – The simple climate model [33] calculates the global GHG concentrations, radiative forcing, temperature increase and sea-level rise projections from the global emission scenarios and profiles. For the default calculations, the model uses the stand-alone IMAGE 2.2 climate model [33], which consists of an oceanic carbon, an atmospheric chemistry and climate model, based mainly on IPCC Third Assessment Report (TAR) science (see table 5). The UNFCCC – Assessment of Contributions to Climate Change (ACCC) climate model is included [74] for alternative global climate calculations. This model is based on Impulse Response Functions (IRFs) for the calculations of GHG concentrations, temperature change and sea-level rise, and the IPCC-TAR functions for radiative forcing. In addition, eight Impulse Response Functions (IRFs)[7] are included for other alternative climate calculations; these are derived from simulation experiments with General Circulation Models (GCMs), as described in [32].

Climate attribution model – This model calculates the regional contribution to climate indicators, i.e. GHG concen-

[7] IRFs form a simple tool for mathematically describing ("mimic") transient climate model response to external forcing [41].

Table 5
Description of the global climate model.

Sub-module	Model
Carbon cycle	Mass balance equation of the anthropogenic CO_2 emissions minus the terrestrial uptake (i.e. Net Ecosystem Productivity* based on IMAGE 2.2 scenarios [46]) and the oceanic uptake (i.e. box-diffusion type model from Joos et al. [50]).
Methane	Tropospheric loss depends on the OH concentration (parameterised as function of CH_4, CO, VOC and NO_x), and stratospheric and biospheric loss based on IPCC-TAR [62].
Tropospheric ozone	Related to CH_4 concentrations and emissions of reactive gas emissions from IPCC-TAR [62].
Halocarbons	For CFCs, PFCs and SF_6 constant lifetimes, and HCFCs and HFCs variable lifetimes [62].
Aerosols and ozone forcing	Forcings from sulphate aerosols (direct and indirect), fossil fuel black carbon, fossil fuel organic carbon and biomass burning aerosols, tropospheric and stratospheric ozone (O_3) and water vapour are calculated as described in IPCC-SAR.
GHGs forcing	The non-linear concentration-forcing relations for CO_2, N_2O and CH_4 (including overlap terms) are based on IPCC-TAR.
Temperature increase and sea-level rise	Upwelling-Diffusion Climate Model of the MAGICC model [82], with IPCC-TAR parameter values, using a climate sensitivity of 2.5°C equilibrium surface temperature change for a doubling of CO_2 concentration.

* From re-growing vegetation (assumed to be an anthropogenic activity) and full-grown vegetation (a natural process).

Table 6
The cases for the regimes with respect to the S550e and S650e profiles.

Reference		Parameters	S550e profile	S650e profile
MS	[25]	First threshold	CR[a] index = 5	CR index = 12
		Second threshold	CR index = 12	CR index = 20
		Intensity targets	Maximum of 3.0%/yr[b]	Maximum of 2.0%/yr[b]
		Burden-sharing key	Per capita emissions	Per capita emissions
BP	[26]	Threshold	35% '90 Annex I per capita income[c,d]	50% '90 Annex I pc PPP$-income
		Burden-sharing key	Temperature increase	Temperature increase
AP	[26]	Participation Threshold	35% '90 Annex I per capita income	50% '90 Annex I pc PPP$-income
		Burden-sharing key	Per capita income	Per capita income
C&C	[23]	Convergence year	2050	2075
CSE		Sustainable level	6.0 $GtCO_2$-eq/yr	8.0 $GtCO_2$-eq/yr
		Convergence year	2050	2075
GC	[26]	Policy delay	10 years	10 years
MCC		Convergence year	2050	2075
GF		Convergence year	2050	2075
		Threshold	35% '90 Annex I per capita income	50% '90 Annex I per capita income
EIT	[23]	Threshold	20% '90 Annex I per capita income	40% '90 Annex I per capita income
		Intensity targets	Maximum rate[e] of 5.0%/yr in 2030	Maximum rate of 3.0%/yr in 2050
TT	[22]	Convergence year	2050	2075
		Convergence EEI[f]-level	50% below best current levels	75% below best current levels
		Convergence of per capita dom. emissions	1.5 tCO_2-eq/capita.yr	3.0 tCO_2-eq/capita.yr
		Conv. intensity power	125 gCO_2-eq/kWh	300 gCO_2-eq/kWh
		Fossil fuel production	Max. reduction 90% below baseline[g]	Max. reduct. 50% below baseline
		Agricultural emissions	Max. reduction 35% below baseline	Max. reduct. 15% below baseline

[a] CR = Capability-Responsibility; [b] maximum decarbonisation rate at 50% of 1990 Annex I per capita PPP$-income; [c] in PPP$; [d] combined with world per capita emissions; [e] maximum intensity improvement rate increases linearly from 2.5% in 2025 to these maximum values; [f] EEI = Energy Efficiency Index; [g] the reduction increases linearly from 0 in 2010 to the maximum reduction in the convergence year.

trations, radiative forcing, temperature change and sea-level rise on the basis of historical GHG emissions [33], founded on the UNFCCC-ACCC methodology [74].

3.3. Emissions allocation model

The emission allocation model calculates regional emission allowances for the different regime approaches. The default parameter settings used for the approaches are given in table 6.

Multi-Stage approach – consists of a system, which divides countries into groups according to level of effort and type of commitments (stages). The approach results in an incremental evolution of the regime, i.e. a gradual expansion over time of the different groups of countries with commitments, where countries adopt different levels and types of commitments according to participation and differentiation rules [6,22,40]. The approach is based on four consecutive stages for the non-Annex I regions:

Stage 1 – no quantitative commitments: the regions in this stage follow their baseline emission trajectories;

Stage 2 – intensity targets: the regions in this stage adopt emission intensity improvement targets defined by the rate of reduction in the emission intensity of their economies, i.e. GHG emissions per unit of economic activity;

Stage 3 – stabilisation of emissions: stabilise emissions for a period of time;

Stage 4 – emission reduction targets: the regions in this stage share the remaining reduction effort[8], needed to achieve the global emission profile on the basis of a burden-sharing key.

All Annex I regions (including the USA)[9] are assumed to start in Stage 4, immediately after the Kyoto period (2012), while the non-Annex I regions enter the different stages according to different participation thresholds. Stage 3 is excluded form the cases analysed here. The participation thresholds are based on the Capability-Responsibility index, which is defined as the normalised sum of per capita income (in PPP$1000 per capita) and CO_2-equivalent emissions (in tCO_2 per capita), reflecting the responsibility for climate change [15].[10] For Stage 2, the intensity improvement targets are defined as a linear function of per capita income level, with a maximum rate chosen to reflect the stringency of the overall climate target while at the same time avoiding de-carbonisation rates in any region that would outpace those of economic growth [29]. The background of the Multi-Stage approach is described in [25].

Brazilian Proposal – During the negotiations on the Kyoto Protocol, the delegation from Brazil presented an approach for distributing the burden of emission reductions *among Annex I Parties.* This was based on the effect of their cumulative historical emissions from 1840 onwards and on the global average surface temperature [73]. The Brazilian Proposal was not adopted but did receive support, especially from developing countries, and has become a subject of continued debate and analysis [75]. Although the proposal was initially only developed for further discussion on differentiation of commitments among Annex-I countries, it is here adopted for application on the global scale. Berk and den Elzen [6] argued that in such case, a threshold for participation of the non-Annex-I regions should be added that would avoid immediate binding targets for developing countries. Such a threshold would allow low-income countries (with considerably lower per capita emissions than high-income countries) to focus on economic development. Such an extended Brazilian Proposal case (from now on referred to as the Brazilian Proposal *approach* to indicate the difference with the original proposal[11]) has been elaborated on by den Elzen et al. [26]. We have selected an income threshold for participation (to the reductions) of non-Annex I regions as a result of their work. For the regions that have passed the threshold, the remaining reduction burden[12] to achieving the global emission profile is shared among all participating regions on the basis of temperature contribution calculations. For the latter, we used the UNFCCC-ACCC methodology [74].

