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SEVENTH FRAMEWORK PROGRAMME

LIMITS Special Issue on Durban Platform scenarios

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Massimo Tavoni(1)*, Elmar Kriegler(2), Tino Aboumahboub(2), Kate Calvin(3), Gauthier De Maere(1), Jessica Jewell(4),Tom Kober(5), Paul Lucas(6), Gunnar Luderer(2), David McCollum(4), Giacomo Marangoni(1), Keywan Riahi(4), Detlef van Vuuren(6)

Affiliation:
(1): Fondazione Eni Enrico Mattei (FEEM) and Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), Corso Magenta 63, Milan, Italy
(2): Potsdam Institute for Climate Impact Research (PIK), P.O. Box 60 12 03, 14412 Potsdam, Germany
(3): Pacific Northwest National Laboratory (PNNL), College Park, MD, USA
(4): International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, 2361 Laxenburg, Austria
(5): Energy research Centre of the Netherlands (ECN), Westerduinweg 3, 1755 LE Petten, The Netherlands
(6): PBL Netherlands Environmental Assessment Agency, Bilthoven, The Netherlands

** Corresponding author: massimo.tavoni@feem.it; +39 02 52036936*

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The distribution of the major economies' effort in the Durban platform scenarios

Abstract

The feasibility of achieving climate stabilization consistent with the objective of 2°C is heavily influenced by how the effort in terms of mitigation and economic resources will be distributed among the major economies. This paper provides a multi-model quantification of the mitigation commitment in ten major regions of the world for a diversity of allocation schemes. Our results indicate that a policy with uniform carbon pricing and no transfer payments would yield an uneven distribution of policy costs, which would be lower than the global average for OECD countries, higher for developing economies and the highest, for energy exporters. We show that a resource sharing scheme based on long-term convergence of per capita emissions would not resolve the issue of cost distribution. An effort sharing scheme which equalizes regional policy costs would yield an allocation of allowances comparable with the ones proposed by the Major Economies. Under such a scheme, emissions would peak between 2030 and 2045 for China and remain rather flat for India. In all cases, a very large international carbon market would be required.

JEL classification number: Q54, F53

Keywords: climate change economics, equity, burden sharing, regional mitigation costs, integrated assessment models

1. Motivation and study design

In spite of the accelerating trend of climate change, no significant progress in international climate policy-making has been observed over the past few years. This has led many analysts and policy-makers to focus on more bottom-up and decentralized approaches to climate change mitigation, which try to reconcile emissions reductions with national and subnational objectives such as economic growth, pollution reduction, and energy security, or provide alternatives to mitigation such as adaptation and geo-engineering. Though such approaches are likely to dominate the political agenda for climate change mitigation in the next few years, the discussion about coordinated action to reduce greenhouse gas emissions will ultimately remain a central one. This is because harmonizing mitigation effort is crucial for ensuring that climate change is tackled efficiently and effectively.

In the next few years, international climate policymaking will be focused on the negotiation process under the Durban platform for enhanced action. This platform provides an interesting opportunity for discussing post-2020 emission reduction commitments beyond the traditional divide of developed versus developing countries. A refocus on the major economies might help achieve more than expected, and calls for new thinking about the best policy instruments which can be put into place to provide adequate incentives to join the coalition. Climate clubs are known to increase the likelihood of the stability of the international agreement, but the need for coordination and for transfer payments will remain a pre-requisite for the coalition to be effective. Global cooperative action implies that some regions with larger mitigation potential undertake a greater mitigation effort to achieve the cheapest global solution. Forming a coalition on climate action will therefore require some form of burden sharing mechanism, which would compensate such countries for the extra costs of CO_2 policies.

Integrated assessment models are extensively applied to assess the global implications and the interactions of climate mitigation policies, and they play an increasing role in the scientific debate about climate change mitigation. Since models vary considerably in the assumptions and methodologies, multi-model ensembles have emerged in the past few years as the best way to identify insights which are robust across a range of assumptions and methodologies. Several of these assessments have included climate stabilization policies which are compatible with maintaining global temperature increase below 2°C (Clarke et al., 2009; Edenhofer et al., 2010; Kriegler et al., Submitted), quantifying the mitigation effort in terms of changes of the energy and land use system, and of their impacts on economic growth. However, few coordinated studies have set forth to assess the distribution of this effort across the major economies for different ways of sharing the mitigation commitments (see below for a literature review). The LIMITS study aims to fill this gap.

Study design

The LIMITS project (http://www.feem-project.net/limits/), which has led to this article and to the overall special issue, has taken on as one of the objectives the issue of regional burden sharing. To this end, a set of coordinated scenarios have been simulated by six integrated assessment models (see the editorial article and the article by Kriegler et. al of this special issue for a detailed description of the participating models). Table 1 summarizes the 4 scenarios, which will provide the backbone of the analysis for this paper. More information about the assumptions underlying each scenario is provided in Table SO1 in the supporting online material.

Scenario Type	Near-term Target / Fragmented Action	Fragmented Action until	Long-term Target / Global Action	Burden Sharing Scheme	NAME in the paper

Baseline	None	N/A	None	None	Base
Climate Policy	Weak	2020	450 ppm CO_2-eq	None	RefPol-450
Climate Policy	Weak	2020	450 ppm CO_2-eq	Per Capita Convergence	RefPol-450-PC
Climate Policy	Weak	2020	450 ppm CO_2-eq	Equal Mitigation Efforts	RefPol-450-EE

Table 1: Scenarios relevant for this paper

The Base scenario is a counterfactual baseline development without climate policy against which climate policy scenarios are evaluated. It portrays a pessimistic view of the future in which no climate change mitigation is carried out, and also in which energy policies are extremely limited. In the project we have also considered two additional 'reference' scenarios, with varying degrees of climate and energy policies; but for simplicity this paper will take as reference the counterfactual baseline. The interested reader is referred to (Kriegler and al., 2013, this issue) for further information.

The RefPol-450 is a scenario which aims at stabilizing climate at a level which would ensure to attain the 2°C objective with a relatively high probability (>60-70%). In particular, the equivalent concentrations of greenhouse gases in the atmosphere are set in 2100 at 450 ppm CO_2-eq. This target can be exceeded before 2100, leading to an overshoot of concentrations. The policy is implemented starting immediately after 2020 (thus, 2025/2030 depending on the model time resolution) via a carbon price which is applied uniformly to all regions and which covers all greenhouse gases. Fragmented action with different regional commitments is implemented before the policy kicks in. This scenario represents the standard cost efficient solution after 2025 with equalization of marginal abatement costs throughout the world and no distribution of emission allowances. No trade of carbon across regions is thus foreseen in this scenario[1].

In order to include the possibility of burden sharing, the multi model ensemble has considered two additional scenarios which can be categorized as *'resource-sharing'* and *'effort-sharing'* respectively (see den Elzen and Höhne (2008, 2010) for a overview of allocation approaches).

[1] Equivalently, this scenario can be seen as one in which allowances are allocate to regions equally to their cost effective abatement levels. As a consequence, there is no incentive to trade.

The RefPol-450-PC is based on a *resource sharing* allocation scheme in which emission rights are eventually allocated according to equalized GHG emissions per capita, This regime is based on both the sovereignty and egalitarian equity principles (Rawls, 1999). The convergence to the per capita equalization of emission rights takes place from 2020 onwards and is attained by 2050. The regional shares of global emissions are calculated according to the following linear interpolation schedule:

$$\frac{E_r(t)}{E_w(t)} = \frac{T_2-t}{T_2-T_1} * \frac{E_r(T_1)}{E_w(T_1)} + \frac{t-T_1}{T_2-T_1} * \frac{P_r(t)}{P_w(t)} [1]$$

Er(t): Regional emissions allowances in time step t

Ew(t): World emissions in time step t

Pr(t): Regional population in time step t

Pw(t): World population in time step t

T1: Reference year for grandfathering (here: 2020)

T2: Target year for convergence (2050)

In addition, we have investigated an *effort-sharing* scheme in which relative climate policy costs are equalized across regions, RefPol-450-EE. This means that at every point in time (from 2025/2030 onwards) all regions within each individual model incur the same policy costs as the global average, ensuring a flat distribution of effort. Policy costs are calculated as percentage of consumption losses from baseline over GDP for macro-economic models, and as mitigation costs (measured as the area under the Marginal Abatement Cost curve or as the additional energy system costs) plus net gains or losses due to permit trading over GDP for energy system models. The following formula summarizes the equal effort rule:

$$\left(\frac{C_r}{Y_r}\right)_{\boldsymbol{t}} = \left(\frac{C_w}{Y_w}\right)_{\boldsymbol{t}} \qquad \forall \boldsymbol{t} \in \{\mathbf{2020}, \mathbf{2030}, \dots, \mathbf{2100}\} [2]$$

C_r: Regional absolute policy costs

C_w: World absolute policy costs

Y_r: Regional GDP

Y_w: World GDP

This allocation scheme represents a novel contribution of this project to the literature, with the exception of Harrison and Rutherford, 1999. The scheme does not attempt to resolve the difficult ethical questions which characterize burden sharing, such as who is responsible for historical emissions and who is likely to suffer the most damage from climate change. Indeed, the equal effort scheme might be seen as unjust from the perspective of those countries – many of which developing ones- which have or will contribute to the climate change problem to a limited extent, or which will suffer most of its adverse consequences. The value of the equal effort scheme is to provide a reference level in terms of emission allocations for which no region is worse off than any other in terms of mitigation costs relative to economic output. It provides a reference for a "level playing field" in which all countries take on similar mitigation costs. This means that countries who fare worse under GHG mitigation (such as energy exporters who lose export revenue) are compensated for their losses through a global carbon market. The outcome of this scenario will be a set of emission allocations which are model-dependent, since different models are likely to foresee a different regional distribution of costs.

