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A Comparability Analysis of Global Burden Sharing GHG Reduction Scenarios

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Abstract[1]

The distribution of the mitigation burden across countries is a key issue regarding the post-2012 global climate policies. This article explores the economic implications of alternative allocation rules, an assessment made in the run-up to the COP15 in Copenhagen (December 2009). We analyse the comparability of the allocations across countries based on four single indicators: GDP per capita, GHG emissions per GDP, population growth, and the GHG emission trend in the recent past. The multi-sectoral computable general equilibrium model of the global economy, GEM-E3, is used for that purpose. Further, the article also compares a perfect carbon market without transaction costs with the case of a gradually developing carbon market, i.e. a carbon market with (gradually diminishing) transaction costs.

JEL codes: Q54, climate; C68, computable general equilibrium models;

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1 INTRODUCTION

The UNFCCC Copenhagen Accord and Cancun Agreements (UNFCCC, 2009, 2010) on climate policy recognize that deep cuts in global greenhouse gas (GHG) emissions are needed "so as to hold the increase in global temperature below 2 degrees Celsius above pre-industrial levels". The required emission reductions in both developed and developing countries to meet the 2 degrees target are very substantial in the 2050 time horizon, which will lead to a major transformation of the energy and economic systems worldwide. World GHG emissions will be cut by 50% globally in 2050[2]. The leaders of the G8 have supported the goal of developed countries to reduce GHG emissions by at least 80% by 2050 (G8, 2009). The EU recently put forward a roadmap detailing a transition scenario in order to reduce its domestic GHG emissions by 80% in 2050 (European Commission, 2011a,b).

Regarding the 2020 time horizon, as a result of the Copenhagen Accord most world countries have announced a series of reduction commitments, known as 'pledges'[3]. For instance, the European Union (EU) will unilaterally reduce its GHG emissions by 20% compared to 1990[4]. Moreover, the EU has made a conditional offer to move to a 30% reduction, provided that other developed countries commit themselves to comparable emission reductions and that more advanced developing countries contribute adequately according to their responsibilities and respective capabilities (UNFCCC, 2011).

The main purpose of this article is to present the ex-ante modelling assessment of the Copenhagen negotiations[5] to inform the European Commission position in the run-up to UN Climate Change Conference in Copenhagen in 2009[6]. The analysis uses the computable general equilibrium (CGE) GEM-E3 model, which covers the interactions between economy, energy system and environment (Capros et al., 2010, 2012).

A key issue before the Copenhagen meeting was the burden sharing of the global mitigation effort between countries. Indeed, the cross-country of the global mitigation effort in the 2020 time horizon is a fundamental difficulty to reach an international agreement on a comprehensive and ambitious global mitigation policy. While many multi-sectoral CGE studies (e.g. Burtraw et al., 2001, Morgenstern et al., 2002) study the allocation of GHG across industries and sectors, this paper emphasizes the

[2] It is much debated whether the 50% GHG reduction should be compared to 1990 or to 2005. A global GHG reduction of 50% in 2050 compared to 2005 is considered a scenario that gives 50% chance to stay below the 2°C target, whereas a global GHG reduction of 50% in 2050 compared to 1990 scenario is a 'likely' 2°C scenario with a probability of 66% to stay below the 2°C threshold (UNEP, 2010).

[3] For an overview of the Copenhagen pledges and other climate policies of the major economies, see Townshend et al. (2011).

[4] That policy was proposed in European Commission (2008). This pledge has been formally adopted by the European parliament and the European Council in June 2009 – in a legislation known as the 'Climate and Energy Package'. It also includes a mandatory 20% share for renewable energy in the EU gross final energy consumption in 2020; and a 20% improvement of energy efficiency. See Soria and Saveyn (2010) for an overview of European climate policies.

[5] A number of studies (e.g. Dellink et al., 2011; Saveyn et al., 2011) analyse ex-post the economic impacts of the Copenhagen Accord/Cancun Agreements for the major global economies.

[6] The article summarizes and explains the methodology and results using the GEM-E3 model as published in the Communication "Towards a comprehensive climate change agreement in Copenhagen" (European Commission, 2009a,b). The modelling work was made in Autumn 2008.

different outcomes of the alternative emission allocations across countries of different low carbon emission carbon scenarios.

These allocations across countries were based on a set of four indicators that relate to country characteristics often brought forward in the international negotiations on climate change as reasons why certain countries should reduce less or more when discussing comparability. These indicators are described as simple because they are based on indicators that are readily available, and that can be easily linked to the mitigation potential by policy makers.