Ability to Pay – This approach is based on the so-called "Jacoby rule", a bottom-up approach for burden-sharing introduced by Jacoby et al. [49] as an illustrative model of accession and burden-sharing. The basic principle behind this approach is the ability to pay. The regional emission allowances are calculated using a mathematical equation. The basis of this equation is that Parties only have to participate to reduce their emissions once they have exceeded a level of per capita welfare (a welfare threshold). Countries that do not pass this threshold do not have binding emission reduction requirements (follow their baseline emissions). Either they take part in the Clean Development Mechanism (see also section 4), or they voluntarily take on "positively binding" emission reduction targets. Under such positively binding targets, emission allowances may be sold if the target is overachieved, but no emission allowances have to be bought, if the target is not reached.[13]

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. In this way the Jacoby rule is highly parameterised, with quite abstract parameters. A simplification of the approach (Ability to Pay) – avoiding these tuning parameters – is certainly possible using the Multi-Stage approach with no stabilisation and intensity stage, the burden-sharing key based on per capita (PPP$) income and income thresholds for the participation of non-Annex I regions. This implies that the approach has become top-down, allowing for better comparison with the other regimes.

Contraction & Convergence – The C&C approach defines emission rights on the basis of a convergence of per capita emissions, where all Parties participate immediately after 2012, with their per capita emission permits (rights) converging towards equal levels over time [55]. More specifically, all regional emission allowance shares converge from actual proportions in emissions to shares based on the distribution of population in the convergence year.

[8] The difference in the remaining emissions, i.e. profile emissions minus total emissions of regions in Stages 1, 2 and 3, at times t and $t-1$.

[9] In the calculations of the future commitments, we have assumed that the USA is going to participate in the reductions from 2012 onwards. Obviously, there is no certainty that this will happen. However, it is hard to conceive of any global climate regime that is compatible with stabilising GHG concentrations at 550 or 650 ppmv equivalent if the USA decides to stay out even after 2012. Within the FAIR model it is possible to analyse the impact of possible further partial or no involvement of the USA in the reductions in the next two decades, as analysed in more detail in [31].

[10] Because the CR-index combines two variables with different characteristics, the variables have to be normalised (to make it unit less) before creating their (weighted) sum. Here, a one-to-one weighting after normalisation already produces satisfactory results, as the CR-index takes into account both variables in an equal way.

[11] Den Elzen and Schaeffer [32] have extensively analysed the deficiencies in the original Proposal.

[12] The difference in the remaining emissions, i.e. global emissions of profile minus the total emissions of all non-participating non-Annex I regions at times t and $t-1$.

[13] The same holds the countries not passing the first participation threshold in the regimes MS, BP, GF and EIT.

CSE Convergence – The CSE has suggested a C&C variant, in which the concept is combined with basic sustainable emission rights [17]. The methodology rests on the assumption that there is a global sustainable emission level, defined as the amount of CO_2 that can be emitted in the very long term without raising the atmospheric CO_2 concentrations.[14] Here, these are equal to the global GHG emissions of the global emissions profile in 2100. This is allocated to all regions on a per capita basis, using the egalitarian equity principle, stating that every human being has the right to a basic emission quotum irrespective of the country where he or she lives. Given future population development, this basic per capita emission quotum will change in time. Besides this basic emission quotum, each human has a remaining quotum, which is determined using the linear convergence methodology with the 'remaining' emissions resulting from the global emission profile minus the global sustainable emission level.

Global Compromise – To solve conflicts between Parties, the Global Compromise approach creates a weighted, arithmetic mean for base proposals and Party preferences [56]. And so, consensus is sought in a doubled-based – population and emissions – distribution proposal on sharing global emission allowances. More specifically, the approach is based on a voting procedure that combines preferences for a distribution of global emission allowances according to emission levels (grandfathering) or population levels (per capita allocation). The calculation takes place in two steps, i.e. a 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 distribution method (per capita or grandfathering). The emission shares per region are then calculated as the (population-) weighted mean between the population and grandfathering shares using the calculated weights. In our model implementation, the emissions and population shares and weights are dependent on a policy delay (pd), i.e. the values of the shares at time t are calculated based on the data of $t - pd$ [26].

Multi-Criteria Convergence – This approach is a variant of the C&C, but now a time-dependent multi-criteria index is used to calculate the convergence of regional emissions. This index is based on the weighting of three indicators, i.e. population, economy (GDP) and the emissions, where, initially, the weight of emissions is 1 (grandfathering), but converge to a distribution based on an equal weight of each indicator over time.

Grandfathering – The emission allowances are distributed according to the present regional emission levels. This is the most common approach in international sharing agreements over scarce resources. It results in a simple flat-rate reduction in our model implementation, combined with an income participation threshold.

Emission Intensity Targets – This approach assumes that all Parties adopt emission intensity targets after reaching a certain income threshold. The rate of improvement of the intensity targets is based on the same income-dependent function as adopted under the intensity stage of the Multi-Stage approach. However, since OECD-Europe and Japan are already relatively efficient, their improvement rates are limited to 50% of the maximum rate. This assumption implies that *all* other regions will ultimately converge to the emission intensity level of these – most efficient – regions, and then follow their rate of improvement. For some low-income regions this will take very long (well beyond 2050). In a way this stimulates the dynamics of the 'catching-up' process with reference to this technological frontier [23].

Triptych – The Triptych approach is a sector- and technology-oriented bottom-up approach allowing different national circumstances to be taken into account. The approach has been used for supporting decision-making in internal target differentiation in the EU, both before and after Kyoto (COP-3) [61]. It originally only included energy-related CO_2 emissions. Groenenberg [39] has extended this approach with other greenhouse gas emissions and sources, and addressed a number of shortcomings. The overall emission allowances are determined by applying various differentiation rules to three distinct sectors: the internationally oriented energy-intensive industry sector, the domestic sector and the power-production sector. The industrial emissions are calculated on the basis of a future growth of production. The growth rates are differentiated by assuming per capita physical production to be a function of per capita PPP income, derived from historical trends [39]. The improvement rates in energy intensity for all regions is calculated by a world-wide convergence in energy efficiency levels, expressed in an aggregated Energy Efficiency Indicator [61] over time. These improvement rates depend on the initial (2010) values of the indicator, the year of convergence and the final convergence level. The latter is a fraction of the indicator value under the best current practices or best available technologies in the convergence year. The domestic emissions depend on the population growth and a convergence of per capita domestic emissions. The power emissions are defined by a growth in the electricity consumption, estimated by the weighted sum of the emission growth in the energy-intensive industry and the domestic sectors, and a convergence in the intensity of the electricity production (emissions per unit of kWh). The approach includes the non-CO_2 GHG emissions from the two other sectors, i.e. fossil fuel production and agriculture. For more details we refer to the model analysis at CO_2-only level in [22].

3.4. Abatement cost model

The cost calculations in the abatement cost model uses aggregated permit demand and supply curves, derived from MAC curves for the different regions, gases and sources. They allow for relatively simple and transparent calculations of the costs (assuming a least-cost approach) of different regions in reaching their respective targets (as set in the emission allocation model). The intersection formed by the ag-

[14] This sustainable level of anthropogenic CO_2 emissions would ultimately have to be reduced to the level of persistent natural sinks, which is around zero, although not clearly defined [63].

gregated MAC curves (total supply) and emission reduction objectives (total demand) of Parties determines the international market equilibrium permit price (henceforth referred to as permit price). Depending on the national/regional MAC curves and reduction objectives this market price determines if Parties will import permits to meet their individual targets, or will abate more than is required to sell this surplus on the international permit trading market [37]. This methodology distributes the regional emission reduction objectives over the different gases and sources following a least-cost approach, taking full advantage of the flexible Kyoto Mechanisms, i.e., International Emissions Trading (IET), Joint Implementation (JI) and the Clean Development Mechanism (CDM). Subsequently, the permit price is used to determine the buyers and sellers on the international trading market, as well as the accompanying financial flows of permit trading and the regional abatement costs resulting from domestic and external abatements.