All three schemes represent idealized policy contexts, none of which will be entirely implemented, even in the rosiest outcome of international climate policies. This simplicity however allows us focusing on the key elements. The approach taken in this paper reflects the importance of including three key elements which have been dubbed as essential for an effective international climate policy: "a framework to ensure that key industrialized and developing nations are involved in differentiated but meaningful ways, an emphasis on an extended time path for emissions targets, and the inclusion of flexible market-based policy instruments to keep costs down and facilitate international equity" (Olmstead and Stavins, 2012).

Throughout the paper, we show results for 10 representative regions (see Box1 in the supporting information for a detailed description of these regions). The choice of regional aggregation is not an univocal one, since different models have different native regions. The one adopted here has been chosen with the aim of best mapping all models native regions into 10 representative regions, but approximations for some specific regional compounds was unavoidable.

Relation to the literature

Effort sharing refers to a differentiation of commitments of reducing global greenhouse gas emissions to avoid dangerous climate change. In general, approaches are based on some sort of equity principle in accordance with their common but differentiated responsibilities and respective capabilities (UNFCCC, article 3). See Ringius et al. (2002), Rose et al. (1998) and Berk and den Elzen (2001) for a discussion of different equity principles. Many effort-sharing approaches have been proposed and discussed in the literature, each with different participation levels, timing of reductions, as well as stringency and type of commitments (See an overview of proposals in e.g. Bodansky, 2004; Gupta et al., 2007; Kameyama, 2004; Philibert, 2005). The equal effort scheme proposed in this paper (RefPol-450-EE) can be related to the GreenHouse development right framework (Baer et al., 2009). The framework allocates emission reductions based on an index, which encompasses both historic responsibility and economic capacity, whereas in this paper we focus only on the latter. Other papers have proposed and tested burden sharing schemes based on the division of effort across members (see Elzen and Höhne (2008, 2010) (Ekholm et al., 2010)).

Furthermore, there is a broad literature on the environmental and economic impacts for specific countries or world regions of such approaches. See for example den Elzen and Lucas (2005) for an assessment of a broad range approaches using the FAIR model, den Elzen and Höhne (2008, 2010) for a meta-analysis of scientific literature focussing on Annex-I and non Annex-I reductions requirements and van Ruijven et al. (2012) for a meta-analysis of the scientific literature focussing reduction requirements and cost implication for China and India. However, few studies have looked at effort sharing in the context of a multi model ensemble. Existing studies include Edenhofer et al. (2010) and Johansson et al. (submitted) who discuss a single regime using different global and national models. While Edenhofer et al. took a global perspective, Johansson et al. focused on China and India only. Luderer et al (2012) investigated four distinct burden sharing regimes with three global models, but concentrated on a stabilization target which is laxer than the one assessed here. They showed that regional mitigation costs are highly dependent on the choice of model and regime, pointing to the need for further research on regional mitigation costs and compensation mechanisms.

The equal effort scheme proposed in this paper can be related to the Greenhouse development right framework (Baer et al., 2009). The framework allocates emission reductions based on an index, which encompasses both historic responsibility and economic capacity, whereas in this paper we focus only on the latter. Other papers have proposed and tested burden sharing schemes based on the division of effort across members (see Elzen and Höhne (2008, 2010) (Ekholm et al., 2010)). An important difference, however, is that the equal effort scheme analysed here is distributes the effort in terms of mitigation costs, while virtually all other approaches proposed in the literature distribute the effort in terms of emission reductions relative to baseline, or distribute the remaining permissible emissions.

Main questions to be addressed

This paper will address the following three main issues:

1. In order to ensure economic efficiency and minimize costs, a policy framework which harmonizes carbon pricing across regions is ideal. But what are the consequences of this arrangement for the distribution of costs between regions? In other words, who are the regional winners and losers in a “cost-effective” set up without regional side payments? We will tackle this issue in Section 2.
2. Alleviating the distributional implications of climate policies while retaining economic efficiency will invariably require allocating different regions with different endowments of carbon permits. What would be the distribution of emission endowments if either the carbon space or the economic effort were shared equally across regions? And to what extent do different endowments of permits mitigate the diverse distribution of effort in terms of mitigation and costs? We will look into this in Section 3.
3. Allocating permits would create endowments which would be traded and distributed across regions, and which would require establishing a global market for CO_2. What would the size of this market be, and which positions each region take with respect to net permit-trading? Section 4 will focus on this.

The final section will conclude and highlight future research avenues. Throughout the paper, we will examine the implications of 10 major countries which cover the whole world. This regional aggregation has been designed to best match the different native regional details across models, which is relatively coarse in terms of spatial disaggregation. The regional definition can be found in the supporting online material.

This paper is related to the other overview article of the special issue of the LIMITS project (Kriegler and al., 2013).. The paper by Kriegler and al., 2013 provides an in depth evaluation of the Durban scenarios with a focus on emissions reduction requirements, the consistency with the 2˚C target and global economic impacts, whereas this article is centred around the discussion of the regional costs under different ways of sharing the burden of the climate policy.

2. The diversity of effort across regions in a cost minimizing setting without compensation

It is instructive to start from a framework in which each region undertakes mitigation based on the same incentive to abate carbon, but without the establishment of a market for GHG emissions endowments. This is the setting of the carbon tax scenario RefPol-450. Pricing carbon equally across regions ensures that the ideal mitigation options are picked irrespectively of where they are located, and that as a result the most efficient outcome is achieved globally. In a world of scarce resources and limited political capital for the cause of climate change, it seems that cost containment should be a top policy priority. However, this method is blind to the issue of distribution of costs; in principle, if a region hosted all the cheaper abatement options (even at the margin), it would carry out the totality of abatement, and face all the costs.

Indeed, the distribution of the mitigation effort –measured in costs- of a carbon tax scenario is quite unevenly distributed, as shown in Figure 1[2]. The chart emphasizes a significant variation of policy costs across regions, and across models in some instances, but reveals a rather clear three-tier pattern. Advanced economies such as Europe, US and Pacific OECD bear a cost which is lower than the global average. Fast growing economies, including Latin America, Southeast Asia, India and Africa, pay a larger fraction of the cost. Finally, energy-exporting countries like Russia and the Middle East bear a policy costs which can be several times the global one[3].

[2] Throughout the paper policy costs are calculated in accordance with equation 2. They are consumption losses over GDP for models with a macro-economic component (MESSAGE; REMIND; WITCH). For REMIND, mitigation costs include, in addition to consumption losses, changes net foreign assets due to changes in current accounts induced by climate policy (for more information, see Aboumahboub et al., this issue). Abatement costs over GDP are used for AIM-Enduse, IMAGE and GCAM, and energy system costs over GDP is used for TIAM-ECN. GDP is expressed in market exchange rates (MER) for all models except TIAM-ECN, who uses purchasing power parity (PPP).

[3] The only model which does not show this last effect is TIAM-ECN. This is due to the assumption about trade of physical CO_2 in the model (though this possibility is also allowed in the GCAM model). This additional element of flexibility provides a source of revenue to energy exporting countries, who can count on a large storage potential, and thus can, at least partly, compensate reduced revenues from decreasing fossil fuel exports by providing CO_2 storage capacity to other regions. For more information see Kober et. al. 2013, this issue.