Firstly, GDP per capita has been chosen as an indicator of the ability to pay for mitigation actions. Secondly, the greenhouse gas (GHG) intensity of the economy, defined as the GHG emission per GDP, is an indicator of the potential to reduce emissions. Thirdly population growth, as a proxy for future population growth, is the third of the indicators that allows relatively less demanding emission reduction targets to countries that experience higher population growth than others. Fourthly, the observed past GHG emission trend is considered an indicator to reward previous action, and was applied specifically for those developed countries that have GHG reduction targets listed under annex B of the Kyoto Protocol.

The GEM-E3 model was run to quantify the macroeconomic implications of the targets implied by each of the four allocation indicators separately. A fifth scenario, resulting from a combination of the four indicators, was studied, called 'Central Scenario'. Furthermore, the second purpose of this article is to document the analysis of the role played by the degree of flexibility in global carbon trading. The article compares the ideal case of a perfect market without transaction costs with the case of a gradually developing carbon market, i.e. a carbon market with (gradually diminishing) transaction costs.

This article has five more sections. Section 2 presents the methodology and, in particular, the features of the GEM-E3 general equilibrium model, and the baseline scenario. Section 3 describes different global mitigation scenarios according to the noted allocation indicators for burden sharing. Section 4 analyses the macro-economic impact of the global mitigation scenarios. Section 5 addresses the role of a global carbon market. Finally, section 6 concludes.

2 METHODOLOGY

This section presents first the main features of the GEM-E3 model. In a second subsection, the baseline scenario is analysed. The baseline scenario is essential as it is the reference with which the reduction scenarios are compared.

2.1 The GEM-E3 model

The world version[7] of GEM-E3 is based on the GTAP database[8] and has 21 geographical regions (including the major world economies individually represented), linked through endogenous bilateral trade.

The GEM-E3 model computes the simultaneous equilibrium in the goods and services markets, as well as in production factors (labour and capital). The competitive market equilibrium under Walras' law also includes more detailed equilibria in energy demand/supply and emission/abatement. The structural features of the energy/environment system and the policy-oriented instruments (e.g. taxation) have considerable sectoral detail.

GEM-E3 can evaluate consistently the distributional effects of policies for the various economic sectors and agents across the countries. The economic consequences of environmental or economic policies can be analyzed on a national level, while ensuring that the world economy remains in equilibrium. The model is recursive-dynamic, driven by the accumulation of capital and equipment. Technological progress is explicitly represented in the production functions.

The economic agents optimize their objective functions (welfare for households and cost for firms) and determine separately the supply or demand of capital, energy, environment, labour and other goods. Market prices adjustments guarantee a global equilibrium endogenously.

The production of the firms is modelled with a nested CES neo-classical production function, using capital, labour, energy and intermediate goods. The model allows for different market clearing mechanisms and alternative market structures, in addition to perfect competition. The amount of capital is fixed within each period. The investment decisions of the firms in the current period affect the stock of capital in the next period. Labour is immobile across national borders.

The consumers decide endogenously on their demand of goods and services using a nested extended Stone Geary utility function. In a first stage, a representative consumer for each region allocates their total expected income between total consumption of goods and services (both durables and non-durables), leisure and savings. If the economic conditions are favourable, households can decide to work more and have less leisure time. In a second stage, the utility function distinguishes between durable (equipment) and consumable goods and services. Households obtain utility from consuming a non-durable good or service and from using a durable good above a subsistence level. The

[7] There are two versions of GEM-E3: GEM-E3 Europe and GEM-E3 World. They differ in their geographical and sectoral coverage, but the model specification is the same. The European version covers 24 EU countries (all EU countries, except for Luxemburg, Malta and Cyprus) and the rest of the world (in a reduced form). It is based on EUROSTAT data.

[8] This analysis from late 2008 used GTAP 6 (base year 2001). The current world version of GEM-E3 is based on GTAP 7 (base year 2004).

consumption of a durable good is directly linked to the consumption of non-durable good, e.g. fuel for the use of transport equipment.

The demand of goods by the consumers, firms (for intermediate consumption and investment) and the public sector constitutes the total domestic demand. This total demand is allocated between domestic goods and imported goods, using the Armington specification.

Government behaviour is exogenous. The model distinguishes between 9 categories of receipts, including indirect taxes, environmental taxes, direct taxes, value added taxes, production subsidies, social security contributions, import duties, foreign transfers and government firms.

This analysis used GEM-E3 to address climate change policies[9]. The model evaluates the energy-related and non-energy related emissions of carbon dioxide (CO_2), other GHG such as methane (CH_4), nitrous oxide (N_20) sulfur hexafluoride (SF_6), hydrofluorocarbon (HFC), and perfluorocarbon (PFC). There are three mechanisms of emission reduction explicitly specified in the model: (i) substitution between fuels and between energetic and non-energetic inputs, (ii) emission reduction due to a decline in production and consumption, and (iii) purchasing abatement equipment.