Table 7 presents the default MAC curves and main parameter settings used in the analysis (for further details, see [79]). Different sets of MAC curves, for the different gases and sources are used, as extensively described in [29,77]. For CO_2 abatement options and cost estimates for energy- and industry-related emissions (energy, feedstock and cement production), impulse response curves from the energy model, TIMER 1.0 [19], are used. This model calculates regional energy consumption, energy-efficiency improvements, fuel substitution, and the supply and trade of fossil fuels and renewable energy technologies, as well as carbon capture and storage. A carbon tax on fossil fuels is imposed for constructing the MAC curves to induce emission abatements, taking into account technological developments, learning effects and system inertia [77]. The CO_2 sinks potential for Afforestation and Reforestation (AR) projects, as determined by the IMAGE model, are extended with sinks from Forest Management with conservative estimates, along with negligible costs. For the non-CO_2 GHG emissions, the set of MAC curves from the GECS project is used [13]. The set includes curves for CH_4 and N_2O emissions from both energy- and industry-related emissions as from some agricultural sources, as well as abatement options for the halocarbons. The non-CO_2 MAC curves have been corrected for measures already applied under our baseline scenario; this is to increase consistency within the analysis (see [79] for the methodology used). In addition to the end-of-pipe measures, as included in the non-CO_2 MAC curves, CH_4 and N_2O emissions can also be reduced by systemic changes in the energy system (for instance, the reduction in use of coal and/or gas reduce CH_4 emissions during production and transport of these fuels). In [80] we account for these effects by a coupled analysis of the FAIR and TIMER models. It should be noted, however, that the total impact of these indirect reductions are relatively small (at maximum about 0.1–0.2 Gt C-eq) (compared to the overall reduction objective of more than 10 Gt C-eq in 2050) and have therefore not been taken into account in the analysis here.

Table 7
Default MAC curves and Kyoto Mechanisms parameter settings used for the cost calculations.

	Settings
MAC curves	
CO_2 Energy and industry-related MAC curves	TIMER
CO_2 AR MAC curves	IMAGE 2.2
Non-CO_2 MAC curves – set	GECS
• Technological improvement	2% per 5 year
Non-CO_2 agricultural emissions	No MAC curves available
• Maximum reduction (below) baseline	35%
• Target year	2040
Kyoto Mechanisms – parameters	
Transaction costs	Sum of a constant \$2 per tC-eq plus 2% of the total abatement costs
CDM accessibility factor	10% of the theoretical maximum in 2010 increasing to 30% in 2030

As the model includes different sets of MAC curves, derived from different sources, several exogenous assumptions need to be taken. The non-CO_2 MAC curves are constructed for the year 2010 only and do not change in time. Therefore, a technological improvement factor is included, increasing the abatement potential per dollar invested over time. Furthermore, no MAC curves are available at the moment for several non-CO_2 land-use emission sources (mainly wetland rice, animals and fertiliser use). Since several abatement options already exist for these sources, exogenous assumptions are made for their reduction potentials. Transaction costs are included for the use of the Kyoto Mechanisms. The non-participating regions that have no commitments in the regimes (MS, BP, AP, EIT and GF) can only participate through CDM projects. For these projects we used an accessibility factor for CDM projects, as only a limited amount of the total CDM abatement potential is assumed to be accessible to the market.

This methodology based on MAC curves taken has several strengths and weaknesses. The description of costs of climate policies using an approach based on marginal abatement costs is transparent and flexible, allowing for a description of emission trading, including possible limitations in the use of flexible instruments (e.g., transaction costs and accessibility of reduction options). Furthermore, the approach used considers all six Kyoto GHGs, allowing for full flexibility in the abatement of these gases (so-called multi-gas approach) and in other options such as sinks. It also has a number of limitations. First of all, MAC curves only represent direct cost effects without feedback to the overall economy; this means that there is no direct link with macroeconomic indicators such as GDP or utility losses. Second, MAC curves are not available for all sources, but this will improve in time. Third, the MAC curves for the non-CO_2 sources do not fully account for the dynamics of the technological developments, learning effects and system inertia as a function of time-pathways of the earlier abatements. In contrast, the CO_2 MAC curves are calculated in the energy model TIMER, which includes these dynamics [77]. To ac-

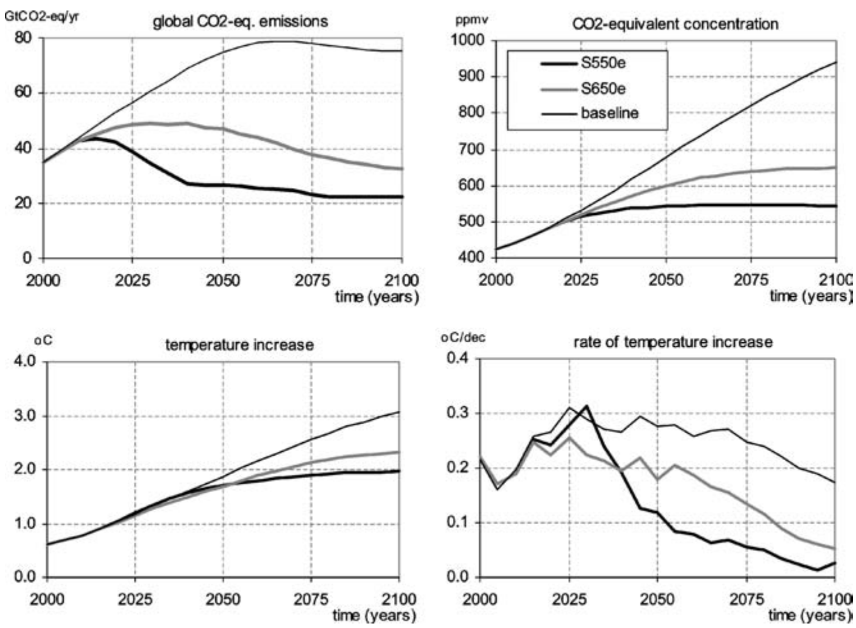

Figure 2. Global GHG emissions and concentrations (upper figure), along with total and rate of temperature increase for the two emission profiles and the baseline scenario.

count for the time-pathways of the earlier abatements, the TIMER response curves have been calculated assuming a linear increase of the permit price after the first commitment period and the final value in the evaluation year.[15] However, if the real permit price shows a different non-linear time-pathway, other response curves needs to be incorporated, or the dynamics of inertia and learning effects need to be parameterised, as for example Ambrosi et al. [2] did. Finally, as mentioned earlier, part of the CH_4 and N_2O emission reductions are closely related to the abatement action taken in the energy system, but are not considered in the calculations.[16]

4. Model analysis

The model analysis evaluates the allocation of the necessary emission reductions and the accompanying abatement costs implications of the ten regimes included in the FAIR model, on the basis of two global emission stabilisation profiles, i.e. stabilising at 550 and 650 ppmv CO_2-equivalent.

4.1. Climate impacts of stabilising at 550 and 650 ppmv CO_2 equivalent

We used the Common POLES IMAGE scenario [14,79] as the baseline scenario (figure 2). This scenario assumes a continued process of globalisation, medium technology development and a strong dependence on fossil fuels. GHG emissions increase from 35 Gt CO_2-equivalent in 2000, to more than 90 Gt CO_2-equivalent in 2050; this corresponds to a medium-level scenario when compared to the IPCC SRES emissions scenarios.

The two stabilisation profiles used lead to a long-term stabilisation of the GHG concentration at 550 and 650 ppmv CO_2 equivalent in 2100 and 2150, respectively [36] (hereafter S550e and S650e). Up to 2010, both profiles incorporate the implementation of the Annex I Kyoto targets for Canada, Japan and Western and Eastern Europe, and an optimal level of banking of excess emissions by the FSU. The USA follows the Bush plan (emission intensity target), but this leads to emissions which do not significantly differ from their baseline values [78]. The Annex I region, Oceania (including Australia), and the non-Annex I regions are assumed to follow their baseline emissions.

After 2010, the profiles are designed in such a way that they meet the long-term CO_2-equivalence stabilisation targets. The GHG emissions continue to rise in the first decades of the simulation, after which the emissions need to be reduced. For the S550e profile, the global anthropogenic GHG emissions would have to peak before 2020 and be back to 1990 levels around 2035. For the S650e profile, the global emissions could peak later (around 2030) and at a higher level; furthermore, they would not have to be back to 1990 levels before 2070.

