Evaluation of post Kyoto GHG reduction paths

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Abstract

Climate change has become a critical issue in the international policy making agenda. At the UNFCC conference in Bali 2007, countries decided on a roadmap to achieve a 'secure climate future'. Given its commitment to limit the temperature increase to 2° Celsius relative to the preindustrial levels, the EU decided in March 2007, as a first step, a 20% reduction of its GHG emissions by 2020, going to 30% if a comprehensive international agreement can be reached. This study uses the multi-sector multi-region world model GEM-E3 in order to identify the world economic implications of different participation schemes for post Kyoto. The scenarios reported in this paper have contributed to the EU communication on 'Limiting Global Change to 2° Celsius the way ahead to 2020 and beyond'.

1. Introduction

Climate change has become a critical issue in the international policy making agenda. At the UNFCC conference in Bali 2007, countries decided on a roadmap to achieve a 'secure climate future'. The EU is committed to limit the temperature increase to 2° Celsius relative to the preindustrial levels by 2100. Towards this end EU decided in March 2007 a 20% reduction of its GHG emissions by 2020, going to 30% if a comprehensive international agreement can be reached.

Given the stringency of the EU 2° target objective there is clearly the need of expanding the participation beyond the Kyoto scheme to achieve it. Moreover, integration of the fast growing and developing countries in this scheme can be important because their lower cost of abatement and the future growth of their emissions and hence their future contribution to climate change. Therefore, besides the global target, an allocation of emission between countries and their dynamic pathway have to be defined. The initial allocation is essential for distributional equity concern.

The focus of this paper is the evaluation of different participation schemes for reaching a global emission reduction level sufficient for reaching the 2° target. The need or desirability of GHG emission reduction for climate change is considered as given. The scenarios reported in this paper have contributed to the EU communication on 'Limiting Global Change to 2° Celsius the way ahead to 2020 and beyond' and are partly also reported in 'Global Climate policies for 2030 and beyond, an analysis of greenhouse gas emission reduction pathway scenarios with the POLES and GEM-E3 models', IPTS 2007. The evaluation is done with GEM-E3 World. The GEM-E3 model is a multi sector, multi country, recursive dynamic general equilibrium model covering the whole world aggregated to 20 regions and 18 sectors. It includes all the GHG emissions (except land use change).

The paper is structured in four sections, in addition to this introduction. Section 2 gives a brief overview of the baseline scenario as it partly conditions the climate policy scenario and provides the basis against which all policy scenarios are compared. Section 3 explains the assumptions behind the global *reduction scenario*, in particular the allocation of targets between countries and the timing of their participation. In Section 4 the global scenarios are presented and analysed. Section 5 extends and

complements the analysis of the previous scenario along several lines: autonomous EU policy (instead of global reduction efforts), impact when there is increased international capital mobility, and also when regions cannot run additional current account deficits in order to meet the emission constraint. Section 6 closes with the main conclusions.

2. Baseline scenario

This section summarises the main elements of the baseline scenario of the GEM-E3 model. It is the scenario against which the reduction scenarios are evaluated and thus influences the magnitude of the emission reduction effort to reach the target. The latest version of GTAP (v.6) database has been used to calibrate the GEM-E3 model to its base year, 2001. The regional and sectoral coverage of the GEM-E3-World model is given in annex. The simulation period extents up to 2050 with a 5 year time step. As indicated in the annex GEM-E3 identifies four groups of energy intensive industries, that is: electricity, ferrous & non ferrous metals, chemical industry and other energy intensive. The model does not include endogenous technical change (this feature is implemented in the GEM-E3 Europe) and has no backstop technologies for very high emission reduction.

Assumptions on GDP and CO_2 emissions growth up to 2030 are in concordance with the POLES baseline scenario developed within the EU impact assessment (IPTS, 2007). The GEM-E3 baseline is in line with the evolution observed in the past decade: energy efficiency improvement, dematerialisation of the developed economies (i.e. improved technical progress) and slow catch up by the developing economies.

In GEM-E3, all markets are competitive including the labour market. The dynamic of the sectoral capital stock is driven by the investment flows, with the allocation of the investment between sectors based on the sectoral profitability. Within one period, capital is assumed to be mobile across sectors within a region, but not across regions. This relative capital mobility can be interpreted as reflecting expectations not well represented in a dynamic recursive model as GEM-E3. Over periods capital is mobile between regions through investment. As a sensitivity test, the possibility of capital mobility within a period between sectors and between regions is also considered.

Table 1 presents the regional GDP levels for 2001 and the annual GDP growth rates for the 2005-2030 period.

Table 1: GDP 2001 and GDP annual growth rate

	2001	2005/2010	2010/2015	2015/2020	2020/2025	2025/2030
Canada	57	3.11%	2.71%	2.38%	2.20%	1.71%
USA	1002	3.30%	3.05%	2.79%	2.54%	1.86%
Australia & New Zealand	36	2.54%	2.53%	2.67%	3.02%	2.51%
Japan	333	1.63%	1.75%	1.99%	2.50%	1.95%
EU27	684	2.16%	2.02%	1.91%	1.84%	1.32%
Other European countries	35	2.30%	2.44%	2.69%	2.88%	2.39%
South & East Mediterranean Countries	35	4.81%	3.96%	3.71%	3.09%	3.84%
Former Soviet Union	32	6.84%	5.04%	3.76%	3.95%	2.84%
Middle East	51	3.91%	3.40%	3.29%	2.06%	5.78%
Middle Africa	17	3.90%	3.84%	4.10%	4.73%	4.99%
South Africa	10	3.90%	4.10%	4.16%	4.80%	4.52%
India	42	5.17%	4.71%	4.90%	4.74%	5.06%
China	108	5.98%	5.00%	4.55%	4.24%	3.88%
East South East Asia	107	4.33%	3.88%	3.51%	3.21%	2.98%
Rest of Asia	23	4.31%	3.89%	3.27%	3.13%	3.25%
Mexico & Venezuela	62	3.75%	3.71%	4.30%	4.62%	4.92%
Brazil	39	3.35%	3.44%	3.44%	3.82%	4.17%
Rest of Latin America	57	3.42%	3.74%	3.80%	4.17%	4.43%
World	2733	3.15%	2.95%	2.83%	2.77%	2.44%

Note: GDP[1] in 10s of billion $2001.