The model is able to compare the welfare effects of various environmental instruments, such as taxes, various forms of pollution permits and command-and-control policy. It is also possible to consider various systems of revenue recycling.

The GEM-E3 model version used in this article is the neoclassical world version, without market imperfections or rigidities in markets.

2.2 The baseline scenario

This subsection describes the assumptions and conditions on which the baseline scenario has been built for developed and developing countries[10]. The baseline scenario takes into account the existence of the Emission Trading Scheme (ETS) market in the EU, the prospect of future climate policies in other countries, and the consequences of the financial crisis in 2008-2010.

Baseline Carbon Price

In the baseline, the carbon price in the EU ETS starts at 20 €/tCO_2 in 2010 and increases linearly to 24 €/tCO_2 in 2030. This is similar to the approach that was used in the baseline scenario to assess the impact of the EU climate change and energy package (Capros et al., 2008). However, the baseline for the EU used in this assessment does neither include the implementation of the unilateral GHG

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[9] GEM-E3 can also be used to analyze air quality problems involving other pollutants such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC), ammonia (NH_3) and particulates (PM_{10}).

[10] In this analysis, developed countries include EU, USA, Japan, Canada, 'Australia and New Zealand', 'Other OECD Europe', and the Commonwealth of Independent States; whereas the developing countries correspond to China, India, Brazil, 'Mexico & Venezuela', Middle East, Southern Africa, 'South &East Mediterranean Countries', 'East South East Asia', 'Rest of Latin America', 'Rest of Asia', and 'Middle Africa'.

reduction target (-20% compared to 1990 by 2020) nor the renewables target (20% by 2020) as proposed in the EU energy and climate change package, which were still under discussion when this assessment was made (European Commission, 2008). Thus the baseline does not include the full implementation of the adopted 'Climate and Energy Package', but only a continuation of the EU ETS.

In the other developed countries a 5 €/tCO_2 carbon price is included for the same sectors as those included in the EU's ETS. This reflects the fact that, despite the absence of an ambitious international agreement, initiatives are taken to reduce carbon emissions and investment decisions are already influenced by the prospect of future more ambitious mitigation policies.

GDP growth and financial crisis

In the baseline between 2005 and 2020, average yearly growth is 2.4% for developed countries and 5.3% for developing countries, resulting in a yearly average global growth of 3.9%. The baseline takes into account the 2008-2010 financial crisis[11].

Total emissions in baseline

The GTAP 6 database has been used to calibrate the GEM-E3 model to its base year 2001. The baseline scenario to the year 2020 has taken into account the GDP and GHG emissions of the POLES baseline scenario (Russ et al., 2009). GEM-E3 does not consider the emissions from land-use, land-use change and forestry (LULUCF).

In developing countries, emissions increase much faster than in developed countries. By 2020 the baseline emissions are about 2% above 1990 level in developed countries. Emissions in developing countries increased significantly over the period 1990 to 2005 and are projected to increase at a slightly lower rate afterwards resulting in an increase of 156% over the entire 1990-2020 period.

Emissions from energy use increase faster than emissions from other sources. On a global level they are projected to increase by 71% over the period 1990-2020. For comparison, the IEA baseline for the World Energy Outlook 2008 projected an increase of energy related global CO_2 emissions of 74% for the same period (IEA, 2008).

Energy GHG emissions are projected to increase by 6% and by 68% in 2020 compared to 2005 in developed countries and developing countries, respectively. Energy GHG emissions from developing countries overtake those of developed countries before 2010. By 2020 they are 43% above those of developed countries.

[11] The growth projections were adapted when the deterioration of growth prospects became obvious in autumn 2008. Growth rates were reduced for the main regions for 2009-2010 using the then most recent IMF economic forecasts (IMF, 2008). Afterwards, it is assumed that growth will pick up again and return to higher levels.

3 GLOBAL MITIGATION SCENARIOS

This section details the specification of the five global mitigation scenarios. The group of developed countries have a 30% reduction target in 2020 compared to 1990. For the developing countries it was assumed that they would also introduce internal actions such that, combined with the targets for developed countries, global emission growth by 2020 is limited to an increase of around 20% compared to 1990. The indicators used to make the country allocation are discussed in Section 3.1. Section 3.2 allocates the emissions of developing countries in 2020 which are about 13% lower than in the baseline. Finally, Section 3.3 presents the modelling of the international carbon markets in the reduction scenarios.