The global emission reduction objective required is defined by the difference between the baseline emissions and the two stabilisation profiles. Figure 2 presents global emissions and accompanying GHG concentrations for the baseline and stabilisation profiles, along with the global mean surface temperature increases and the rate of temperature rise. The GHG concentrations and thus the climate impacts do not only depend on the CO_2-equivalent emission levels, but also on the shares of the six GHGs, due to their different

[15] A full integration of the FAIR cost model and the energy model TIMER would be even better. It allows for constructing the TIMER CO_2 MAC curves each time step, instead of creating the curves for the complete timeframe prior to the FAIR calculations. This would lead to a better implementation of the path-dependency in the MAC curves.

[16] Using the final CH_4 and N_2O emission reductions from the energy model, TIMER, improves the integrated analysis.

lifetimes in the atmosphere. The shares are calculated using the cost-optimisation methodology of the cost model. As for many of the non-CO_2 gases, relatively cheap reduction options exist to reduce part of these emissions, the contribution of the non-CO_2 gasses in the total reduction is large in the beginning of the century. After 2050 their contribution becomes more proportional to their share in total emissions, and as a result, the reductions in the CO_2 emissions become more important. The different shares, their changes in time and their impacts on the GHG concentration and climate indicators are discussed in more detail in van Vuuren et al. [80].

For a climate sensitivity of 2.5°C[17] and other default climate settings, the S550e profile already results in a 2°C rise by 2100, while in the S650e profile, the rise is about 0.3°C more. Interestingly, the S550e profile shows a somewhat higher temperature increase in the period from 2020 to 2050 than the S650e profile. This is due to the higher SO_2 emission reductions for the S550e profile, which results in a decrease in the present cooling effect of SO_2 in the future [81]. This effect is better visible for the rate of temperature change. For the S550e profile its resulting rate of temperature change is, in fact, similar as the rate under the baseline up to 2020, and drops under the rate of the S650e profile around 2040. This shows the dominant effect of SO_2 emissions on the temperature effect at the beginning of the stabilisation profile. Hence, any decreasing temperature effect because of mitigation actions, which also mitigate SO_2 emissions, cannot be expected to be given immediately.

4.2. Regional emission allowances

For analysing the regional emission allowances, the parameter settings of the two bottom-up approaches (EIT and Triptych) are adjusted to allow for a comparison of the bottom-up with the top-down approaches. The EIT approach has been implemented with parameter settings leading to total emissions comparable to both emission profiles. For the Triptych approach, the convergence in domestic per capita emissions accommodates the emission space available for domestic emissions under the global domestic emission ceiling, i.e. the difference between the ceiling for the profile and the sum of the emissions allocated to the other sectors [22]. This results in more domestic emission allowances up to 2030 compared to the domestic emission allowances under the bottom-up approach. In general, the parameters of the reference cases are chosen in a way that the Annex I countries take the lead in the reduction efforts when compared to the baselines, followed by the middle- and high-income non-Annex I regions and, finally, low-income non-Annex I regions (in line with Article 3.1).

4.2.1. Profile versus regime

The first step in the evaluation of future obligations is a comparison of emission reduction levels for Annex I and non-Annex I regions for the regime cases under the two stabilisation profiles. Figure 3 depicts the change in the regional emission allowances compared to the baseline levels for the ten aggregated regions. This provides information on the spread in reduction efforts required of the different Parties for two time horizons, i.e. the short-term (2025) and the long-term (2050). We have not yet focused on the differences between the approaches; this will be done in the next section.

Annex I regions – Figure 3 shows average emission reductions over all regimes for each region to be more influenced by the assumed emission profiles than by the regime options explored. However, for some regions (i.e. EU plus and FSU),

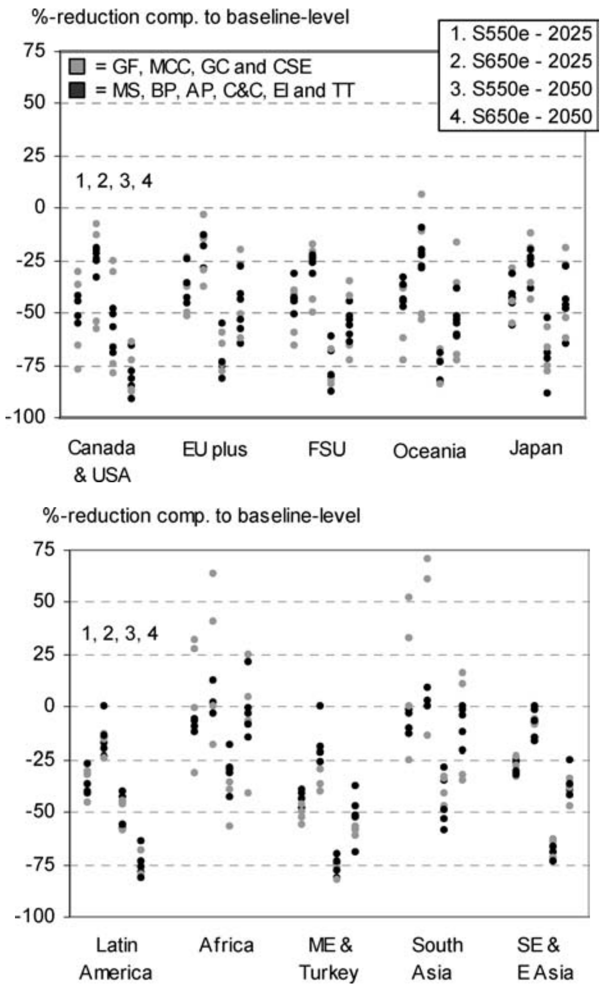

Figure 3. Impact of the stabilisation profiles versus regimes on the emission reductions relative to the baseline emissions.[18] The GF & MCC, on the one hand, and GC & CSE, on the other, are regimes that lead to the lowest or highest Annex I reductions, respectively. This is reversed for the non-Annex I reductions (indicated with grey dots).

[17] The climate sensitivity is defined as the equilibrium global temperature increase over pre-industrial level that would result from a doubling in CO_2-equivalent concentrations [18].

[18] The increase of the baseline emission levels compared to 1990 levels is for the Annex I regions: 35% in 2025 and 37% in 2050 for Canada & USA; 5% and 7% for EU plus; 0% and 5% for the FSU; 52% and 68% for Oceania and 24% and 19% for Japan. For the non-Annex I regions: 126% and 256% for Latin America; 184% and 406% for Africa; 230% and 412% for Middle East & Turkey; 211% and 432% for South-Asia and 180% and 281% for South-East and East Asia.

the range of outcomes from the different approaches for the S550e profile still overlaps with the range of outcomes for the S650e profile, even when the notable exceptions of some extremes are excluded. The exceptions are basically the GF and MCC approaches (upper range) and CSE and GC approaches (lower range), i.e. the lowest and highest Annex I reductions, respectively (indicated in grey in figure 3). For the intermediate cases, reductions of 25–55% below baseline in 2025 are needed to achieve the 550-ppmv target, whereas for the 650-ppmv target this ranges from 10–40%. In 2050, reductions are 50–90% (S550e) and 30–70% (S650e), respectively.

Non-Annex I regions – For the non-Annex I regions, the results are generally more differentiated than for the Annex I regions, while the same extremes exist. The range of both profiles for these regions does not overlap after excluding the extremes. For the low-income regions the reductions in 2025 are limited compared to the baseline level for either profile, while these regions may even have excess emission allowances. For the S550e profile, the reductions increase to 20–60% in 2050, whereas for the S650e profile, the reductions remain marginal. For the middle income regions the reductions are in line with the reductions for the Annex I regions, while the reductions for the low to lower middle-income regions are slightly lower.