[1] The database that the GEM-E3-World model uses is the GTAP v6. GTAP uses the ATLAS method of the World Bank in order to convert GDP expressed in national currency to US $.

The evolution of the GHG emissions is given in Table 2. The world GHG emissions in 2030 are 70% higher than the 2001 emissions and 72% compared to 1990 emissions.

Table 2: GHG emissions (annual growth rate)

	2005/2010	2010/2015	2015/2020	2020/2025	2025/2030
Canada	1.33%	1.88%	1.37%	1.25%	0.66%
USA	1.72%	2.46%	1.60%	1.27%	0.44%
Australia & New Zealand	-0.20%	0.85%	0.55%	1.05%	0.60%
Japan	0.26%	0.95%	1.10%	0.93%	0.63%
EU27	0.87%	1.56%	0.70%	0.57%	0.32%
Other European countries	-0.07%	0.64%	0.72%	1.10%	0.70%
South & East Mediterranean Countries	2.85%	2.03%	2.36%	1.35%	1.90%
Former Soviet Union	2.52%	2.97%	1.57%	0.73%	0.04%
Middle East	3.27%	1.51%	4.14%	0.10%	4.28%
Middle Africa	2.27%	1.81%	2.43%	2.47%	2.94%
South Africa	1.57%	1.61%	1.97%	2.06%	2.16%
India	4.38%	3.53%	3.28%	3.15%	3.28%
China	3.56%	3.63%	3.14%	2.06%	1.59%
East South East Asia	0.12%	1.60%	1.51%	1.34%	1.29%
Rest of Asia	2.97%	3.84%	3.95%	4.37%	5.29%
Mexico & Venezuela	2.27%	1.31%	2.32%	2.38%	2.46%
Brazil	-2.45%	-0.08%	0.49%	1.31%	2.00%
Rest of Latin America	0.94%	1.20%	1.87%	2.04%	2.37%
World	1.94%	2.38%	2.01%	1.53%	1.41%

3. GHG emission reduction targets and their allocation

3.1. Definition of the GHG targets and their allocation

The implementation of a certain global GHG emissions reduction target in GEM-E3 requires. i) the determination of the GHG emission reduction target at a world level, ii) the allocation of the global target among the groups of countries(defined according to certain criteria) and the allocation of the group target to the regions of each group.

The global target was set to a reduction of 30% by 2050 compared to 1990 for the world as a whole (IPTS, 2007). The proposed level of the target results in an emissions scenario which gives a 50% chance to limit the temperature increase by 2 degrees C relative to the pre-industrial level. The required global emission reduction was allocated to the different regions depending on their level of development. The participation schedule for each region to the global carbon market is based on the assumption that the carbon market only gradually develops into a global market.

The GEM-E3 model countries have been grouped to define their participation in the climate policy for the GEM-E3 simulations. The number of potential regional groups is conditioned by the country/regions already identified in the model (cf. Annex 1), that is eighteen in total. Three groups have been defined as:

- Group 1 (Annex I countries). These are the Annex I countries: Australia & New Zealand (AUZ), Japan (JPN), Canada (CAN), USA, EU27, Other European countries (OEU), and Former Soviet Union (FSU).
- Group 2 (fast growing developing economies): Mexico & Venezuela (MEV), South & East Mediterranean Countries (MED), Middle East (MEA), East South East Asia (EAS). These countries have a target from 2020 onwards
- Group 3 (rest of the world): Brazil (BRA), Rest of Latin America (LAM), India (IND), China (CHN), Rest of Asia (RAS), and South Africa (SAFR). These economies have a gradually increasing target from 2030 onwards.

Note that the eighteenth region of the model, Middle Africa (MAFR), does not have to reduce its emissions and therefore is not included in any group.

These three country groupings take on reduction commitments at different timing, the following pattern of participation (who does how much, and when) was implemented:

- 2010. Only the Annex I countries have targets, according to the Kyoto Protocol, except for the USA for which an annual energy efficiency improvement of 1% per year is assumed.
- 2020. For this period Group 2 countries also have a target:
    - -31% *versus* 1990 for Annex I countries (Group 1)
    - +21% *versus* 1990 for fast growing countries (Group 2)
- 2025. As in the previous period, both Groups 1 and 2 do have targets:
    - -34% *versus* 1990 for Annex I countries (Group 1)
    - +20% *versus* 1990 for fast growing countries (Group 2)
- 2030. Group 3 also joins the mitigation efforts:
    - -55% *versus* 1990 for Annex I countries (Group 1)
    - +3% *versus* 1990 for fast growing countries (Group 2)
    - +135% *versus* 1990 for the rest of the world (Group 3)
- 2050. The three groups adopt much more stringent targets, which translates into emission reduction at the world of 30% versus 1990:
    - -75% *versus* 1990 for Annex I countries (Group 1)
    - -43% *versus* 1990 for fast growing countries (Group 2)
    - +94% *versus* 1990 for the rest of the world (Group 3)

The Group 3 can still increase their emissions compared to 2001 or 1990, these targets imply however a reduction of 12% in 2030 and of 50% in 2050 compared to the baseline.

Table 3 hereafter summarizes the assumptions and the targets they imply for the different groups, both compared to 1990 and 2001.