3.1 Targets Developed Countries

The four indicators on which the individual country targets are based are GDP/capita, GHG/GDP, early action and population trends[12]. These targets for all developed countries of all options add up to reach the overall 30% emission reduction target in 2020 compared to 1990 in all scenarios[13]. Table 1 lists the four single indicators and their respective reduction targets, as well as the central scenario based on the four single indicators together[14].

"GDP per capita" scenario

GDP/capita is the first single indicator in order to attribute a reduction target to a country. The higher the indicator, the more stringent the reduction target is set. The income level of a country determines to a large extent the ability to pay for mitigation action. Rich countries have a higher ability to invest in reductions than poor ones and can invest more in GHG reductions in other countries through offsetting mechanisms.

One can measure GDP/capita in current prices or in purchasing power parity (PPP). As most clean environmental technologies and services required for large scale investments in low carbon energy infrastructure are traded internationally at world market prices, the GDP/capita in current prices was selected. It reflects more appropriately the availability of financial resources to invest in globally traded goods.

"GHG emissions per GDP" scenario

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[12] They are related to the four IPCC main drivers for GHG emissions , i.e. changes in energy and carbon intensity, population growth, and global per capita income growth. While these are often seen as drivers for emission growth, they can also be looked at as indicators for the ability to mitigate (IPPC, 2007).

[13] The target for the group of developed countries as a whole is smaller than 30% as the table compares to 2005, and the emissions have decreased in the developed countries between 1990 and 2005.

[14] See Annex in European Commission (2009b) for more details on how the Central Scenario was constructed based on 4 single indicators (with unequal weights).

The ratio GHG emissions per unit of GDP, is the second single indicator that could be used to attribute a reduction target to a country. The higher the indicator, the more emissions are needed to generate GDP, and the more ambitious the reduction target can be. The total emissions a country emits in order to produce its goods and services may indicate whether there is a potential to reduce emissions. Low carbon productivity can be attributed either to a carbon intensive energy mix or to a high degree of energy inefficiency. These conditions generally offer substantial mitigation potential at lower cost than those economies that have a low carbon energy mix or are highly energy efficient.

Table 1: Key indicators and targets for developed countries

	GDP/cap		GHG/GDP		Early Action		Population trends		Central Scenario
	GDP per capita in 1000€, 2005[a]	Target in 2020 compared to 2005	GHG/GDP, 2005, in kg of CO2 per US$(2000)[b]	Target in 2020 compared to 2005	GHG trend 1990 to 2005 (in %)[c]	Target in 2020 compared to 2005	Population trend 1990 to 2005 (in %)[d]	Target in 2020 compared to 2005	Target in 2020 compared to 2005
EU	22.5	-25.1%	0.43	-20.1%	-8%	-22.4%	4.0%	-38.1%	-24%
USA	33.8	-45.3%	0.53	-26.8%	16%	-41.5%	17.1%	-13.1%	-34%
Japan	28.7	-37.1%	0.24	-6.1%	7%	-36.1%	3.5%	-38.4%	-29%
Canada	28.3	-36.5%	0.67	-32.5%	25%	-46.8%	16.5%	-14.4%	-39%
Australia, New Zealand	26.9	-34.2%	0.77	-36.7%	27%	-47.9%	20.3%	-6.2%	-38%
Other OECD Europe	45.7	-64.5%	0.19	-2.1%	5%	-35.1%	9.1%	-30.5%	-30%
Commonwealth of Independent States	3.6	15.5%	4.66	-46.0%	-35%	6.0%	-4.6%	-42.7%	-12%
Developed countries		-27.3%		-27.3%		-27.3%		-27.3%	-27%

a Adapted from World Bank and Eurostat
b Data from IEA2007
c Data database UNFCCC website
d UN population data

"Early action" scenario

The observed GHG emission trend is the third single indicator that could be used to attribute a reduction target to a country. The steeper the reduction has been since 1990, the less ambitious the future reduction target is set. Over the 1990-2005 period total GHG emissions of the group of developed countries has actually declined. But there have been huge differences across countries, with large reductions in some while others have increased their emissions substantially. By taking early action many (cheap) emission reduction options have already been realised in the past, or it reflects that the countries have experienced an economic downturn. At the same time, taking early action into account provides a reward and an incentive for the future. The data used in this assessment are the historic GHG emissions trend over the period 1990-2005, excluding the LULUCF sector.

"Population growth" scenario

Population trend is the fourth single indicator that could be used to attribute a reduction target to a country. The higher the indicator, the less stringent the reduction target can be. Countries with an increasing population will face more difficulties to reduce their emissions than countries with stable or declining populations, assuming per capita income, carbon and energy intensity are all stable. The data used in this assessment are the historic population trends over the period 1990-2005.