4.2.2. Comparison of the regimes for both the profiles

To compare the emission reductions to the baseline emissions under the different regimes in more detail, the results of our analyses for 17 regions are summarised for both the profiles in table 8. Since the differences between the regimes in the short term are most pronounced, we focus on 2025. The reductions for each region under the different regimes are compared to their average reduction (defined as the average of the absolute reductions over the regimes). The tables are sorted in such a way from left to right, that the regimes with the lower total non-Annex I reductions can be found in columns more to the left, while the regimes with the lower Annex I reductions are found more to the right. The numerical values for each region indicate the absolute reduction compared to the baseline. The colour of the cells indicates the relative difference of change in reduction for this regime compared to the average reduction. For example, the absolute reduction for Canada under the GC case is 74.3%, which represents a difference in reduction of 19.3% compared to the averaged reduction (55%). The relative difference between 19.3% and 55% is now 35% (= 100·19.3/55), therefore occurring in the 25–50% range; this indicates that the GC case is not really attractive for Canada.

Table 8 can be used for assessing which approaches are more and less favourable or attractive for the various regions. The approach resulting in the relatively least emission reductions (or highest emission allowances) will be hereafter classified as the "most" favourable or most attractive approach, indicated by the dark-grey cells with dots and white numbers. The approach resulting in the relatively highest emission reductions (or lowest emission allowances) will be hereafter classified as the "least" favourable or least attractive approach, indicated by the dark grey cells with black numbers. As regimes should not lead to abnormal and disproportional burdens (Article 3.1 UNFCCC), in other words, extreme results[19] for some countries, or be more attractive in terms of reductions for certain Parties, the ten regime cases can be subdivided in three groups. 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. This means that we have to be careful about drawing conclusions about regimes.[20]

The first group represents the cases resulting in extreme results, i.e. GC, CSE, MCC and GF. The GC and CSE cases are clearly the most attractive approaches for the non-Annex I regions, except for the Middle East & Turkey. In the short-term, these cases lead to large excess emission allowances for the low-income non-Annex I regions, but also for Northern Africa due to the initial reshuffle of emission allowances towards a better division in emissions per capita. The MCC and GF cases represent the most attractive approach for the Annex I regions, while leading to high reductions for the low- and middle-income non-Annex I regions.

The second group of cases represent roughly those more attractive in terms of reductions for certain Parties, i.e.: AP, EIT and BP, while clearly unattractive for some other Parties. The AP case with a burden sharing based on per capita income is attractive to most low and medium income countries. The EIT case is, in general, attractive to the OECD regions with relatively low emission intensities, in particular, for OECD-Europe and Japan, but unattractive for particularly South Asia and Northern Africa due to their early entry into the emission reductions. Furthermore, for the last two regions, the adopted intensity improvement rates exceed the trend in their baselines. The Brazilian Proposal case is unattractive to OECD-Europe due to its relatively large historical contribution to temperature increase, but also to Latin America. Southern Africa, South Asia and Northern Africa benefit from the no-binding commitments before participating in the emission reductions, which for them makes BP attractive.

The remaining regimes, the Multi-Stage, the Triptych and C&C, occupy a position more to the middle. All three regimes appear in the middle of table 8 for the S550e profile, while for the less stringent S650e profile the C&C approach, more on the right, is more attractive to the Annex I regions. In conclusion then, the Multi-Stage and Triptych approaches are the "most-acceptable" approaches as they form a middle approach of all analysed regimes in terms of reduction targets for both stabilisation profiles.

[19] Here defined as a relative differences of more than 50%, i.e. the dark grey cells with the white numbers in the table.

[20] Elsewhere [22,26] we have showed that the chosen parameter settings can be as important as the choice of the regime. The most important policy parameters are threshold levels, burden-sharing key and convergence dates.

Table 8
Comparison of the reduction efforts for the regimes in 2025 for the S550e profile (upper) and the S650e profile (lower).

2025, S550e	Average	Std. Dev	GC	CSE	AP	MS	C&C	TT	BP	EIT	GF	MCC
Canada	55.0	10.4	74.3	67.3	61.3	54.8	53.5	39.8	52.6	53.8	50.5	42.5
USA	47.5	15.0	77.9	65.3	55.0	50.9	43.3	42.1	35.0	40.5	35.1	29.7
OECD Europe	40.2	10.8	53.5	51.8	51.2	38.4	39.2	35.4	45.6	23.1	39.8	23.6
Eastern Europe	32.4	7.6	46.4	44.1	24.4	29.0	29.9	35.2	31.7	28.7	30.8	23.3
Former USSR	46.0	10.0	65.7	59.3	31.8	44.2	43.8	43.1	41.4	50.8	41.1	39.4
Oceania	45.0	13.1	73.1	62.1	44.9	46.9	43.7	36.7	37.3	33.0	38.6	33.3
Japan	44.4	9.4	55.4	55.1	55.7	42.9	43.8	41.1	45.1	31.1	44.6	28.7
Central America	33.5	8.0	22.5	24.1	37.4	34.0	29.4	27.1	40.4	41.5	47.1	31.9
South America	36.2	5.1	34.8	33.6	36.7	37.2	33.3	27.1	40.3	40.6	45.4	32.9
Northern Africa	13.0	12.1	-2.0	3.8	0.0	11.6	19.1	16.0	24.5	27.1	0.0	30.1
Western Africa	-13.1	34.1	-78.8	-69.7	0.0	0.0	-13.4	-6.2	0.0	9.2	0.0	28.0
Eastern Africa	-29.3	52.3	-130.5	-117.7	0.0	0.0	-44.1	-15.0	0.0	3.7	0.0	10.2
Southern Africa	18.2	14.3	28.1	23.3	2.7	9.1	32.5	20.1	20.3	0.3	2.7	43.3
Middle East	46.3	5.3	55.7	49.6	43.4	47.7	46.0	41.0	39.5	41.1	52.9	46.2
South Asia	-3.2	22.6	-51.7	-33.0	0.0	1.1	3.4	12.6	0.0	10.7	0.0	25.1
East Asia	31.5	2.6	28.1	31.8	27.1	30.4	32.2	34.7	30.4	31.6	35.7	32.6
South East Asia	22.7	11.1	6.2	13.9	17.4	10.2	27.0	22.5	42.2	28.5	25.2	34.0
Annex-I	44.8	10.7	66.5	59.3	47.4	45.1	42.2	40.2	39.8	38.0	38.5	30.7
non-Annex I	23.1	7.2	8.3	13.3	21.5	23.1	25.0	25.8	26.6	27.3	27.6	32.9

2025, S650e	Average	Std. Dev	CSE	GC	AP	BP	MS	EIT	TT	C&C	GF	MCC
Canada	37.1	16.2	59.6	57.0	45.8	43.6	38.8	37.8	22.7	34.3	5.9	25.6
USA	26.6	16.8	57.7	53.7	32.1	23.9	24.1	19.9	17.4	17.2	13.5	6.3
OECD Europe	23.2	10.9	40.0	32.1	33.0	32.5	23.3	14.7	16.1	16.8	19.2	4.8
Eastern Europe	11.4	10.3	30.5	20.9	13.6	19.5	11.8	4.1	11.7	4.3	-1.5	-1.2
Former USSR	27.8	10.8	49.7	43.7	24.6	31.1	26.4	22.4	20.5	21.1	20.9	17.2
Oceania	23.9	18.2	53.4	50.9	29.0	27.8	25.3	9.8	18.2	19.6	-6.4	11.2
Japan	28.0	10.3	44.1	35.7	38.7	35.5	29.3	20.3	22.2	23.3	19.0	11.7
Central America	11.1	7.6	3.8	6.3	1.5	0.0	15.6	21.2	13.3	13.5	20.0	15.6
South America	17.1	6.9	16.2	17.0	23.6	0.0	19.6	19.9	17.8	15.6	25.6	15.3
Northern Africa	-2.1	10.4	-22.6	-16.4	0.0	0.0	0.0	0.0	-1.8	5.6	0.0	14.4
Western Africa	-19.3	44.2	-118.3	-81.3	0.0	0.0	0.0	9.2	-6.4	-14.5	0.0	18.3
Eastern Africa	-36.3	65.7	-180.1	-132.4	0.0	0.0	0.0	3.7	-8.6	-44.4	0.0	-1.3
Southern Africa	6.9	10.1	2.5	15.2	0.0	0.0	0.0	0.3	3.9	19.4	0.0	27.8
Middle East	26.2	11.6	36.7	40.2	0.0	36.4	19.5	19.2	24.1	29.9	26.3	29.9
South Asia	-11.9	28.9	-70.5	-61.1	0.0	0.0	0.0	0.0	1.7	-3.3	0.0	14.1
East Asia	10.3	6.3	13.8	9.7	1.4	0.0	5.9	7.8	17.2	14.7	17.5	15.0
South East Asia	4.5	9.8	-9.6	-7.4	0.0	0.0	0.0	3.7	12.2	14.5	11.6	20.2
Annex-I	25.7	12.9	49.8	44.0	30.5	28.6	24.7	18.8	18.0	18.4	14.9	9.2
non-Annex I	6.1	8.8	-10.3	-6.3	2.9	4.2	6.9	8.6	12.3	11.2	13.6	17.5