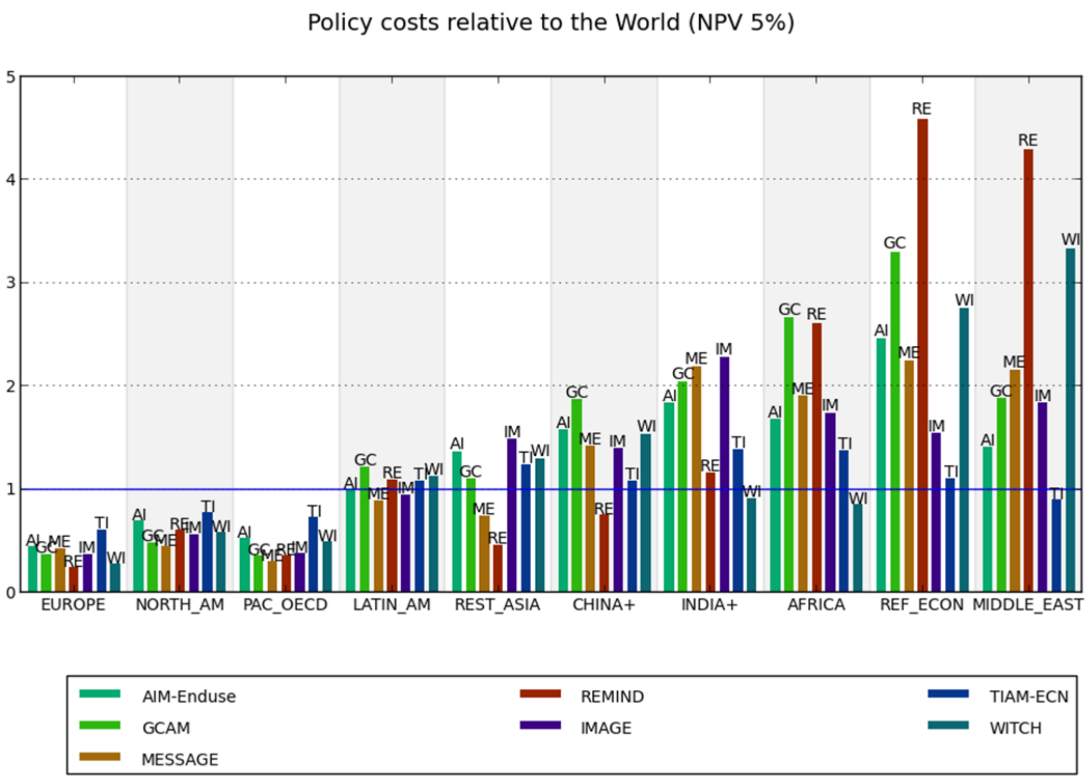

Figure 1: The uneven distribution of regional policy costs. The chart shows regional policy costs across models in the carbon tax scenario (RefPol-450), relative to the global level (indicated by the blue line at 1). Costs (see Footnote 3) are actualized in Net Present Value (NPV) from 2020 to 2100 using a 5% discount rate.

The regional discrimination in terms of economic effort to achieve a 2°C climate change control target via a uniform carbon tax policy instrument is robust to different cost metrics. As Table 2 indicates[4], the regional ordering is almost unchanged when measuring costs in a variety of different ways[5]. *OECD* remains the ones *below global costs; fast growing economies* are generally *above global costs*; and *energy exporting* countries are *well above global costs*. The use of different discount rates suggests that this ranking is rather persistent over time.

	NPV_5	NPV_3	NPV_0	max2050	max2100	NPV_5

[4] Note that Table 2 displays averages across participating models. Though models project different distribution of costs because of different assumptions, as shown in Figure 1 the ranking of the regions is quite robust across models. The use of averages is thus justified.

[5] The regional difference is less evident for the PPP case, though the ranking remains unchanged. However, given the different cost metric and different set of models included, the values in this column cannot be directly compared to the other columns.

						PPP
MIDDLE_EAST	2.6	2.5	2.3	2.3	2.3	1.1
REF_ECON	3.0	3.0	3.1	3.0	3.5	0.9
AFRICA	2.1	1.9	1.6	1.6	1.4	1.2
INDIA+	2.0	1.7	1.5	1.4	1.4	1.2
CHINA+	1.6	1.5	1.3	1.5	1.4	0.8
REST_ASIA	1.3	1.2	1.1	1.1	1.2	0.8
LATIN_AM	1.2	1.2	1.1	1.1	1.2	0.7
NORTH_AM	0.7	0.7	0.8	0.8	0.9	0.5
PAC_OECD	0.5	0.6	0.7	0.7	1.1	0.4
EUROPE	0.5	0.5	0.6	0.5	0.7	0.4

Table 2: Robust ordering of regional costs. The table reports policy costs relative to the global average (as in Figure 1) for different cost metrics. Figures are average across models. Npv_5, npv_3 and npv_0 are NPV calculations of costs in the period 2020-2100 at yearly discount rates of 5%, 3% and 0% respectively. Max_2050 and max_2100 is the maximum costs in the periods 2020-2050 and 2020-2100. In the last column, costs are calculated based on PPP GDP[6] (for the models reporting it, IMAGE, MESSAGE, and TIAM-ECN). Red colouring is used for costs above global average (e.g. >1) and blue colouring for below the global average (e.g. <1).

There are various reasons why policy costs differ so widely across regions. And given the given the characteristics of the group of countries identified above, likely candidates include variables which characterize regional economic and energy/land use systems, such as: *economic growth, energy intensity, fossil energy trade exposure, low carbon resources*.

Table 3 provides a decomposition of regional costs to such factors. We use a simple linear regression in which regional policy costs (in log) are explained by abatement, total emissions in the BAU, the energy intensity of the economy, and dummies for groups of regions (EEX and Developing Countries) and for general equilibrium versus

[6] Given the different cost metric and different set of models included, the values in this column cannot be directly compared to the other columns.

partial equilibrium models[7]. In order to control for the potential multi-collinearity of the explanatory variables, different specification are reported[8].

The results of the regression show that relative abatement, as well as the size of regional BAU emissions and energy intensity, are significant and all affect policy costs positively. When controlling for modelling and regional differences, the coefficient of baseline emissions becomes more significant and higher. This is mostly due to the fact that developing countries have a larger size (see specification 4). Energy intensity is not significant with the full specification (number 2), because of its relation with the energy exporting dummy variable (see the specification number 3).

The results of the dummy variables also confirms the intuition: General Equilibrium models are found to be more expensive compared to the other models (and not to be statistically different from each other)[9], due to larger feedback of the energy sector on the economy[10]. For bottom up, partial equilibrium models, IMAGE and MESSAGE are cheaper than GCAM[11], and TIAM-ECN is not significantly different. Finally, regional patterns are also identified: energy exporting countries show have policy costs which are statistically higher than the ones in the OECD[12], highlighting the role of terms of trade effects for these regions.

	(1) Cost (log)	(2) Cost (log)	(3) Cost (log)	(4) Cost (log)
Abatement	3.112***	3.528***	3.247***	3.065***
	(9.42)	(12.25)	(10.35)	(9.26)
Emi_BAU	0.296*	0.638***	0.410**	0.293*

[8] Correlation between coefficients is at any rate rather modest, never exceeding 0.5-

[9] The dummy for WITCH has been automatically dropped from the regressions. Thus, the coefficient for REMIND must be interpreted as relative to WITCH.

[10] MESSAGE is treated as a 'partial equilibrium' model despite its link to a macro-economic module, and the fact that policy costs are calculated as consumption losses, similarly to WITCH and REMIND. But the economic module is not hard linked as in WITCH and REMIND, and the model is linear, and it has a more detailed representation of the mitigation technologies.

[11] The dummy for GCAM has been automatically dropped from the regressions. Thus, the coefficient for the other bottom up models must be interpreted as relative to GCAM.

[12] The dummy for the OECD has been automatically dropped from the regressions. Thus, the coefficients for EEX and DCs must be interpreted as relative to the OECD.