Central scenario

The central scenario simultaneously takes into account all four single indicators[15]: a GDP/capita, GHG/GDP, GHG emission trends and Population trends. Each developed country has intermediate targets which lie between the extremes of the single-indicator targets. However, the individual country targets in the central scenario for all developed countries still add up to 30% emission reduction target in 2020 compared to 1990.

3.2 Targets Developing Countries

For the developing countries it was assumed that they would also introduce internal actions to ensure that, combined with the targets for developed countries, global emission growth by 2020 is limited to an increase of around 20% compared to 1990. Therefore the developing countries as a group have a reduction target of about 13% in 2020 compared to baseline.

Table 2: Targets for developing countries (in % vs. baseline 2020)

	GDP/cap	GHG/GDP	Population trend ’05-‘20	Targets
Brazil	-13.2%	0.0%	3.9%	-9%
China	-4.2%	-13.0%	1.0%	-16%
India	-0.5%	-12.2%	4.9%	-8%

In order to determine the individual level of action by developing countries, single indicators similar to those of developed countries were used. Firstly, GDP per capita also is for developing countries an indicator for the ability to pay for emission reduction within their country. The higher a country's GDP per capita, the more national actions it would undertake to limit emissions growth compared to baseline. Secondly, GHG per GDP is an indicator for the opportunities to reduce GHG emissions. The higher a country's GHG emissions per GDP, the more it would need to undertake action to limit emission growth compared to baseline. Thirdly, the population trends over the period 2005–2020 is a

[15] See Annex in European Commission (2009b) for more details on how the central scenario is defined.

proxy for future population trends, and a indicator for future pressures on the projected emission evolution. The higher a country's projected population growth rate up to 2020, the less mitigation action it would need to undertake. As the focus of this paper is on the allocation across developed countries, the same individual targets for the developing countries are used for all scenarios.

As the focus of the paper is on the allocation across developed countries, the same individual targets for the developing countries are used across all scenarios. Table 2 gives the implications of each indicator on the total amount of reduction needed compared to baseline in this internal action scenario for China, Brazil and India. Brazil being the richest of these three countries would need to limit emissions most according to its GDP/Capita. For Brazil the reverse is true for GHG intensity of its economy, where it is one of the better performers. Finally, India has a high population growth rate while that of China is low resulting in a different amount of allowed increase compared to baseline. In total, China is expected to reduce more than the other two compared to baseline.

3.3 Gradually developing global carbon market

A global carbon market with a single carbon price across all world regions and sectors leads to minimum cost for compliance with a certain emission reduction target. The scenarios developed in this article, however, assume a gradually developing global carbon market with an increasing availability of carbon permits from the developing countries. This imperfectly working carbon market represents a more realistic behaviour in line with the existence of transaction costs, such as the building up of the administrative capacity to implement trading, in particular in developing countries. These transaction costs are assumed to decrease over time, resulting in a gradually increasing penetration of the carbon market in developing countries, maintaining the principle of economic efficiency through trading.

In order to reduce emissions in the range of 30% compared to 1990, developed countries set up a trading system similarly to the EU ETS which establishes a carbon price for the energy intensive industrial sectors, including the power sector. There is a single carbon price path across developed countries from 2015 on.

From 2015 on, developing countries are exposed to a low carbon price through policy instruments such as Clean Development Mechanism (CDM). In a perfectly working carbon market, the developing countries would reduce up to the point where the carbon abatement cost equals the global permit price. Developing countries are 'net sellers' of carbon credits generated by emission reductions beyond their own emission reduction targets. In a gradually developing carbon market, however, developing countries abate less carbon than the point where abatement costs equal global carbon price. Hence, they do not sell the full 'potential' of carbon permits than they would do in a perfectly working carbon market for a corresponding carbon price. Table 3 illustrates the carbon market penetration in developing countries in 2020. We assume that middle-income countries such as Brazil trade about 70% of what they do in a perfect carbon market, whereas low-income countries (such as sub-Saharan Africa, excl. southern states) only reach about 30% of their potential.

Table 3: Carbon market penetration in developing countries in 2020 (in %)

Brazil	76%	China	55%
Southern Africa	73%	India	33%
Rest of Eastern Asia	72%	Rest of Asia	30%
Rest of Latin America	67%	Middle Africa	30%

Non-energy intensive sectors such as, transport, agriculture, residential and service sectors do not participate in the global carbon market. Reductions are obtained by domestic measures.

The degree of development of the global carbon market in 2020 is an important factor to assess the costs of GHG mitigation. In Section 5 we compare the costs for mitigation policies for a developing carbon market with two extremes, i.e. no global carbon market at all and a perfect global carbon market which equalises on a global scale the marginal abatement costs in the sectors involved.