less non-Annex I reductions ← → **More non-Annex I reductions**

decrease relative to average reduction > 50%	-X.X	X.X	increase relative to average reduction > 50%
decrease relative to average contribution > 25%	-X.X	X.X	increase relative to average reduction > 25%
decrease > 10%	-X.X	X.X	increase > 10%
decrease < 10%	-X.X	X.X	increase < 10%

X.X is absolute reduction compared to the baseline

Explanation: The first column gives the average reductions (average of the absolute reductions over the regimes) compared to the baseline (in %) per region, the second column gives the standard deviation. The other columns indicate the reductions for the alternative cases. Columns are sorted from left to right, with increasing reductions for non-Annex-I. The colour of the cell and its number is a function of the relative change of a regional reduction with respect to the default average reductions of the particular region (as explained in the text).[21]

More specifically, the C&C case is attractive to OECD-Europe and Japan because of its relatively low per capita emissions and the fact that under C&C, all countries contribute. The earlier contribution of the non-Annex I regions makes C&C a relatively less attractive approach for South Asia and East Asia. Since the per capita emissions for East Asia are close to the world average per capita emissions, they do not gain from the C&C, and therefore the C&C case is not so an attractive approach to them. In the short term, Eastern and Western Africa gain from the excess emissions for both profiles, in particular, for the S650e profile.

The Triptych approach is, in general, attractive to the OECD regions with relatively low emission intensities, i.e.

[21] Due to the excess emission allowances for Western- and Eastern Africa high negative relative differences arise, even when the baseline is followed. Therefore, the cells with no reductions, or excess emissions are depicted white. Also the average reductions of these regions are strongly influenced by the very high excess emissions (more than 80% above baseline) under GC and CSE.

OECD-Europe and Japan. The approach is also attractive to the middle-income regions, Latin America and the Middle East & Turkey. The Triptych is in particular unattractive for South Africa, South Asia and East Asia due to their relative inefficiency in the power and industrial sector, and their dependency on coal. For the S650e profile, surplus emission allowances occur for Eastern and Western Africa, and also for South Asia, due to the convergence in the domestic emission allowances.

The Multi-Stage case leads to high reductions for the USA and Central and South America. It is less restrictive for South Asia, which can follow the baseline emissions, and also for East Asia, as its per capita emissions are close to the world average. However, for Eastern and Western Africa, this case is less attractive than the C&C cases because it does not experience excess emissions.

4.3. Regional abatement costs

The regional emission reduction levels are used within the abatement cost model to calculate the regional abatement costs, making full use of the flexible Kyoto Mechanisms like emissions trading and substitution of reductions between the different gasses and sources. The net regional costs or gains for the different regimes result from the costs of domestic abatement combined with the costs or gains from emissions trading. Given the large differences in income between the regions, the costs (or gains) are compared to the regional GDP levels in PPP$ terms.[22] This ratio, further referred to as the 'effort rate', gives an indication of costs in comparison to the 'carrying capacity' of the local economy.

4.3.1. Profile versus regime

Figure 4 presents the international permit price and the global effort rate for the ten regimes and two stabilisation profiles. The permit prices and effort rates remain somewhat below the prices and effort rates of the gradual participation regimes for the full participation regimes, such as C&C and MCC. This difference results from the participation of the non-Annex I regions in the emissions trading market. For the full participation cases, all non-Annex I regions are assumed to fully participate in emissions trading after 2012, whereas for the other cases, participation increases with time. The non-participating non-Annex I regions have no commitments, and can therefore only participate through CDM. CDM allows participating regions to fulfil part of their reduction objective by buying emission reductions of non-participating regions on a project basis. The limited accessibility of viable CDM projects lowers the supply of emission reductions on the international market, thereby increasing the permit price. Figure 4 shows larger differences between the outcomes of the two stabilisation profiles than between the different regimes. Concluding that the international permit price and the global effort rate are more dependent on the stabilisation level chosen, than on the regimes considered.

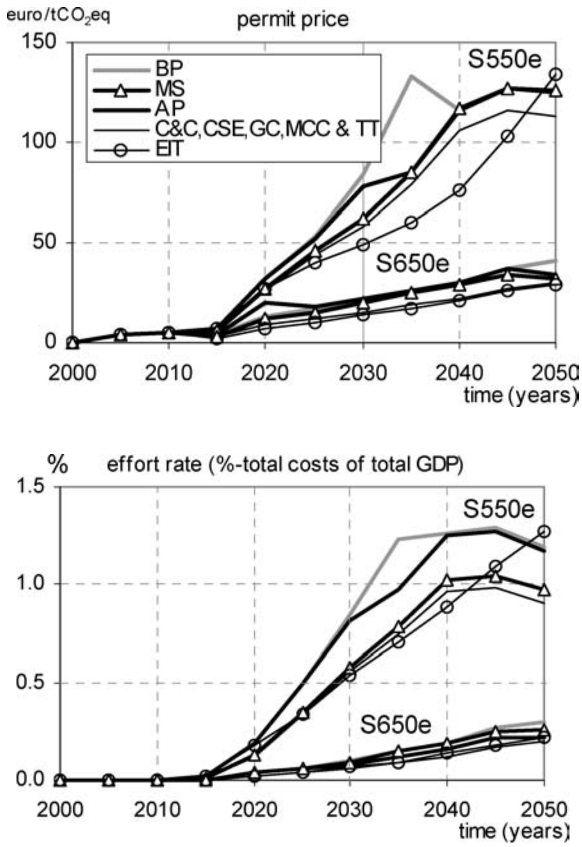

Figure 4. Permit price and global effort rate for the ten regimes and both stabilisation profiles. Note that delayed participation of South Asia under the BP case in 2040 leads to a sudden decrease in the permit price.

4.3.2. Comparison of the regimes for both the profiles

Estimating costs of regimes is beset with uncertainties [79]. This is already an important issue for short-term cost calculations of the Kyoto Protocol, but the uncertainties for the medium- to long-term calculations are growing. Therefore, we focus on the short-term (2025) only. The regional effort rates are presented in figure 5 and in more detail in table 9. The effort rates differ largely across the various regimes and regions; these differences can be explained by the differences in regional reduction objectives (table 8), reduction potentials and income levels.

Annex I regions – For the S550e profile, the effort rates of the OECD regions are about 0.2–1%, except for the CSE and GC cases (see also figure 3). Although the differences are small, total abatement costs tend to be relatively high for Canada & USA and Oceania (regions with the highest per capita emissions), and somewhat lower for Europe and Japan (regions with medium per capita emissions). The costs for the FSU are much higher due to their relatively high emissions per capita and medium income levels. For the S650e profile the effort rates are much lower, ranging from 0–0.2%, with the highest values for CSE and GC.

[22] The GDP can be expressed either in Market Exchange Rates (MER). However, as the lion's share of the reduction efforts is taken domestically, comparison of abatement costs to GDP measured in PPP terms might be more relevant as an indication of potential economic impacts.