Table 3: Emission reduction targets of the groups

		GROUP 1	GROUP 2	GROUP 3	WORLD
2010	% *vs* 1990	-6%			
	% *vs* 2001	4%			
2015	% *vs* 1990	-14%			
	% *vs* 2001	-5%			
2020	% *vs* 1990	-31%	21%		
	% *vs* 2001	-24%	2%		
2025	% *vs* 1990	-34%	20%		
	% *vs* 2001	-27%	1%		
2030	% *vs* 1990	-55%	3%	135%	8%
	% *vs* 2001	-51%	-13%	96%	6%
2050	% *vs* 1990	-75%	-43%	94%	-25%
	% *vs* 2001	-73%	-52%	62%	-26%

The final stage in formulating the targets in the model is the allocation of the group (Group 1 to 3) targets to the countries. The allocation between regions/countries within the groups is based on the grandfathering principle. For the Group 1 countries, it is based on the average between their base year emissions (2001) and their 1990 emissions, while for the other groups it is based on their baseline emissions in the corresponding year such as not to penalize the fast growing countries.

3.2. Implementation of the climate policy in GEM-E3

3.2.1. Policy instrument

The policy instrument chosen for the implementation of the climate policy is emission trading. A distinction is made between the energy intensive sectors and the other sectors:

- Energy intensive sectors: a world emission trading system (ETS), i.e. an international emission trading system for these sectors between all groups contributing to the target

- Other sectors: a domestic trading system for household and sectors not included in the ETS

The use of clean development mechanisms (CDM) is possible depending on the scenarios but it is limited to the sectors participating in the ETS. In GEM-E3 the energy intensive sectors are: the electricity sector, the ferrous and non ferrous metal sectors, the chemical sector for its activity generating emissions and the other energy intensive sectors (non metallic mineral and paper & pulp).

The allocation of the reduction target for a region between energy intensive sectors (which can participate in the worldwide ETS) and the other sectors is based on cost efficiency within the country/region. The distinction between ETS and non-ETS limits the overall flexibility of the global market, it is implemented to reflect the difficulty and the transaction cost of putting up a full global market.

3.2.2. Modelling assumptions

There are three key assumptions in the model runs related to its closure rules. Firstly, in order to prevent the climate policy from being financed through running public deficit, public budget neutrality is ensured through lump sum transfer. This means that in the climate policy scenario the net savings position of the public sector in every country of the model remain unchanged compared to the reference case.

Secondly, no specific constraint is imposed on the current account[2]. In a sensitivity scenario it is assumed that the current account of each region as a share to GDP remains fixed to the baseline level to evaluate the impact of capital flows.

Finally, as in the baseline scenario, capital is mobile between sectors within a region but not between regions; the impact of this assumption will also be analysed in a sensitivity scenario allowing full capital mobility between sectors and regions within one period.

[2] The global current account is zero by construction in a CGE model.

4. The global scenarios

4.1. Definition of the scenarios

Based on the assumptions described in the previous section, different global scenarios (with the participation of all regions at some points of time) have been defined. The first of the scenarios (called 'Scenario 1, early participation') is the broad participation case of the EC impact assessment (Variant 1 in section 6.2.5). This scenario has relatively a high degree of flexibility because from 2020 Group 1 and Group 2 countries can benefit from low cost abatement possibilities in Group 3 countries. In particular, four large countries in Group 3 (Brazil, other Latin America, South Africa, and China) are participating in the ETS from 2020 onwards. These economies only have a target from the year 2030. For the periods when they do not have a reduction target (2020 and 2025) and participate they are endowed with the baseline emissions of the sectors in the country participating in the ETS.

Moreover, two other scenarios have been studied, which differ from the previous one in terms of the timing of participation of countries in the worldwide emission trading system. These two other cases could be considered as 'lower flexibility cases'. In the first scenario all countries participate in the international ETS only when they have a reduction target ('Scenario 2, participation when target'), at the time when they implement also a domestic permit system. This means that the possibility of buying emission permits to Group 3 countries in 2020-2025 disappears, implying higher abatement costs in Group 1 and 2 countries to meet their targets. From the year 2030, however, Group 3 countries have emission reduction targets and then participate in the international ETS in what concerns their energy intensive sectors.

The second case is even more restrictive than the previous in the Annex I countries are the only ones participating in the ETS ('Scenario 3, Annex I only in ETS'). This means that for the 2020-2025 period Group 1 countries are alone in the international ETS bubble. They cannot benefit from lower abatement costs of Group 2 countries (in other words, there are not CDMs) and, furthermore, that for the 2030 period, the Group 3 trading possibilities do not exist either. All groups reach their reduction target by implementing a domestic permit system for all sectors. This is an extreme case that can illustrate the benefits of flexibility in terms of the overall cost of the global mitigation target and its regional distribution.

4.2. Results

4.2.1. Overview

The overall results for the three scenarios are given in Table 4. The table represents for 2020 and 2030 the average GHG permit price, the economic welfare and the GHG emissions for five large players: two Annex I regions –USA and EU 27- and three large non-Annex I countries –China, India and Brazil-. More detailed tables, with results for all the model regions, also including the GDP changes, are given in the next section.