4 ECONOMIC IMPLICATIONS OF VARIOUS ALLOCATIONS

This section gives the effects on the economic welfare, GDP, employment and private consumption of the developed countries of the targets listed in Table 1 for the four 'single-indicator scenarios', and for the 'central scenario'. The targets for the developing countries (as in Table 2) are kept identical across all 5 different allocations for the developed countries. All scenarios use free allocation (grand-fathered permits), both for the EU and the other countries.

Four single-indicator scenarios

Table 4 list the economic impacts for the 4 allocations based on a single indicator. In general, the allocation option that leads to the smallest economic impacts for the group of developed countries is the one that uses GHG intensity of the economy, but this is also the one that has the relatively most negative impact on the Commonwealth of Independent States reflecting the very high mitigation potential but relative low GDP.

If one looks at the impact on welfare, US, Canada and Australia & New Zealand all would favour population trend as the preferred option to allocate targets, whereas the EU, Japan and Other OECD Europe would prefer the option based on the GHG intensity of the economy. Welfare in the Commonwealth of Independent States could even increase if targets were set only in accordance with the option using early action or GDP/capita. Europe would be faced with the highest economic impacts with the option using population trends as the sole indicator. USA, Japan and Other OECD Europe would incur highest welfare losses when using GDP/capita.

Table 4: Results in 2020 for 4 indicators for developed countries (compared to baseline)

Impact on economic welfare	GDP/Cap	GHG/GDP	Early action	Population trends
EU27	-1.6%	-1.1%	-1.3%	-2.6%
USA	-1.2%	-0.5%	-1.0%	-0.3%
Japan	-1.0%	-0.1%	-0.9%	-0.9%
Canada	-2.2%	-1.6%	-3.1%	-0.8%
Australia & New Zealand	-1.8%	-1.7%	-2.6%	-0.7%
Other OECD Europe	-5.7%	-0.5%	-1.9%	-1.5%
Commonwealth of Independent States	1.2%	-8.5%	0.8%	-7.7%
Average Developed countries	-1.3%	-0.9%	-1.1%	-1.4%
Impact on GDP	**GDP/Cap**	**GHG/GDP**	**Early action**	**Population trends**
EU27	-1.5%	-1.0%	-1.3%	-2.1%
USA	-1.2%	-0.5%	-1.0%	-0.5%
Japan	-1.0%	-0.2%	-0.9%	-0.9%
Canada	-2.0%	-1.5%	-2.7%	-0.9%
Australia & New Zealand	-2.0%	-1.8%	-2.8%	-1.0%
Other OECD Europe	-4.8%	-0.3%	-1.3%	-1.0%
Commonwealth of Independent States	-2.6%	-7.3%	-2.5%	-6.6%
Average Developed countries	-1.4%	-0.8%	-1.2%	-1.2%
Impact on employment	**GDP/Cap**	**GHG/GDP**	**Early action**	**Population trends**
EU27	-0.4%	-0.4%	-0.4%	-0.7%
USA	-0.5%	-0.3%	-0.4%	-0.2%
Japan	-0.4%	-0.1%	-0.4%	-0.4%
Canada	-0.7%	-0.6%	-0.9%	-0.4%
Australia & New Zealand	-0.7%	-0.8%	-1.1%	-0.4%
Other OECD Europe	-1.8%	0.1%	-0.2%	-0.2%
Commonwealth of Independent States	-1.6%	-2.2%	-1.5%	-1.9%
Average Developed countries	-0.7%	-0.7%	-0.7%	-0.8%
Impact on private consumption	**GDP/Cap**	**GHG/GDP**	**Early action**	**Population trends**
EU27	-2.1%	-1.4%	-1.8%	-3.3%
USA	-1.9%	-0.8%	-1.6%	-0.6%
Japan	-1.6%	-0.3%	-1.5%	-1.5%
Canada	-3.4%	-2.5%	-4.7%	-1.3%
Australia & New Zealand	-3.0%	-2.8%	-4.3%	-1.3%
Other OECD Europe	-8.3%	-0.6%	-2.5%	-2.1%
Commonwealth of Independent States	-0.2%	-12.5%	-0.7%	-11.2%
Average Developed countries	-2.1%	-1.2%	-1.8%	-1.8%

Relative impacts on GDP are very similar to the relative impact on overall welfare. Note that GDP decreases in the Commonwealth of Independent States, when early action or GDP/capita is used as the indicator to establish the targets while economic welfare increases. The reason is that the Commonwealth of Independent States becomes a net seller in the carbon market, and the model assumes that the revenue is used for extra consumption rather than for investments that would increase GDP growth. For employment and private consumption similar relative differences can be noted.