	(2.01)	(4.39)	(2.69)	(2.09)
Enint_BAU	86.81***	-21.58	105.5***	
	(6.48)	(-0.89)	(7.26)	
IMAGE		-0.543**	-0.0942	-0.548**
		(-3.06)	(-0.48)	(-2.80)
MESSAGE		-0.625**	-0.252	-0.558*
		(-3.20)	(-1.14)	(-2.38)
REMIND		-0.0110	-0.0791	-0.0127
		(-0.07)	(-0.41)	(-0.05)
TIAM-ECN		0.224	-0.0532	0.103
		(1.45)	(-0.35)	(0.65)
GE		0.534**	0.937***	0.592**
		(3.15)	(5.31)	(2.87)
DC		0.285	-0.271	
		(1.91)	(-1.95)	
EEX		1.664***		

		(6.49)		
Constant	-3.364***	-3.634***	-3.717***	-2.807***
	(-12.34)	(-13.55)	(-13.35)	(-9.89)
N	227	227	227	227
adj. R^2	0.463	0.671	0.588	0.505

t statistics in parentheses (based on robust standard errors)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Results of the linear regression of the log of policy costs (NPV 5%) with respect to abatement (cumulative to 2100 and relative to the BAU), total emissions in the BAU (cumulative to 2100), and the energy intensity of the economy (computed from cumulative values as well). Some of the 4 specification also include a dummy variable for energy exporting countries (EEX) and one for developing countries (DC), as well as a dummy for the two general equilibrium models WITCH and REMIND (GE). The regression has been done on 4 scenarios (2 policy baselines and 2 climate stabilization targets) in the LIMITS data set[13].

We further elaborate on energy exporting countries in Figure 3, which shows the effect of stabilization on energy export revenues. All the models show that there is a decrease in energy export revenues for the Middle East and Reforming Economies. However, while the effect on export revenue as a proportion of GDP is fairly consistent for the Middle East region, the results for the Reforming Economies differ by an order of magnitude. Export revenues for the Middle East drop by between 14 and 48 trillion dollars over the century or 1% and 6% of GDP. For the Reforming Economies, most models agree that the drop in export revenues would be between 0.4 and 3 trillion dollars or 1% and 6% over the century[14].

[13] The two policy baselines represent two scenarios with moderate and stringent policies, based on extrapolation of the Copenhaghen pledges. The two climate stabilization targets are the 450 ppm-eq considerated in this paper, as well as a 500 ppm-eq. See Kriegler et. al 2013, this volume, for the description of the scenarios. The database has 6 models, 4 scenarios and 10 regions, yielding a total of 240 observations, of which only 227 are included, given that negative policy costs have been dropped when taking the logarithm.

[14] ReMIND is a clear outlier. Its Reforming Economy region only includes Russia which according to ReMIND would lose over 5 trillion dollars of 20% of the region's GDP from lost export revenues. This high drop is due to the fact that in ReMIND the baseline leads to a high proportion of gas use (and as a result gas trade), which is primarily supplied by Russia. In contrast,

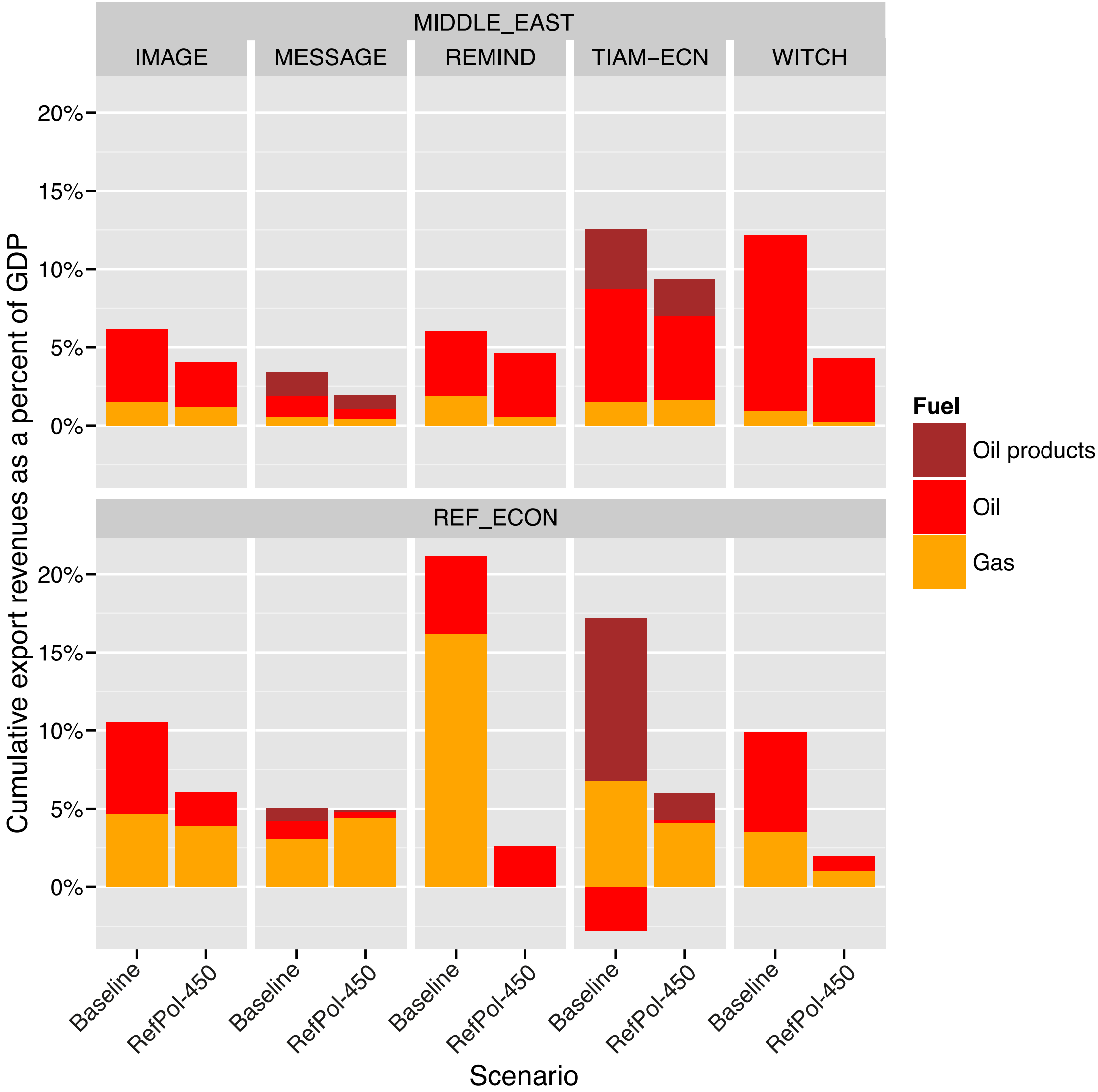

Figure 3: Energy export revenue for the Middle East and the Reforming Economies in BAU versus RefPol-450.

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under ReMIND's 450 scenarios, gas is phased out by the end of the century and the region does not benefit from these export revenues.

3. The impact of different emission allocation schemes on the distribution of allowances and the policy costs.

The previous section has highlighted the regional variation in economic costs mitigation in a setting where carbon is priced efficiently but which does not allow for compensating the mitigation effort. The results highlight a tension between efficiency and equity. As standard in economics, this tension can be alleviated by designing an appropriate market for emissions which allows for financial transfers between countries. In a world with no transaction costs and perfect markets, as is the one normally represented by integrated assessment models, the creation of endowments of carbon allowances and the possibility to freely exchange them allows to perfectly separate efficiency and equity. This independence property, originally formulated in (Coase, 1960), is particularly convenient when analysing international climate regimes, despite its limited predictive power. There are many reasons why the Coase theorem might not perfectly hold in practice. These include transaction costs, market power, institutional and political factors, etc. See (Hahn and Stavins, 2010) for a review of the relevance of these factors.

This section focuses on the two burden sharing schemes analysed in the LIMITS project, the per capita convergence and the equal effort schemes. It quantifies the initial allocations of permits associated with those, in relation to the cost effective emission reductions. This comparison is shown in Figure 4, for the year 2030. The chart shows that OECD countries would receive a higher GHG reduction obligation, compared to their optimal mitigation level, for both the resource and effort sharing schemes. This result for effort sharing is intuitive since as we have shown previously the carbon tax scenario induces lower mitigation costs in the industrialized regions; the chart makes the additional point that the OECD emission reductions in the tax scenarios are also lower than the ones prescribed by the Rawlsian principle of equality of carbon space in the atmosphere. Given their fast growing economies and associated emissions, Latin American and Asian countries have to undertake to less stringent mitigation to current levels in the tax case and the burden sharing regimes (but not necessarily to their baseline). The three allocation schemes show relatively similar commitments for these regions, with the noticeable exception of China: the per capita convergence scheme appears to be particularly disadvantageous to China, which would receive an allocation which is below todays values already in 2030 (and significantly so). The resource sharing per capita scheme is also quite stringent for the energy exporting countries in 2030, while the opposite holds for the equal effort, since as we have seen in the previous sections these regions incur the highest mitigation costs, and would need to be compensated when aiming at an equalization of mitigation efforts.