Table 4: Overview of the global scenarios

(% difference compared to baseline)

	Scenario 1: early participation				**Scenario 2: participation when target**				**Scenario 3: Annex I only in ETS**			
	2020		2030		2020		2030		2020		2030	
	Economic Welfare	GHG Emissions	Economic Welfare	GHG Emissions	Economic Welfare	GHG Emissions	Economic Welfare	GHG Emissions	Economic Welfare	GHG Emissions	Economic Welfare	GHG Emissions
USA	-1.37%	-39.5%	-3.4%	-52.1%	-1.41%	-46.6%	-3.4%	-52.1%	-1.43%	-47.4%	-3.6%	-61.7%
EU27	-2.34%	-28.1%	-5.7%	-41.6%	-2.38%	-33.6%	-5.8%	-41.6%	-2.42%	-34.4%	-6.0%	-50.3%
Brazil	-0.3%	-4.8%	-1.5%	-15.0%	-0.3%	3.6%	-1.5%	-15.0%	-0.3%	3.6%	-1.4%	-12.3%
India	-0.9%	0.5%	-1.6%	-23.3%	-0.7%	0.7%	-1.6%	-23.3%	-0.8%	0.6%	-2.4%	-12.3%
China	0.3%	-29.5%	-0.8%	-32.8%	-0.8%	1.8%	-0.8%	-32.7%	-0.8%	1.6%	-2.1%	-12.3%
World inequality aversion[3]=0	-1.2%	-25.9%	-3.4%	-37.2%	-1.3%	-23.6%	-3.4%	-37.2%	-1.3%	-23.6%	-3.6%	-37.2%
World inequality aversion=1	-0.4%		-1.4%		-0.5%		-1.4%		-0.5%		-1.5%	
GHG permit price (US$2001/ton CO2eq)		40.9		83.4		73.5		83.3		73.6		96.4

[3] Inequality aversion parameter in the social welfare function allows taking into account the equity dimension, the higher the more important

Concerning Scenario 1, the reduction targets for 2020 are already stringent for the developed world and further increase in 2030. This translates into a doubling of the GHG permit price, from 40.9 US$2001/tCO2eq in 2020 to 83.4 US$2001/tCO2eq. In terms of welfare, the cost compared to the baseline remains limited for the USA and EU27, in a 1 to 2% range (compared to the baseline scenario levels), and increasing with the stringency of the target, to 4 to 6% in 2030. Note that in 2020 China experiences an improvement in its economic welfare of 0.3% due to its significant sale of emission permits to Group 1 and 2 countries (Brazil also sell permits, but to a much lower extent). China does not have a target in that period but reduces its emissions by nearly 30% compared to the baseline scenario. In the 2030 period China has a target (12%), and reduces its emissions by almost 33% compared to the baseline. The welfare loss of China can be partly explained by the existence of a domestic target and also by the fall in global activity due to the stronger constraint in global emissions.

The impact is more neutral for the other early participants such as Brazil: they benefit from the smaller decrease of activity in the Annex I countries but do not gain much from their early participation because they are less carbon intensive.

In Scenario 2, with less flexibility in the international ETS, the GHG permit price increases significantly in the year 2020, compared to Scenario 1, almost doubling to 73.5 US$2001/tCO2eq. The non-participation of some developing countries from 2020 onwards in this scenario increases slightly the welfare cost of the reduction for the Annex I countries before 2030. With regard to large developing countries, Brazil and India remain the same, but the Chinese economic welfare is worse off than in Scenario 1 because it does not receive the transfers from the sale of permits.

Moreover, the overall gain from an early participation (scenario 1) lies predominantly in a further reduction of the World GHG emissions. Global emissions fall by 25.9% in Scenario 1 and by 23.6% in Scenario 2.

Concerning Scenario 3, where Group 1 countries can only make ETS within the same group, the GHG permit in 2030 become higher than that under Scenario 1. In 2030, both US and EU27 have slightly higher welfare losses, relative to Scenario 1. India and China welfare levels are worse than under Scenario 1. They suffer from the higher decrease in activity in the Annex I

countries and, furthermore, cannot benefit from their participation in the ETS.

At sectoral level, the implementation of the ETS for the energy intensive sectors reduces the loss of competitiveness of these sectors in the countries having higher reduction target (Annex I countries). Early participation of China and others has the same positive effect. The shares of these sectors in Annex I countries in the World production are even slightly increasing in the two scenarios where all countries are in the ETS. They are decreasing when the ETS is limited to Annex I countries.

4.2.2. Scenario 1: early participation in the ETS

Table 5 presents the results for all countries under Scenario 1, including emissions targets and GDP changes. Under this scenario large developing countries (in particular, China, South Africa and Latin America) are participating with the energy intensive sectors in the international ETS from 2020 onwards. It is mainly China which contributes to the ETS, with a reduction of its emissions of almost 30% compared to the baseline. USA, Canada, Australia and EU27 are benefiting mostly from the ETS and therefore also from their participation: their emissions are reduced by approximately 10 percentage points compared to their target. Group 2 countries are also buying in the international ETS. In 2030 China, India and South Africa are the main sellers in the ETS, with the largest emissions reduction compared to their target.

In terms of the macroeconomic adjustment (measured with the change of GDP), due to the GHG emission constraint the reduction remains limited in annualised terms. For the EU27 region, in 2020 the GPD is estimated to be 2.1% below the level of the baseline scenario. Annualising that figure over a fifteen period means an annual reduction of GDP growth of around 0.14%. For 2030 the GDP change is 5%, and annualised translates into 0.21%. The policy reduces the average growth rate of EU27 from 2% a year in the baseline scenario till 2020 to 1.9% a year in the policy scenario and till 2030 from 1.8% to 1.6%. The annualised GDP change for the world economy is 0.11% and 0.17%, respectively for 2020 and 2030.