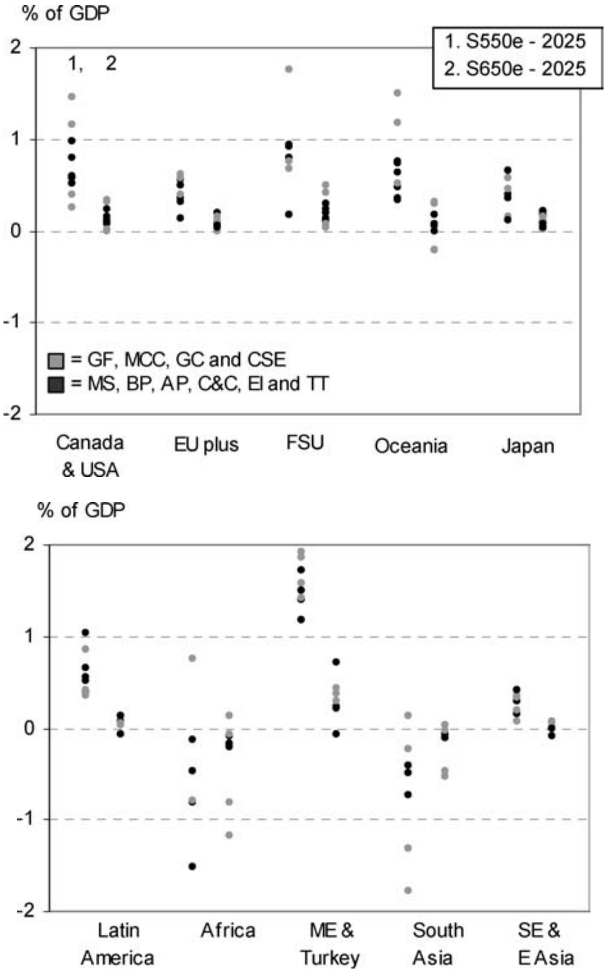

Figure 5. Impact of the stabilisation profiles, vs. regimes, on the regional effort rates.

Non-Annex I regions – As a consequence of the more differentiated emission reduction targets among the non-Annex I regions than among the Annex I regions (see figure 3), the costs between the non-Annex I regions are also more differentiated (figure 5). The Middle East & Turkey are confronted with the highest effort rates (1–2%), mainly due to their relatively high per capita emissions and medium-income levels, while the effort rates of Latin America are about the same as the OECD regions for both profiles. Except for the MCC case, the low-income regions gain in all regimes and under both profiles. These gains range from 0–3% of their GDP and are the highest for the CSE, C&C and GC cases. Finally, for the low to lower middle-income region (SE & E. Asia) the effort rates are below the world average (about 0.3% of GDP). This is due to their relatively high gains from emissions trading, which partly compensate their costs for emission control. Again, the effort rates are much lower for the S650e profile, while the pattern of costs and gains is similar as to that under the S550e profile.

In general, the differences in costs between regions reflect the differences in reduction targets, since the reduction efforts and abatement costs are strongly related. For example, in most Annex I regions the GC case leads not only to the highest reduction targets, but also to the highest costs. However, due to a limited reduction potential and/or a low income, regimes with low reduction efforts, for example, the Multi-Stage case for the Middle East & Turkey, can still lead to high abatement costs, and might therefore not be that attractive.

Den Elzen et al. [30] have systematically analysed the regional effort rates of three regime approaches, i.e. Brazilian Proposal, Multi-Stage and C&C. By comparing the effort rates with the world average, they identified four groups of regions with similar efforts in line with the income classes in table 3. One is the high-income regions in group 1, generally showing average costs when compared to other regions; the middle-income regions in group 2, confronted with the highest costs; the low to lower middle income regions in group 3 confronted with low to average costs; and the low income regions in group 4 showing net gains from emissions trading. Table 9 shows that this grouping also holds for the ten regime approaches under both profiles analysed here. The only exceptions are the AP and MCC cases under the S650e profile, with small net gains for all non-Annex I regions for the AP case, and net costs for most non-Annex I regions for the MCC case. Furthermore, Southern Africa, group 3, forms an exception for C&C, GC and MCC, as this region is confronted with high costs for the regime cases.

Table 9 can also be used to evaluate whether regimes are more or less attractive for the various regions in terms of their costs burden. This table uses the same sequence of the regimes as in table 8, and in general the pattern of attractive regimes is, in general, quite similar. It can be concluded that for group 1 the MCC and EIT, and to a lesser extent also the Multi-Stage, Triptych and C&C, are the most attractive regimes, while BP and, in particular, AP, are least attractive. For the Middle East and FSU (group 2), almost all the regimes seem unattractive, since most of them lead to high costs. For Latin America (also group 2), the GF is the least attractive, while the other regimes show moderate costs. For group 3, in particular Southern Africa, C&C and MCC are less attractive than regimes with income thresholds (Multi-Stage and AP). For group 4, all regimes except MCC are reasonably attractive and lead to high gains, in particular C&C.

Summarising over all regions and stabilisation profiles, it may be concluded that the Multi-Stage and the Triptych approaches seem to result in a more even distribution of costs than the other approaches, in particular, among the Annex I regions, although the FSU remains more highly affected. Within each income class region, these approaches also show the least differences compared to the averaged costs for the income class. For this reason, they seem to provide the best prospects for a negotiation outcome based on compromises of all Parties. However, it should be acknowledged that the quantitative results are highly dependent on the policy parameter settings, as analysed in [22,26], and marginal abatement cost curves, the baseline emis-

Table 9

Effort rate for the ten regimes explored in 2025 for the S550e profile (upper) and the S650e profile (lower).

2025, S550e	Average	Std. Dev.	GC	CSE	AP	MS	C&C	TT	BP	EIT	GF	MCC
Canada	0.77	0.23	1.27	1.08	1.01	0.76	0.72	0.41	0.74	0.63	0.68	0.43
USA	0.69	0.31	1.48	1.16	0.96	0.79	0.58	0.52	0.36	0.43	0.36	0.23
OECD Europe	0.40	0.18	0.60	0.57	0.63	0.37	0.38	0.32	0.52	0.10	0.42	0.13
Eastern Europe	0.28	0.18	0.70	0.63	0.02	0.21	0.24	0.35	0.27	0.14	0.23	0.05
Former USSR	1.01	0.41	2.10	1.75	0.17	0.93	0.91	0.93	0.79	1.05	0.76	0.66
Oceania	0.67	0.29	1.51	1.18	0.73	0.75	0.64	0.35	0.47	0.24	0.52	0.34
Japan	0.42	0.16	0.58	0.58	0.65	0.39	0.40	0.35	0.45	0.17	0.44	0.16
Central America	0.39	0.20	0.10	0.14	0.51	0.40	0.28	0.22	0.60	0.50	0.80	0.34
South America	0.53	0.17	0.48	0.45	0.57	0.56	0.44	0.27	0.69	0.54	0.86	0.43
Northern Africa	-0.07	0.29	-0.60	-0.41	-0.26	-0.18	0.08	-0.02	0.23	0.33	-0.26	0.43
Western Africa	-2.32	2.39	-8.22	-7.47	-0.63	-0.51	-2.80	-2.14	-0.61	-0.76	-0.63	0.64
Eastern Africa	-3.11	3.37	-11.32	-10.32	-0.36	-0.29	-4.62	-2.32	-0.35	-0.78	-0.36	-0.42
Southern Africa	-0.26	1.27	0.61	0.23	-1.87	-0.95	0.96	0.01	-0.20	-1.31	-1.86	1.84
Middle East	1.44	0.27	1.85	1.57	1.39	1.51	1.40	1.15	1.17	0.99	1.92	1.41
South Asia	-0.49	0.40	-1.78	-1.31	-0.24	-0.49	-0.41	-0.17	-0.23	-0.17	-0.24	0.14
East Asia	0.28	0.09	0.20	0.30	0.11	0.26	0.32	0.39	0.23	0.23	0.39	0.33
South East Asia	0.10	0.28	-0.32	-0.12	-0.10	-0.24	0.22	0.10	0.66	0.26	0.14	0.40
World	0.34	0.04	0.34	0.34	0.39	0.35	0.33	0.32	0.38	0.27	0.39	0.33