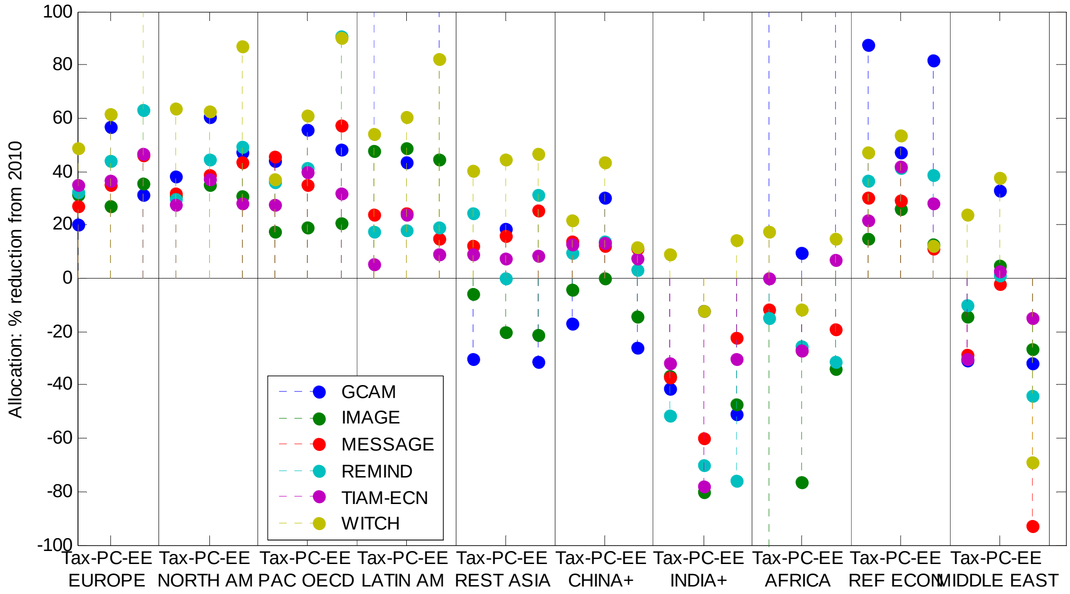

Figure 4: Allocation of allowances for the three different sharing scenarios (Tax, Per Capital convergence, and Equal Effort). Emissions allocations are expressed in reductions in 2030 from 2010 values. The scale of the y-axis has been limited at +/-100%[15].

The variation across models reflect different regional assumptions about baseline emissions, global emissions pathways consistent with the 2°C objective, and regional abatement potential (see also van der Zwaan et al., 2013, this issue). This is especially important for models which foresee large mitigation potential already early in the century for specific parts of the world: for example GCAM finds allowances reductions from todays' levels which largely exceed 100% for regions like Latin America and Africa, which are endowed with large biomass potential and can achieve significant net negative emissions already in 2030 due to massive reforestation programmes in the tropics.

The econometric analysis in the previous section has indicated relative abatement from baseline to be the most important explanatory variable for policy costs, all other things equal. In order to understand the economic implications of the burden sharing schemes, it is thus instructive to look into the distribution of allocation across schemes and time. Table 4 reports how the allocation effort is distributed, showing a high level of agreement across models. In the per capita scheme, the allocation effort would be beard in a similar way between OECD countries, China and the energy exporting countries. Developing countries with current low per capita emissions, such as Africa

[15] Some of the outliers show an allocation of net negative emissions in 2030. This is due to assumptions – most notably in the GCAM model- about large mitigation potential in the tropics via afforestation practices.

and India, would get a less stringent target, but only in the first half of the century. During the second half, when emissions cuts are deeper, the distribution is almost even, with all regions undertaking mitigation exceeding 90% from baseline. These figures already suggest that the per capita scheme is unlikely to resolve the distributional conflicts identified so far in this paper, a result on which we will elaborate more in the following.

	PC				EE			
	2020-2050		2050-2100		2020-2050		2050-2100	
	Mean	*CV*	mean	*CV*	Mean	*CV*	Mean	*CV*
MIDDLE_EAST	65.7	*0.1*	96.7	*0.0*	33.3	*0.2*	81.5	*0.1*
REF_ECON	69.0	*0.1*	97.6	*0.0*	51.4	*0.4*	92.5	*0.2*
AFRICA	32.1	*0.5*	90.7	*0.1*	62.4	*0.6*	86.8	*0.1*
INDIA+	46.6	*0.2*	94.3	*0.0*	54.2	*0.2*	87.1	*0.1*
CHINA+	65.9	*0.2*	96.8	*0.0*	55.1	*0.2*	95.9	*0.1*
REST_ASIA	51.3	*0.2*	95.1	*0.0*	54.8	*0.3*	94.4	*0.1*
LATIN_AM	60.7	*0.1*	95.8	*0.0*	68.5	*0.5*	109.8	*0.2*
NORTH_AM	69.3	*0.1*	97.8	*0.0*	72.1	*0.2*	114.1	*0.1*
PAC_OECD	63.2	*0.2*	97.6	*0.0*	85.6	*0.3*	115.5	*0.1*
EUROPE	62.6	*0.1*	96.3	*0.0*	79.5	*0.2*	109.8	*0.1*

Table 4: Allocation of allowances in the first and second half of the century, for both burden sharing schemes (Per Capita, left, and Equal Effort, right). Emission allocations are expressed in % reductions from Baseline, in cumulative terms from 2020 to 2050, and from 2050 to 2100. Figures are averages across models. Red and blue colouring are used for emissions reductions above and below 80% respectively. The coefficient of variation (CV) is also shown: dark green indicates high confidence (<0.5), light green medium confidence (0.5-1), and white low confidence (>1).

The equal effort provides a more diverse allocation of abatement across countries, with OECD regions always bearing a significantly higher mitigation effort, which would exceed 100% in the second half of the century. The energy exporting countries, especially in the Middle East, would receive significant lower mitigation targets, as a way to make up for the large economic losses incurred otherwise.

In all cases, emissions reductions in the latter part of the century would be very significant; this is a result of the very tight carbon budget which allows meeting 2C with sufficiently high probability, roughly of about 1200 GtCO2[16].

Looking more specifically at the equal effort scenario –given its novelty-, we plot the temporal allocation of emissions allowances in Figure 5 for four major economies. The chart shows that -on average across models- Europe and North America would receive an emission allocation roughly 50% below todays' levels in 2030, ramping up to 80%-100% in 2050. The latter target is quite consistent with the aspirational targets delineated at the Major Economies Forum meeting in 2009. For Europe, this profile resembles quite closely the one proposed in the EU low carbon roadmap. Regarding China, the larger consensus across models is that allowances would be equal to today's values between 2030-2040. These patterns are somewhat more ambitious than the low carbon scenario for China developed in (Kejun et al., 2010). Finally, India would receive a rather flat allocation of allowances over time, which for most models is always above today's value, but which would grow to a 50% emission reduction with respect to BAU by mid-century (not shown on the graph). This is due to relatively high mitigation costs in the country mostly due to continued growth in emissions due to population and economic increase and a lower abatement potential due to CCS and renewable limitations[17].

[16] Throughout the paper, emissions include all Kyoto gases, and are thus expressed in CO2 equivalent levels.
[17] With the exception of WITCH, which foresees a higher mitigation potential in earlier periods.

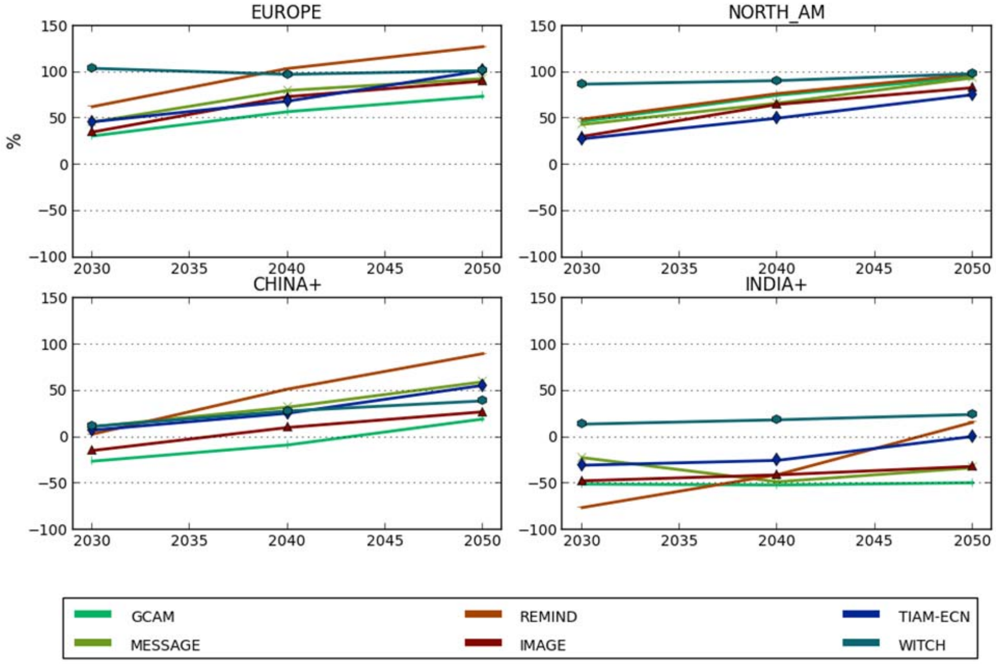

Figure 5: Emission allowances over time for the equal effort scenario, expressed in reductions from 2010 values.