Table 5: Scenario with early participation in ETS

(% difference compared to baseline. GHG permit price in US$2001/tCO2eq)

		2020				2030			
		GHG Emissions		welfare	GDP	GHG Emissions		welfare	GDP
		target	scenario			target	scenario		
Group 1 (Annex I)	USA	-50%	-40%	-1.4%	-1.9%	-64%	-52%	-3.4%	-4.5%
	Canada	-46%	-36%	-2.5%	-2.8%	-61%	-50%	-6.0%	-7.0%
	EU27	-37%	-28%	-2.3%	-2.1%	-52%	-42%	-5.7%	-5.0%
	Other European countries	-25%	-22%	-1.2%	-1.1%	-46%	-41%	-2.9%	-3.4%
	Former Soviet Union	-38%	-38%	-3.3%	-4.5%	-53%	-49%	-7.7%	-10.3%
	Australia & New Zealand	-33%	-26%	0.1%	-1.4%	-51%	-40%	-0.9%	-4.5%
	Japan	-37%	-28%	-1.0%	-1.1%	-54%	-42%	-3.0%	-3.1%
Group 2	Mexico & Venezuela	-23%	-18%	-1.6%	-1.0%	-45%	-34%	-5.1%	-3.7%
	South & East Mediterranean	-23%	-22%	-1.1%	-1.7%	-45%	-35%	-4.2%	-5.7%
	Middle East	-23%	-22%	-1.2%	-1.8%	-45%	-39%	-4.6%	-5.3%
	East South East Asia	-23%	-21%	-0.7%	-1.1%	-45%	-36%	-2.3%	-3.4%
Group 3	Brazil	0%	-5%	-0.3%	-0.6%	-12%	-15%	-1.5%	-2.2%
	Rest of Latin America	0%	-3%	-0.3%	-0.6%	-12%	-13%	-1.4%	-2.2%
	China	0%	-30%	0.3%	-0.5%	-12%	-33%	-0.8%	-2.5%
	South Africa	0%	-5%	0.7%	-0.3%	-12%	-23%	1.5%	-1.0%
	India	0%	0%	-0.9%	-1.0%	-12%	-23%	-1.6%	-2.4%
	Rest of Asia	0%	1%	-0.3%	-0.5%	-12%	-14%	-1.2%	-1.9%
	Middle Africa	0%	2%	-0.8%	-0.6%	0%	6%	-2.0%	-2.5%
	World (inequality aversion=0)	-24%	-26%	-1.2%	-1.7%	-37%	-37%	-3.4%	-4.2%
	World (inequality aversion=1)				-0.4%				-1.4%
	GHG permit price	41				83			

If India would also participate in 2020, it would be beneficial for this country and for the world. The GHG permit price and the World GHG emissions would slightly decrease. China would however gain less from its early participation having to share the demand of permits with India.

4.2.3. Scenario 2: participation when emission reduction target is imposed

The non-participation of China, Brazil and the other in the international ETS in 2020 increases the marginal cost of reduction, as already noted. The GHG permit price at a world level is very high in 2020 (compared to Scenario 1) as the reduction targets for 2020 are already stringent for the developed world. In terms of GDP adjustment cost, the deviation with respect to the baseline remains rather close to the previous scenario with early participation.

A change compared to the previous scenario is that in 2020 the FSU becomes the seller of permits within the Group 1 and 2 bubble, replacing China. Indeed, in terms of welfare and GDP changes most Annex I (Group 1) countries are worse off than in Scenario 1. The FSU is better off because of its sale of permits in the ETS market.

The GHG permit price reaches 73.5 US$ in 2020 and increases only slightly in 2030 though the reduction target is much higher. The participation in 2030 of great emitters such as China and India with still low reduction targets in 2030 explains the low increase.

Table 6: Scenario with participation when target imposed

(% difference compared to baseline. GHG permit price in US$2001/tCO2eq)

		2020				**2030**			
		GHG Emissions		welfare	GDP	GHG Emissions		welfare	GDP
		target	scenario			target	scenario		
Group 1 (Annex I)	USA	-50%	-47%	-1.4%	-2.1%	-64%	-52%	-3.4%	-4.6%
	Canada	-46%	-42%	-2.6%	-2.9%	-61%	-50%	-6.0%	-7.1%
	EU27	-37%	-34%	-2.4%	-2.2%	-52%	-42%	-5.8%	-5.1%
	Other European countries	-25%	-23%	-1.4%	-1.1%	-46%	-41%	-3.0%	-3.4%
	Former Soviet Union	-38%	-46%	-2.0%	-3.4%	-53%	-49%	-7.9%	-10.4%
	Australia & New Zealand	-33%	-32%	0.1%	-1.5%	-51%	-40%	-1.0%	-4.6%
	Japan	-37%	-34%	-1.0%	-1.1%	-54%	-42%	-3.0%	-3.1%
Group 2	Mexico & Venezuela	-23%	-22%	-1.6%	-1.0%	-45%	-34%	-5.1%	-3.7%
	South & East Mediterranean	-23%	-28%	-0.9%	-1.7%	-45%	-35%	-4.4%	-5.8%
	Middle East	-23%	-27%	-1.2%	-2.0%	-45%	-39%	-4.7%	-5.5%
	East South East Asia	-23%	-27%	-0.5%	-1.1%	-45%	-36%	-2.4%	-3.5%
Group 3	Brazil	0%	4%	-0.3%	-0.2%	-12%	-15%	-1.5%	-2.2%
	Rest of Latin America	0%	2%	-0.4%	-0.5%	-12%	-13%	-1.4%	-2.2%
	China	0%	2%	-0.8%	-0.8%	-12%	-33%	-0.8%	-2.3%
	South Africa	0%	2%	-0.2%	-0.6%	-12%	-23%	1.6%	-0.8%
	India	0%	1%	-0.7%	-0.9%	-12%	-23%	-1.6%	-2.4%
	Rest of Asia	0%	1%	-0.3%	-0.4%	-12%	-14%	-1.3%	-1.9%
	Middle Africa	0%	2%	-0.7%	-0.5%	0%	6%	-2.0%	-2.5%
	World (inequality aversion=0)	-24%	-24%	-1.3%	-1.7%	-37%	-37%	-3.4%	-4.3%
	World (inequality aversion=1)				-0,5%				-1.4%
	GHG permit price	74				83			

4.2.4. Scenario 3: Annex I only participating in ETS

In this scenario only Annex I countries are participating in the ETS and this limits the possibility of benefiting from the low cost GHG reduction potentials of large countries like China, or from Group 2 countries. For 2020 the results are close to scenario 2 (the differences are due to the non-participation of Group 2). In 2030 however the GHG permit price is higher than in the previous scenario, and the cost in terms of welfare and GDP growth is also higher. This is as expected as limiting the participation in the ETS is less cost efficient. While in 2030 all Annex I countries are worse off compared to Scenario 1, the FSU appears again as the seller of permits to its Annex I partners, experiencing lower welfare and GDP changes than in Scenario 1.