Some of the single-indicator scenarios have large differences in emission targets across developed countries resulting in large differences in the economic impact. Most notably, the indicators for GHG intensity in the economy or population trends lead to ambitious targets for the Commonwealth of Independent States, and their respective impacts are high. Similarly, GDP per capita leads to high impacts for Other OECD Europe. The same is true to a lesser extent for Canada using the early action indicator. The overall result confirms why certain countries prefer certain allocation methods when discussing comparability of effort. Japan would probably bring forward it is already GHG efficient, Russia will refer to its economic downturn in the early 90's or the fact that it still has a lower GDP per capita. Canada and Australia could bring forward that their populations are still growing fast.

Central Scenario

Table **5** reports on the economic impacts of the targets for the central scenario for each region. For every country, impacts are between the extremes of impacts of the policy scenarios based on single indicators (Table 4 list the economic impacts for the 4 allocations based on a single indicator. In general, the allocation option that leads to the smallest economic impacts for the group of developed countries is the one that uses GHG intensity of the economy, but this is also the one that has the relatively most negative impact on the Commonwealth of Independent States reflecting the very high mitigation potential but relative low GDP.

If one looks at the impact on welfare, US, Canada and Australia & New Zealand all would favour population trend as the preferred option to allocate targets, whereas the EU, Japan and Other OECD Europe would prefer the option based on the GHG intensity of the economy. Welfare in the Commonwealth of Independent States could even increase if targets were set only in accordance with the option using early action or GDP/capita. Europe would be faced with the highest economic impacts with the option using population trends as the sole indicator. USA, Japan and Other OECD Europe would incur highest welfare losses when using GDP/capita.

Table 4). Overall impacts for the group of developed countries are very close to the outcome for the GHG intensity indicator, which has the lowest impact of the 4 single-indicator scenarios.

Table 5: Economic Impacts resulting from the Central Scenario in 2020

Change compared to baseline	Target vs. 2005	Economic Welfare	GDP	Employment	Private consumption
EU27	-24%	-1.4%	-1.2%	-0.4%	-1.8%
USA	-34%	-0.7%	-0.8%	-0.4%	-1.2%
Japan	-29%	-0.6%	-0.6%	-0.3%	-1.0%
Canada	-39%	-2.2%	-2.0%	-0.7%	-3.4%
Australia & New Zealand	-38%	-1.9%	-2.0%	-0.8%	-3.2%
Other OECD Europe	-30%	-1.5%	-1.0%	-0.1%	-2.0%
Commonwealth of Independent States	-12%	-1.4%	-3.0%	-1.5%	-3.4%
Average Developed Countries	-27%	-1.0%	-1.0%	-0.6%	-1.5%

All impacts, be it on economic welfare, GDP, employment or private consumption at country level fall within the interval of highest and lowest impact for any of the 4 previous scenarios with the allocation method based on one single indicator, the exception being the impact on employment for the EU27 and Commonwealth of Independent States which is equal to the smallest impact across the previous four scenarios. Whereas every country clearly has one or two single indicators that it might prefer to discuss comparability of efforts, it is clear that only by combining these indicators one generates results that are comparable and potentially acceptable across countries. Hence, any agreement on comparability of effort across developed countries will require a combination of indicators. The 4 single indicators used in this exercise seem to be the type of indicators that are readily available, easy to understand and can result in a combination of efforts that is comparable.

Impacts on welfare are highest for Canada and Australia & New Zealand, who have also the highest targets compared to 2005. The Commonwealth of Independent States has also a relatively higher impact, particularly for GDP, even with relatively low targets compared to the others. Importantly, in countries where the economic impact looks relatively high compared to the 2020 baseline, growth rates are higher and impacts appear less significant when compared in terms of overall GDP growth over the period 2001- 2020 (Table 6).

Table 6: Impact on growth over the period 2001-2020

	Baseline	Central Scenario
EU27	38.9%	37.2%
USA	51.8%	50.6%
Japan	37.5%	36.6%
Canada	55.1%	52.0%
Australia & New Zealand	61.8%	58.5%
Other OECD Europe	38.1%	36.7%
Commonwealth of Independent States	99.7%	93.7%

The US and Japan face the lowest economic impacts (

Table **5**). For Japan this is partly due to the fact that it has a very low GHG intensity per GDP. So even if marginal costs are relatively high per ton of CO_2 reduced, total costs are small compared to GDP. The US has a similar GHG/GDP intensity as EU-27 in 2020. However, the domestic production and exports of energy intensive products is higher in the EU-27 than in the US.

Concerning Canada, Australia & New Zealand, these countries face higher impacts because their GHG emissions/GDP and energy consumption/GDP shares are rather high compared to the rest of developed countries. Furthermore, domestic production and exports of energy intensive industrial products are higher in Canada, Australia & New Zealand.