In Figure 6, we show how the allocation of carbon permits compares to the optimal level of abatement for 4 major economies. This provides an immediate intuition on the direction of trade in the carbon market, a topic which will be discussed in more detail in the next session. The figure clearly indicates that both the EU and North America would be endowed with an emission allocation significantly below the cost effective mitigation level, implying that both countries will find it convenient to purchase the additional emission reductions on the global carbon market. For most models, China would on the other hand sell emission credits, though in a rather contained fashion. India would receive an allocation rather close to the optimal level, with limited need to resort to the global CO_2 permits market.

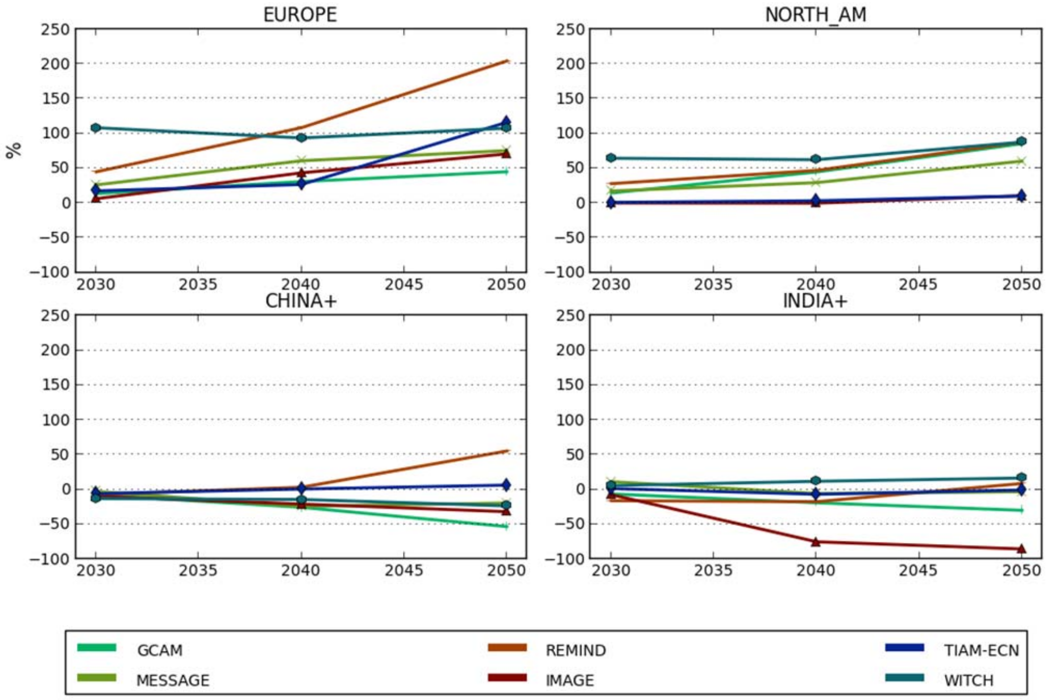

Figure 6: Emission allowances over time for the equal effort scenario, expressed in reductions from the optimal mitigation levels.

The different initial allocation of emission permits has no influence on the global policy costs due to the independency property of efficiency and equity. This requires the appropriate certificate trading platform, otherwise, without full carbon certificate trade, policy cost impacts can be expected (see carbon certificate trade sensitivity analysis in Kober et al., 2013, this issue). However, the initial allocation of certificates, even in a perfect carbon certificate market, has a direct impact on the regional costs: indeed, it is designed to do so to make sure that either resources or efforts are shared in a responsible manner.

Table 5 shows the extent to which the skewed distribution of costs outlined in Table 2 is smoothed for the per capita scheme (by design, it is equalized in the equal effort case). The table indicates that the per capita, resource sharing, scheme does not seem to alleviate the problem of distribution of costs across regions. Developing countries with low per capita emissions and growing populations –such as India and Africa- benefit from the per capita schemes in the early decades of the century (se the PC/Max 2050 cost metric), but eventually suffer from them, as reflected in significantly higher than average long term (maximum) costs. For some models, this is a direct consequence of their high carbon intensity of the economy through long-term periods affected by their limited CCS and renewable potential relative to their high growth of final energy demand. However, for Africa, there is substantial disagreement across models, especially with respect to costs as net present value, making a definitive statement not possible. China appears to even be worse off under a per capita scheme than under a tax, in line with previous findings (Luderer et. al, 2012).

	PC/NPV5		PC/Max2050		PC/Max2100	
	Mean	CV	Mean	CV	Mean	CV
MIDDLE_EAST	3.8	*0.3*	3.4	*0.2*	3.0	*0.4*
REF_ECON	2.5	*0.8*	3.7	*0.5*	3.1	*0.6*
AFRICA	1.2	*2.4*	0.5	*1.5*	3.1	*0.8*
INDIA+	2.1	*0.6*	0.9	*0.7*	2.6	*0.7*
CHINA+	2.0	*0.5*	1.9	*0.4*	1.9	*0.8*
REST_ASIA	1.3	*0.6*	1.0	*0.5*	1.3	*0.4*
LATIN_AM	0.4	*4.0*	1.2	*0.8*	1.0	*0.9*
NORTH_AM	0.6	*0.3*	1.1	*0.3*	0.7	*0.3*
PAC_OECD	0.4	*1.2*	0.9	*0.6*	0.7	*0.4*
EUROPE	0.5	*0.6*	0.7	*0.5*	0.7	*0.6*

Table 5: The table reports policy costs relative to the global average (as in Table 2) for the Per Capita convergence allocation, and different cost metrics (NPV at 5% d.r. and maximum by 2050 and 2100). Figures are averages across models. Red colouring is used for costs above global average (e.g. >1) and blue colouring for below the global average (e.g. <1). The coefficient of variation (CV) is also shown: dark green indicates high confidence (<0.5), light green medium confidence (0.5-1), and white low confidence (>1).

Overall, the same ordering and division into 3 main groups (OECD below global costs, fast growing economies above global costs, and energy exporters well above global costs) is preserved under the per capita allocation scheme. This results somewhat contradicts the existing literature, which traditionally showed higher than average costs for OECD countries, for 2050 (Hof et. al 2009). The difference can be attributed to various factors. First, baseline emissions have been updated in several models, with a redirection towards more growth in developing countries. Second, the Durban Action Platform scenarios considered in this paper achieve 2C with sufficiently high probability (>60-70%) and assume a more realistic transition towards full cooperation after 2025; as a result, the carbon budget is very limited, and very deep cuts in emissions are needed everywhere, including in the developing countries. Finally, models heavy reliance of negative emissions has shifted the emissions reduction profile over time, putting at further disadvantage future generations, especially in countries with fast growing economies. Overall, these results suggest a tension between equity –measured by the distribution of effort- and climate safety – measured by the stringency of the climate objective, which is of direct relevance for policy (Tavoni et. al 2012).

5. The carbon and financial transfers in the carbon market

The creation of emissions rights immediately translates into financial flows trading across regions. Given the models' assumption about a frictionless international carbon market, regions sell and buy permits freely without incurring extra costs (e.g. such as transaction costs), depending only on their relative marginal abatement costs and to the permits endowments of a given allocation scheme.

As a result, very significant trading of emissions occurs across regions. Already in 2030[18], physical transfers of carbon permits under the PC regime range between 2 and 13 $GtCO_2$ (see Figure 7), covering 10-25% of global abatement. The size of the market tends to contract in the EE case, where it never exceeds 6 $GtCO_2$/yr. The magnitude of these transactions is very sizeable compared to the experience of present day carbon markets. For example, the total number of carbon credits issued to date in the Clean Development Mechanism is about 1.2 GtCO2, and the total supply is estimated to reach 8 GtCO2 by 2020 (UNFCCC[19]). But these are cumulative numbers over the whole duration of the respective periods, whereas the figures indicated by the models suggests that similar levels of trading would occur each year from 2030 onwards. Needless to say, managing a carbon market of this size would require a major institutional effort in many countries.