On sectoral level, limiting the ETS to the Annex I countries increases the reduction cost for the sectors and especially for the energy intensive sectors. It also deteriorates the competitive position of those sectors in Annex I because of the lower target in the non Annex I countries.

Table 7: Scenario with Annex I only in ETS

(% difference compared to baseline. GHG permit price in US$2001/tCO2eq)

		2020				**2030**			
		GHG Emissions		welfare	GDP	GHG Emissions		welfare	GDP
		target	scenario			target	scenario		
Group 1 (Annex I)	USA	-50%	-47%	-1.4%	-2.1%	-64%	-62%	-3.6%	-4.9%
	Canada	-46%	-43%	-2.6%	-3.0%	-61%	-59%	-6.4%	-7.5%
	EU27	-37%	-34%	-2.4%	-2.2%	-52%	-50%	-6.0%	-5.4%
	Other European countries	-25%	-24%	-1.4%	-1.1%	-46%	-44%	-3.2%	-3.5%
	Former Soviet Union	-38%	-47%	-1.6%	-3.1%	-53%	-61%	-5.0%	-8.9%
	Australia & New Zealand	-33%	-33%	0.1%	-1.5%	-51%	-50%	-0.9%	-5.1%
	Japan	-37%	-35%	-1.0%	-1.1%	-54%	-51%	-3.0%	-3.2%
Group 2	Mexico & Venezuela	-23%	-23%	-1.6%	-1.0%	-45%	-45%	-5.5%	-4.1%
	South & East Mediterranean	-23%	-23%	-1.1%	-1.6%	-45%	-45%	-4.8%	-6.5%
	Middle East	-23%	-23%	-1.3%	-1.9%	-45%	-45%	-4.9%	-5.8%
	East South East Asia	-23%	-23%	-0.6%	-1.1%	-45%	-45%	-2.4%	-3.9%
Group 3	Brazil	0%	4%	-0.3%	-0.3%	-12%	-12%	-1.4%	-1.9%
	Rest of Latin America	0%	2%	-0.4%	-0.5%	-12%	-12%	-1.3%	-2.0%
	China	0%	2%	-0.8%	-0.8%	-12%	-12%	-2.1%	-2.7%
	South Africa	0%	2%	-0.2%	-0.6%	-12%	-12%	0.2%	-1.4%
	India	0%	1%	-0.8%	-0.9%	-12%	-12%	-2.4%	-2.7%
	Rest of Asia	0%	1%	-0.3%	-0.5%	-12%	-12%	-1.3%	-1.8%
	Middle Africa		2%	-0.7%	-0.5%		6%	-1.8%	-2.3%
	World (inequality aversion=0)	-24%	-24%	-1.3%	-1.8%	-37%	-37%	-3.6%	-4.5%
	World (inequality aversion=1)				-0,5%				-1.5%
	GHG permit price	74				96			

5. Additional scenarios

5.1. Autonomous EU policy in 2020

If EU acts alone till 2020 with the possibility of CDM with China, the cost for Europe is limited but the benefits in terms of World GHG emission reductions are also small (around -3%). The emission reduction through CDM is limited to 30% of the EU target for 2020. This strategy of Europe can be seen as a first step towards a cooperative climate agreement.

Table 8: EU autonomous policy in 2020 with 21% reduction target compared to 1990

(% difference compared to baseline)

	without CDM			**with CDM**		
	Economic Welfare	Gross Domestic Product	GHG Emissions	Economic Welfare	Gross Domestic Product	GHG Emissions
USA	-0.1%	-0.1%	0.4%	0.0%	0.0%	0.0%
EU27	-1.1%	-1.1%	-27.4%	-0.2%	-0.2%	-5.1%
Brazil	-0.1%	0.0%	0.6%	0.0%	0.0%	0.1%
India	-0.1%	-0.1%	0.1%	0.0%	0.0%	0.0%
China	-0.1%	-0.1%	0.2%	0.1%	-0.1%	-15.3%
World	-0.3%	-0.3%	-3.3%	0.0%	-0.1%	-3.5%
GHG permit price (US$2001/ton CO2eq)			55.5			4.7

5.2. Impact of capital mobility

In the global scenarios above it was assumed that there was no capital[4] mobility between regions beyond the one implied by the new investment. To evaluate the possible impact of delocalisation at an increased speed, a scenario was run where it was assumed that capital was also mobile between regions. The comparison - however, is not straightforward. It can only give some indications because, as there is no reason to assume that capital could be more mobile with a carbon constraint than without such a constraint, the same assumption about capital mobility is also imposed in the baseline. Thus the emissions are not exactly the same in both reference cases.

Assuming full capital mobility shifts the activity towards the fast growing and developing world in the baseline. This means a decrease of the emissions in the developed and thus a decrease in their reduction effort compared to the baseline, the target compared to 1990 remaining the same. In 2030 the overall target and cost are rather similar in both scenarios at the world level but there are differences on country level mostly because a change in the reduction effort.

At sectoral level, the differences are not as great as the ETS already allows a more evenly distribution of the reduction cost.