2025, S650e	Average	Std. Dev.	CSE	GC	AP	BP	MS	EIT	TT	GF	C&C	MCC
Canada	0.19	0.14	0.32	0.31	0.31	0.37	0.21	0.15	0.08	-0.09	0.14	0.08
USA	0.13	0.10	0.34	0.32	0.22	0.14	0.12	0.07	0.05	0.03	0.06	-0.02
OECD Europe	0.09	0.07	0.14	0.11	0.16	0.21	0.09	0.03	0.04	0.06	0.04	-0.01
Eastern Europe	0.00	0.06	0.15	0.08	0.01	0.06	0.00	-0.03	0.00	-0.12	-0.04	-0.08
Former USSR	0.19	0.12	0.50	0.41	0.13	0.30	0.17	0.10	0.10	0.07	0.08	0.03
Oceania	0.09	0.15	0.32	0.30	0.16	0.18	0.11	-0.02	0.01	-0.20	0.05	-0.01
Japan	0.10	0.07	0.15	0.11	0.18	0.21	0.10	0.04	0.06	0.05	0.06	0.01
Central America	0.01	0.07	-0.03	-0.02	-0.10	-0.07	0.05	0.08	0.03	0.09	0.03	0.05
South America	0.06	0.06	0.05	0.06	0.14	-0.06	0.09	0.07	0.06	0.14	0.04	0.04
Northern Africa	-0.08	0.07	-0.26	-0.21	-0.05	-0.09	-0.03	-0.05	-0.09	-0.03	-0.02	0.06
Western Africa	-0.64	0.67	-2.88	-2.09	-0.12	-0.23	-0.09	-0.04	-0.43	-0.09	-0.58	0.14
Eastern Africa	-0.90	0.96	-3.93	-2.98	-0.07	-0.13	-0.05	-0.10	-0.40	-0.05	-1.11	-0.23
Southern Africa	-0.02	0.21	-0.14	0.13	-0.12	-0.25	-0.09	-0.15	-0.12	-0.09	0.22	0.40
Middle East	0.29	0.21	0.37	0.42	-0.06	0.72	0.19	0.14	0.22	0.29	0.29	0.29
South Asia	-0.13	0.15	-0.53	-0.47	-0.04	-0.08	-0.03	-0.04	-0.05	-0.03	-0.08	0.04
East Asia	0.01	0.07	0.05	0.01	-0.11	-0.10	-0.03	0.01	0.07	0.08	0.05	0.05
South East Asia	-0.03	0.06	-0.13	-0.12	-0.04	-0.08	-0.08	-0.03	0.02	0.01	0.04	0.08
World	0.04	0.01	0.04	0.04	0.06	0.07	0.05	0.03	0.04	0.05	0.04	0.04

XX	costs 4 times world average
XX	costs 2 times world average
XX	costs 20% above world average
XX	costs about world world average
XX	costs less than 80% world avg
XX	low gains (50% world average)
XX	average gains less world average
XX	high gains 2 times world average
XX	very high gains 3 times world avg
value	absolute change in contribution

Note: The sequence of the regimes is similar to those in table 8. The first and second columns give the average and the standard deviations of the effort rates for the ten regimes per region.

sion scenario chosen and the climate target set, as analysed in earlier studies [30,79]. Therefore, we should be careful about drawing conclusions with respect to regimes on the basis of the quantitative outcomes presented. Moreover, in practice, regime proposals will be evaluated on the basis of a much wider set of considerations. This can be done through a qualitative multi-criteria analysis to identify relative strengths and weakness of the regime approaches examined on the basis of environmental criteria, political criteria, economic criteria and technical criteria (e.g., [23,42]).

5. Conclusions

This article describes the policy decision-support tool FAIR 2.0. The model aims to assess the environmental and abatement costs implications of post-2012 regimes for differentiation of future commitments, as proposed over the last ten years in academic circles, non-governmental organisations and by Parties to the UNFCCC. The model also allows for a consistent and quantitative comparison of various regime proposals, i.e. about ten allocation-based, unilateral approaches.

The modelling approach presented has several strengths and weaknesses, as previously discussed. The main strengths are: (i) that the integration of the climate model allows to determine the direct climate impacts of the different emission profiles and baseline scenarios, taking into account the uncertainties on the climate sensitivity; (ii) that this approach allows to compare environmental and costs implications for the different world regions considering that the model includes many approaches for differentiation of commitments in international climate policy-making, already proposed in academic, non-governmental and policy circles; (iii) that the model provides a full, and detailed, description of the different sources of GHG emissions and their abatement options and potential, allowing for full flexibility in substitution between abatements of the sources, gases and regions; (iv) that the description of costs of climate policies using the approach based on marginal abatement cost curves is transparent and flexible, allowing for a description of emissions trading, including possible limitations in the use of the flexible instruments (e.g., transaction costs and accessibility of reduction options).

The main weaknesses of our approach are that: (i) the costs calculated only represent the direct-cost effects based on MAC curves, but not the various linkages and rebound effects via the economy or the impacts of carbon leakage; (ii) the model uses GWPs to determine total CO_2-equivalent emission levels and a cost-effective distribution of the different reduction options. Although this GWP concept has some shortcomings, it is, at the same time, completely consistent with the way climate policies are currently formulated (e.g., Kyoto Protocol); (iii) furthermore, as the model combines different sets of MAC curves from different sources, not all interactions and co-benefits are taken into account.

The second part of this article analyses the environmental and mitigation cost implications of ten regimes (all included in the FAIR model) for two constrained global emission profiles compatible with long-term stabilising atmospheric greenhouse gases concentrations at 550 ppmv and 650 ppmv CO_2-equivalent. The ten regimes act as effective schemes to systematically derive emission targets on the basis of principles of fair distribution of emission reduction obligations. The key difficulty in designing long-term post-2012 regimes is, of course, related to the acceptability of the corresponding emission reduction targets to the different Parties. The regimes should not lead to extreme results (for example, when regional costs as percentage of GDP far exceeds the world average costs), or be particularly (un)attractive in terms of reductions for certain Parties only.

Comparing the resulting reduction targets showed that the Global Compromise and CSE convergence, but also that the Ability to Pay approach are the most attractive approaches for most non-Annex I regions. On the other hand, the Multi-criteria Convergence and Grandfathering approach are the most attractive for the Annex I regions. The Emission Intensity Target approach is, in general, attractive to the OECD regions with relatively low emission intensities, in particular, for OECD-Europe and Japan. The Multi-Stage and the Triptych approach and to a lesser extent, the C&C approach, have a kind of middle position in terms of reduction targets compared to the other regimes. 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.

With respect to the abatement costs, four groups of regions with similar costs were already identified in earlier studies exploring a smaller set of regimes, and emphasised in the more in-depth analysis presented here. From this perspective, it can be concluded that for the Annex I regions, excluding the FSU (group 1), the Multi-Stage and Contraction & Convergence are attractive regimes, whereas the Global Compromise, CSE convergence and, to a lesser extent, the Brazilian Proposal are unattractive. For the Middle East & Turkey, the FSU and, to a lesser extent, Latin America (group 2), all regimes seem unattractive, since all lead to high costs, in particular the Global Compromise. For South-East Asia, East Asia, Northern Africa and in particular Southern Africa (group 3), Contraction & Convergence can be less attractive than approaches with income thresholds (the Multi-Stage and the Brazilian Proposal). For Western- and Eastern Africa and South Asia (group 4), all regimes seem attractive, in particular those where the allowable emission levels are higher than the baseline emissions (excess emission allowances) as under Contraction & Convergence, CSE convergence and Global Compromise.

Here, the conclusion can be drawn that for both the reduction targets and the abatement costs, the Multi-Stage and the Triptych approach, and to a lesser extent the C&C, seem to result in, relatively speaking, the most even distribution of costs amongst all Parties, and therefore will seem to provide the best prospects for a negotiation outcome based on compromises of all Parties. However, although for some regions the reduction targets seem moderate, the abatement costs can be quite high. Therefore, in assessing regional reduction objectives for different regime approaches, an in-depth analysis of the accompanying costs is required if disproportional results are to be identified and avoided.

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