[18] For brevity, from now on, quantities will be described as belonging to 2030, 2040 or 2050 even if they actually represent decadal averages over the periods 2025-2035, 2035-2045 or 2045-2055 respectively.
[19] http://cdm.unfccc.int/Statistics/Public/files/201305/CER_potential.pdf

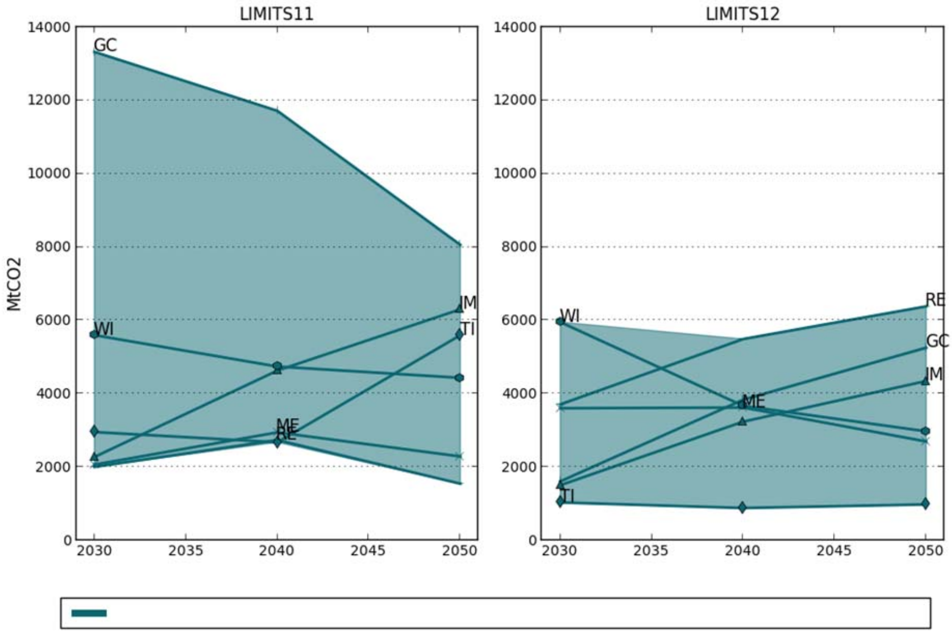

Figure 7: Global emission trade volumes (PC left, EE right).

The financial flows associated with these trading would also be considerable, due to the large trading volumes and the sustained carbon prices needed to attain policies compatible with 2°C (see Kriegler et. al, this issue, for more information on carbon prices). Figure 8 quantifies the financial exchanges tied to the carbon market in 2030 for all the major economies. In both schemes, in 2030 OECD countries would be net buyers of permits worth up to and more than 100 USD Billions. Permits would be sold mostly by India and Africa in the per capita allocation scheme, and by all non-OECD countries in the equal effort scheme. In the per capita case, China would be either neutral or even a permit buyer in 2030, whereas it would be a net seller in the equal effort case. Energy exporting countries would be net buyer of permits in the per capita scheme, thus further exacerbating the impact of climate policies on their economies.

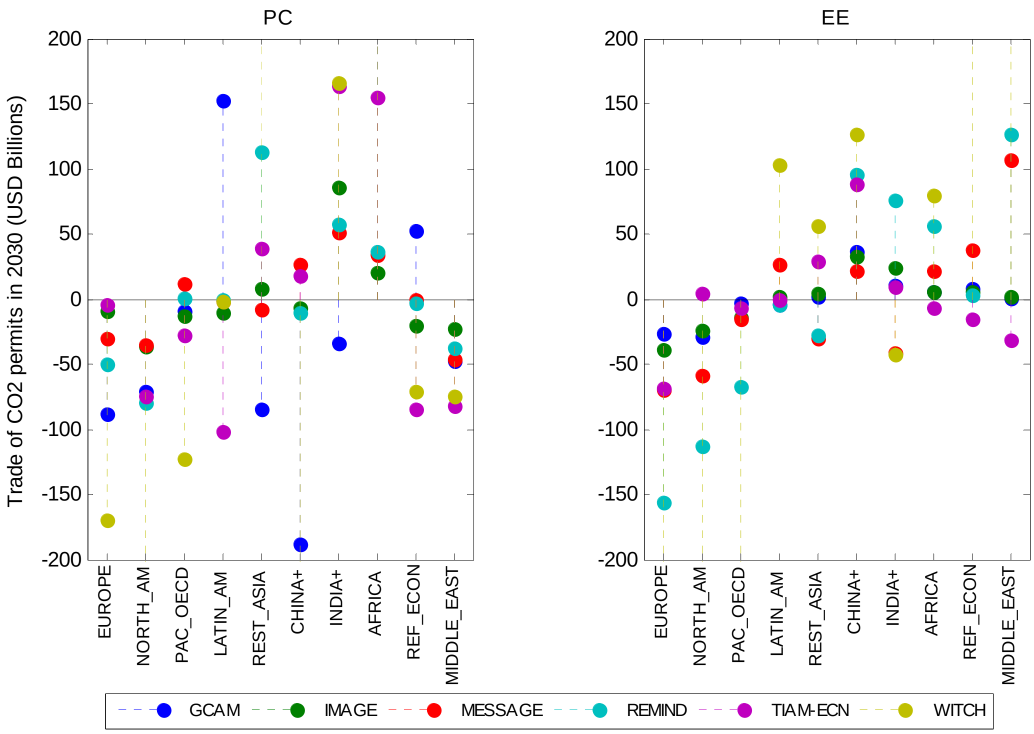

Figure 8: Regional trade flows of GHG emission permits in 2030 for the PC and EE schemes (positive=selling, negative=buying).The y axis is truncated at +/- 200 USD Billions.

When looking at the overall patterns aggregated over the whole century, terms of trade in the carbon markets change as a result of the changing allocation and the rising price of permits at which carbon permits are traded. Table 6 shows that in net present value, OECD countries would slightly be net seller of permits in the per capita scheme, and net buyers in the equal effort scheme. For energy exporters, the pattern is reversed. China is a net-buyer in in the per-capita scheme and a net-seller in the equal-effort one while India is a net buyer in both.

	PC		EE	
	Mean	CV	Mean	CV
MIDDLE_EAST	-2.3	1.5	3.0	1.6
REF_ECON	-0.4	13.4	3.5	1.2

AFRICA	1.2	4.4	0.4	5.2
INDIA+	-0.4	2.9	-0.2	6.6
CHINA+	-1.6	2.4	0.4	2.4
REST_ASIA	0.6	3.5	-0.3	2.9
LATIN_AM	1.9	2.6	0.1	2.5
NORTH_AM	0.4	1.6	-0.5	1.2
PAC_OECD	0.2	2.6	-0.5	1.1
EUROPE	0.0	18.9	-0.9	1.3

Table 6: Trade of CO2 permits as % of GDP for the PC and EE schemes (actualized in NPV at 5% d.r.). Positive (red) = selling. Negative (yellow)=buying. Also reported is the coefficient of variation across models.

In all cases, there is a disagreement across models, testified by the high coefficients of variations[20]. In many circumstances, different models disagree on the sign of the total trading, as a result of different projections about regional mitigation potential and different carbon prices. Nonetheless, this variation testifies that the financial flows associated with the carbon markets would be considerable as compared to the economy, representing several percentage points of regional economies. As a point of reference, all foreign direct investments (FDI) in China currently represent around 3-4% of the economy.

Such trading patterns could have profound economic and social repercussions -such as dutch-disease, corruption, etc.- and would require the existence of strong property rights and institutions, all of which is ignored in the model assessment presented in this paper. In this respect, the experience of CDM –despite being on a much smaller scale- has already emphasized the difficulty of implementing market mechanisms in key emitting countries, due to difficulties in verifiability and correct implementation (Wara, 2007).

[20] Please not that the some of the coefficient of variation are high as a result of the mean being close to zero.