[4] Capital here is productive capital; financial capital is mobile in all scenarios and reflected in the change in current account.

Table 9: Scenario with early participation in ETS with and without capital mobility

(% difference compared to baseline. GHG permit price in US$2001/tCO2eq)

		without capital mobility				**with capital mobility**			
		2030				**2030**			
		GHG Emissions		welfare	GDP	GHG Emissions		welfare	GDP
		target	scenario			target	scenario		
Group 1 (Annex I)	USA	-64%	-52%	-3.4%	-4.5%	-61%	-50%	-3.0%	-4.0%
	Canada	-61%	-50%	-6.0%	-7.0%	-60%	-49%	-6.4%	-7.8%
	EU27	-52%	-42%	-5.7%	-5.0%	-47%	-38%	-5.0%	-4.2%
	Other European countries	-46%	-41%	-2.9%	-3.4%	-45%	-40%	-2.1%	-2.5%
	Former Soviet Union	-53%	-49%	-7.7%	-10.3%	-46%	-47%	-6.0%	-9.4%
	Australia & New Zealand	-51%	-40%	-0.9%	-4.5%	-63%	-50%	-2.7%	-7.8%
	Japan	-54%	-42%	-3.0%	-3.1%	-58%	-46%	-1.6%	-1.7%
Group 2	Mexico & Venezuela	-45%	-34%	-5.1%	-3.7%	-55%	-43%	-10.2%	-8.5%
	South & East Mediterranean	-45%	-35%	-4.2%	-5.7%	-55%	-44%	-8.7%	-12.2%
	Middle East	-45%	-39%	-4.6%	-5.3%	-55%	-47%	-9.0%	-10.7%
	East South East Asia	-45%	-36%	-2.3%	-3.4%	-55%	-44%	-2.0%	-3.5%
Group 3	Brazil	-12%	-23%	-1.6%	-2.4%	-16%	-28%	-3.6%	-5.5%
	Rest of Latin America	-12%	-14%	-1.2%	-1.9%	-16%	-18%	-0.3%	-0.3%
	China	-12%	-15%	-1.5%	-2.2%	-16%	-19%	-0.3%	-1.0%
	South Africa	-12%	-13%	-1.4%	-2.2%	-16%	-17%	-0.9%	-1.5%
	India	-12%	-33%	-0.8%	-2.5%	-16%	-33%	-1.3%	-3.1%
	Rest of Asia	-12%	-23%	1.5%	-1.0%	-16%	-26%	1.0%	-1.7%
	Middle Africa	0%	6%	-2.0%	-2.5%	0%	10%	1.3%	1.9%
	World (inequality aversion=0)	-37%	-37%	-3.4%	-4.2%	-37%	-37%	-3.4%	-4.2%
	World (inequality aversion=1)				-1.4%				-1.5%
	GHG permit price	83				83			

5.3. Current account equilibrium

In the previous scenarios no specific constraint was imposed on the countries' current account. The general equilibrium mechanisms implicit in the model structure will balance the country overall equilibrium through price and quantity changes such as the savings by the different agents (inclusive the ROW) allows financing the investment demand in the country. This implies perfect financial capital mobility between regions. It seems however also interesting to examine what the impact is of less capital mobility, what if countries are more reluctant to finance investment in other countries. The scenario takes into account this issue by imposing a current account constraint, that the share of current account deficit/surplus to GDP should remain the same as in the reference case. Countries where the current account deteriorates with the climate policy will have to find resources within their countries to finance their investment or decrease their investment. Countries with a surplus will have more resources to spend within the country. This adjustment will occur through a change of the domestic interest rate.

Overall the cost is negative mainly because the negative impact of the decrease in activity in the Annex I countries is higher than the positive effect that the decrease of the interest rate could have on the domestic demand. All regions are worse off than in the case of no constraint in the current account.

Table 10: Scenario with early participation in ETS with free current account and with fixed current account in terms of GDP

(% difference compared to baseline. GHG permit price in US$2001/tCO2eq)

		no constraint on current account				**constraint on current account**			
		2030				**2030**			
		GHG Emissions		welfare	GDP	GHG Emissions		welfare	GDP
		target	scenario			target	scenario		
Group 1 (Annex I)	USA	-64%	-52%	-3.4%	-4.5%	-64%	-52%	-3.8%	-5.1%
	Canada	-61%	-50%	-6.0%	-7.0%	-61%	-50%	-6.6%	-7.6%
	EU27	-52%	-42%	-5.7%	-5.0%	-52%	-42%	-7.3%	-5.6%
	Other European countries	-46%	-41%	-2.9%	-3.4%	-46%	-41%	-3.3%	-3.9%
	Former Soviet Union	-53%	-49%	-7.7%	-10.3%	-53%	-50%	-6.7%	-11.4%
	Australia & New Zealand	-51%	-40%	-0.9%	-4.5%	-51%	-40%	-1.1%	-5.1%
	Japan	-54%	-42%	-3.0%	-3.1%	-54%	-42%	-4.5%	-3.5%
Group 2	Mexico & Venezuela	-45%	-34%	-5.1%	-3.7%	-45%	-34%	-4.9%	-4.3%
	South & East Mediterranean	-45%	-35%	-4.2%	-5.7%	-45%	-36%	-4.8%	-6.2%
	Middle East	-45%	-39%	-4.6%	-5.3%	-45%	-39%	-4.7%	-5.9%
	East South East Asia	-45%	-36%	-2.3%	-3.4%	-45%	-36%	-2.4%	-4.2%
Group 3	Brazil	-12%	-23%	-1.6%	-2.4%	-12%	-23%	-2.4%	-2.9%
	Rest of Latin America	-12%	-14%	-1.2%	-1.9%	-12%	-14%	-1.7%	-2.6%
	China	-12%	-15%	-1.5%	-2.2%	-12%	-15%	-1.8%	-2.8%
	South Africa	-12%	-13%	-1.4%	-2.2%	-12%	-13%	-1.9%	-2.7%
	India	-12%	-33%	-0.8%	-2.5%	-12%	-32%	-1.8%	-3.1%
	Rest of Asia	-12%	-23%	1.5%	-1.0%	-12%	-23%	2.9%	-1.9%
	Middle Africa	0%	6%	-2.0%	-2.5%	0%	5%	-2.5%	-3.1%
	World (inequality aversion=0)	-37%	-37%	-3.4%	-4.2%	-37%	-37%	-4.0%	-4.8%
	World (inequality aversion=1)				-1.4%				-1.7%
	GHG permit price	83				83			

6. Conclusions

This paper has assessed the consequences of targeting the EU 2°C objective using the multi-sectoral, multi-country general equilibrium GEM-E3 global model. The model allows to get insights into the order of magnitude of the world and regional welfare changes required to meet that temperature target, within a sound theoretical framework, that of general equilibrium theory, while using consistent National Accounts statistics. Several sensitivity analyses to key assumptions of the model and the policy setup have been also carried out. The focus is on the period till 2030, but it is clear that to reach the 2° target of the EU further reduction will have to be done.

Under a broad participation scheme, in the year 2020 the average GHG permit price is estimated at 40 US$2001/tCO2eq. That cost almost doubles if there is less flexibility in the international emission trading system. In particular, if Annex I countries cannot buy permits form the rest of the world, not only most of Annex I countries are worse off in terms of welfare and GDP changes, but also some developing countries are worse off, as they cannot benefit from the extra revenues from the sale of permit rights in the international ETS or CDMs.

The estimated GHG permit price for the 2030 period is 83 US$2001/tCO2eq, assuming broad participation (high flexibility) in the international ETS market.

The overall change in annual GDP for the world economy is estimated to be 0.11% in 2020, and 0.17% in 2030. For the EU27 region those figures are 0.14% and 0.21%, respectively. If the EU would reduce unilaterally its emissions the annualised GDP changes would be below those figures, even without having access to CDM.

The model assumes that capital is not mobile across countries. When that assumption is removed, allowing for full capital mobility at world scale, the GHG permit price in 2020 becomes lower (33.8 US$2001/tCO2eq), because there is less activity in the baseline scenario, and therefore the absolute GHG emission targets are less costly to meet.

In another sensitivity run, countries are not allowed to deviate from the current account position in the baseline scenario. Most regions experience larger welfare losses, because of this additional constraint.

A number of caveats must be mentioned. In interpreting the results from the CGE based analysis one should take into account the modelling assumptions made on key issues. The GEM-E3 model version used for this study assumes that there are no imperfections in goods, capital, labour and permit market. The values for fundamental parameters such as production or Armington elasticities have been selected from literature surveys and were not econometrically estimated for the exact regional and sectoral dimension of the model. The effects of the climate policies computed with the model are driven by relative price changes in all the markets of the economy.

This modelling exercise, anyhow, has considered that there is no global perfect market for emission trading, covering all sectors and countries and this leads to higher abatement costs estimates compared to studies assuming perfect carbon markets.

7. References

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8. Annexes

8.1. Annex 1: Countries/Regions in GEM-E3 world

The country aggregation is conditioned by the country aggregation in GTAP6 database which is used for GEM-E3.

Number	Code	Name	Number	Code	Name
1	AUZ	Australia	14	EU27	Austria
		New Zealand			Belgium
		Rest of Oceania			Denmark
2	CHN	China			Finland
		Hong Kong			France
3	JPN	Japan			Germany
4	EAS	Korea			United Kingdom
		Taiwan			Greece
		Rest of East Asia			Ireland
		Indonesia			Italy
		Malaysia			Luxembourg
		Philippines			Netherlands
		Singapore			Portugal
		Thailand			Spain
5	RAS	Viet Nam			Sweden
		Rest of Southeast Asia			Bulgaria
		Bangladesh			Cyprus
		Sri Lanka			Czech Republic
		Rest of South Asia			Hungary
6	IND	India			Malta
7	CAN	Canada			Poland
		Rest of North America			Romania
8	USA	United States of America			Slovakia
9	MEV	Mexico			Slovenia
		Venezuela			Estonia
10	BRA	Brazil			Latvia
11	LAM	Colombia			Lithuania
		Peru	15	OEU	Switzerland
		Rest of Andean Pact			Rest of EFTA
		Argentina			Rest of Europe
		Chile	16	FSU	Russian Federation
		Uruguay			Rest of Former Soviet
		Rest of South America	17	MED	Turkey
		Central America			Morocco
		Rest of Free Trade Area of the Americas			Tunisia

		Rest of the Caribbean			Rest of North Africa
12	MEA	Rest of Middle East			Albania
13	SAFR	Botswana			Croatia
		South Africa	18	MAFR	Malawi
		Rest of South African Customs Union			Mozambique
		Rest of Southern African Development Community			Tanzania
					Zambia
					Zimbabwe
					Madagascar
					Uganda
					Rest of Sub-Saharan Africa

8.2. Annex 2: sectoral breakdown

The GTAP 57 sectors have been aggregated into the following classification:

No	GEM-E3 Sector
01	*Agriculture*
02	*Coal*
03	*Oil*
04	*Gas*
05	*Electricity*
06	*Ferrous and non ferrous metals*
07	*Chemical Products*
08	*Other energy intensive*
09	*Electric Goods*
10	*Transport equipment*
11	*Other Equipment Goods*
12	*Consumer Goods Industries*
13	*Construction*
14	*Telecommunication Services*
15	*Transport*
16	*Services of credit and insurances*
17	*Other Market Services*
18	*Non Market Services*