6. Discussion and Conclusions

This paper provides a multi-model assessment of the regional implications of three post-2020 climate regimes consistent with the objectives enunciated in the Durban platform for enhanced action. It uses the results of a subset of the scenarios designed in the LIMITS project to assess the distribution of effort across 10 major economies, contributing with the largest consistent study on burden sharing for 2C policies. We provide a contribution to the rich quantitative discussion about effort sharing in international climate negotiations (den Elzen and Höhne (2008, 2010),Clarke et al., 2009; Ekholm et al., 2010; Johansson et al., 2012; Luderer et al., 2012), taking advantage of a multi-model ensembles of scenarios with different burden sharing regimes and fully consistent with the 2°C target. We assess a regime without transfers, and compare it to a resource burden sharing scheme based on long-term convergence of per capita emissions and an effort sharing scheme which equalizes policy costs across regions. Our analysis provides a number of important insights, which can be summarized as follows:

- With a carbon tax and no transfers between regions, the economic effort to achieve 2°C would be widely differentiated across regions, with a clear grouping of regional costs relative to the global average costs: below global average for the OECD, somewhat above global average for the fast growing developing economies, and well above global average for energy exporting countries. These patterns are well explained by a series of factors, which include abatement, baseline emissions, energy intensity and regional characteristics.
- The asymmetric distribution of costs could be alleviated only to a limited extent when endowing regions with emission permits based on convergence to per capita by 2050, and allowing free trade of such permits. Developing countries with current low per capita emissions would benefit in the next few decades, but would nonetheless be penalized in the longer term. China and the energy exporting countries would always be worse off.
- An allocation scheme based on the equalization of climate policy costs across regions would allocate OECD with emission reductions compatible with those enunciated by the Major Economies Forum and the European Commission. China would receive emissions allowances which return to today's levels by 2030 to 2040. India would receive a rather flat allocation of allowances over time, generally above today's values.
- The size of the carbon permit trade market would be significant in all the assessed regimes, exceeding by far the experience of CDM. The main actors on the market would differ between the two burden sharing schemes.

All in all, these results emphasize the distributional challenge of achieving 2C, in terms of balancing costs across the different regions.

While we found a number of robust patterns and insights, the uncertainty in regional mitigation cost estimates, and estimates of the effect of alternative burden sharing regimes, remains substantial. These variations reflect uncertainties about future development pathways in different regions and their mitigation potentials. We also identify areas where more analysis is needed. Focusing on the interplay between partial cooperation and effort sharing, and on the best way to link multiple coalitions and to harmonize different policy instruments and different carbon markets could yield important insight which are relevant given the current fragmentation in international climate policy. The relation between transfers originating from burden sharing schemes and side payments which are needed to ensure the stability of the coalition would also link the two strands of literature. Since carbon trade flows are projected to be a significant portion of regional output, giving rise to a number of institutional challenges for implementing a global burden sharing scheme, further research is needed that goes beyond the idealized assumption of full separability of efficiency and equity. Going beyond this approach is likely to exacerbate the distributional tensions identified in this paper.

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Supporting online material

Scenario	*Description*
Base	Scenario with no climate change mitigation policies of any kind. This "no-policy baseline" is used for comparative purposes in the paper.
RefPol	Scenario with present and planned climate-related policies and regulations implemented in those regions where they exist. Examples include greenhouse gas (GHG) emissions reduction targets, GHG intensity reduction targets, and nuclear power and renewable energy targets. Policies with a time horizon to 2020 are extended to 2100 assuming efforts continue at a similar level of stringency. See Kriegler et al. (this issue) for further information on the policies assumed in this scenario.
RefPol-450	Climate change mitigation scenario that leads to radiative forcing of 2.8 W/m^2 in 2100 (overshoot allowed in the interim), not including direct forcing from land use albedo changes, mineral dust aerosols, and nitrate aerosols. Such a forcing target would yield a likely to very likely (>70%) chance of reaching the 2°C target. Mitigation commences immediately after 2020; the RefPol reference policy baseline pathway is followed up until that point. Mitigation occurs when (after 2020) and where it is most cost-optimal (thus, globally-harmonized carbon prices). No burden-sharing regimes are in place.
RefPol-450-PC	Similar to the RefPol-450 scenario but with trade of GHG emission allowances between regions being permitted as of 2020. This scenario foresees implementation of aper capita convergence scheme, in which the per-capita GHG emissions of all regions linearly converge to a common value by 2050 and then maintain equal per-capita emissions in all subsequent years. The common values are derived from the global per-capita emission levels calculated by each model for 2050 and beyond in a cost-optimal mitigation scenario without burden-sharing (i.e., the RefPol-450 scenario). The purchase or sale of emission allowances allows individual regions to emit either more or less than they do in the RefPol-450 scenario, so long as they achieve the globally-harmonized per-capita level between 2050 and 2100.
RefPol-450-EE	Similar to the RefPol-450 scenario but with trade of GHG emission allowances between regions being permitted as of 2020. This scenario foresees implementation of a burden-sharing regime that attempts to equalize mitigation costs across regions, i.e., all regions incur the same mitigation costs (formulated as either consumption losses or the area under the marginal abatement cost curve, depending on whether a model is general or partial equilibrium, respectively) as a percentage of their gross domestic product after emissions trading has taken place. Allowance allocations for each region and in each year are based on this equalization rule (as of 2020 and then in all subsequent years).

Table SO1. Details of the scenarios assessed in this paper.

Box 1. Regional definitions used in this paper

This paper adopts the same regional definitions as used in the overall LIMITS project, namely the ten “super regions” (plus a Rest of World region). Each of these regions is comprised of a number of geographically- and/or culturally-similar countries (thus with relatively similar energy system structures and requirements). The harmonized set of regions has been chosen so that comparisons can be performed across the suite of LIMITS models. Because the native regions in these models all differ, it would otherwise be difficult, if not impossible, to carry out such regional comparisons. The 10+1 super regions offer a kind of “least common denominator” for this purpose: they represent the most disaggregated set of harmonized regions that could be attained. Nevertheless, not even this set provides a perfect match across the LIMITS models; notable discrepancies are marked below, where applicable. The full list of the super regions is given below, along with a sampling of countries that are included in each (the country lists are meant to be representative, not exhaustive).

AFRICA	*countries of Sub-Saharan Africa; some models also include North African countries, others do not; for REMIND and WITCH South Africa is included in the REST_WORLD region*
CHINA+	*countries of centrally-planned Asia; primarily China; for some models this may also include Cambodia, Vietnam, North Korea, Mongolia, etc.*
EUROPE	*countries of Eastern and Western Europe (i.e., the EU27); some models (except REMIND and WITCH) also include Turkey*
INDIA+	*countries of South Asia; primarily India; for some models this may also include Nepal, Pakistan, Bangladesh, Afghanistan, etc.*
LATIN_AM	*countries of Latin America and the Caribbean; Mexico, Brazil, Argentina, and other countries of Central and South America*
MIDDLE_EAST	*countries of the Middle East; Iran, Iraq, Israel, Saudi Arabia, Qatar, etc.; for some models this may also include countries of North Africa (e.g., Algeria, Egypt, Morocco, Tunisia); for REMIND the former Soviet states of Central Asia are included*
NORTH_AM	*countries of North America; primarily the United States of America and Canada; for REMIND Canada is included in the REST_WORLD region, for WITCH it is included in the PAC_OECD region*

PAC_OECD	*countries of the Pacific OECD (Organisation for Economic Co-operation and Development); for most models this primarily includes Japan, Australia, and New Zealand; for REMIND only Japan is included, Australia and New Zealand are included in the REST_WORLD region; WITCH does not include Australia, which is instead part of the REST_WORLD region; WITCH also includes Canada in the PAC_OECD*
REF_ECON	*countries from the Reforming Economies of Eastern Europe and the Former Soviet Union; primarily Russia, Ukraine, Kazakhstan, Azerbaijan, etc.; for WITCH Turkey is also included; for REMIND this region only includes Russia*
REST_ASIA	*other countries of Asia; South Korea, Malaysia, Philippines, Singapore, Thailand, Indonesia, etc.; for WITCH South Korea is included in the REST_WORLD region*
REST_WORLD	*only consists of countries for REMIND and WITCH that are not categorized elsewhere; for REMIND this includes Australia, Canada, Iceland, Norway, New Zealand, Moldova, Serbia, South Africa, Switzerland, Turkey, Ukraine, and some other smaller countries; for WITCH this includes Australia, South Africa, and South Korea*

Note that when we refer to "Industrialized" countries in this paper, we are referring to those countries that comprise the following regions: EUROPE, NORTH_AM, PAC_OECD, REF_ECON, and REST_WORLD. All other regions are then a part of the "Developing" world. We recognize that this grouping creates some non-trivial inconsistencies for the REMIND and WITCH models, though they are not enough to alter the overall results and conclusions of this paper.