5 ROLE OF GLOBAL CARBON MARKET

The carbon market may have a crucial role to play in order to implement the climate policies in a cost-efficient way. It is not only a manner to reduce overall costs; it also is a mechanism that links climate policies in the developed and developing world. In our scenarios, the offsetting mechanisms are limited to the sectors which are typically part of the EU ETS. In section 4, it was assumed that the global carbon market is imperfect as there are significant transaction costs in the transactions with developing countries. This simulates a more realistic gradual development of the carbon market but as a consequence developing countries are unable to sell the full potential of their carbon credits given the carbon price.

This section analyses the sensitivity of the economic effects in the central case with respect to the degree of development of the global carbon market. We assess the macro-economic costs of climate policy according to the different degrees of development of the global carbon market. The targets for Table 2 show that developing countries also receive an allocation which is lower than the baseline emissions, but these can be seen as own appropriate action, that does not generate any international offsetting credits. The allocation of these economy-wide targets creates global carbon market with a demand for emission reduction credits by developed countries from developing countries; such that the latter potentially reduce their emissions beyond their own appropriate action.

Table 7: Emission reductions and trade in emissions permits

	No Global Carbon Market	Gradual Global Carbon Market	Perfect Global Carbon Market
	2020 target (vs. 2005 emissions)	Domestic reduction in 2020 (vs. 2005 emissions)	Domestic reduction in 2020 (vs. 2005 emissions)
Average Developed Countries	-27%	-23%	-20%
EU27	-24%	-19%	-18%
USA	-34%	-29%	-25%
Japan	-29%	-22%	-19%
Canada	-39%	-25%	-21%
Australia & New Zealand	-38%	-19%	-13%
Other OECD Europe	-30%	-27%	-26%
Commonwealth of Independent States	-12%	-19%	-14%
	2020 target (vs. baseline emissions)	Domestic reduction in 2020 (vs. baseline emissions)	Domestic reduction in 2020 (vs. baseline emissions)
Average Developing countries	-13%	-16%	-19%
Mexico & Venezuela	-18%	-18%	-16%
Middle East	-16%	-18%	-15%
Brazil	-9%	-12%	-13%

Southern Africa	-14%	-17%	-18%
South & East Mediterranean Countries	-8%	-15%	-18%
East South East Asia	-11%	-14%	-16%
Rest of Latin America	-6%	-9%	-10%
China	-16%	-21%	-25%
India	-8%	-11%	-16%
Rest of Asia	-7%	-10%	-17%
Middle Africa	0%	-3%	-8%

Table 7 represents the domestic reduction for the Central Scenario with a 'No Global Carbon Market', a 'Gradual Global Carbon Market', and a 'Perfect Global Carbon Market'. The amount of traded emission permits increases for the left side to the right side. As there is no trade in emission permits for 'No Global Carbon Market', the domestic reductions in the left column correspond with the targets for the Central Scenario as allocated in Section 3.

Case 1: Gradual global carbon market

This standard approach is used in section 4. GHG emissions in developed countries endogenously decrease by 23% in 2020. The remainder 4% of their target (both compared to 2005) needs to be achieved through offsetting mechanisms in the global carbon market.

Case 2: No global carbon market

The developed countries reach the -30% target completely domestically (vs. 1990).

Case 3: Perfect global carbon market

There is a global carbon market encompassing all ETS sectors in both developed and developing world, and we assume there are no transaction costs. GHG emissions in developed countries endogenously decrease by 20% in 2020. The remainder 7% of their target (both compared to 2005) are achieved through offsetting mechanisms in the global carbon market.

Similarly, with a gradual global carbon market developing countries reduce their emissions compared to baseline by around 16%, of which 3% can be sold through the carbon market. This surplus increases to 6% with a perfect global carbon market. This means that still 13% of reductions in developing countries come from domestic actions that are not directly supported by the international carbon market (which corresponds to target in section 3.2).

Table 8: Impact of gradual development of the carbon market

	Welfare compared to baseline			GDP compared to baseline		
2020	Perfect market	Gradual market	No market	Perfect market	Gradual market	No market
EU27	-0.7%	-1.4%	-1.4%	-0.4%	-1.2%	-1.5%
USA	-0.5%	-0.7%	-0.7%	-0.4%	-0.8%	-1.0%
Japan	-0.3%	-0.6%	-0.6%	-0.3%	-0.6%	-0.7%
Commonwealth of Independent States	-1.3%	-1.4%	-1.7%	-2.7%	-3.0%	-2.1%
China	0.5%	0.3%	-0.2%	-1.4%	-0.8%	-0.5%
Brazil	0.0%	-0.1%	-0.2%	-0.5%	-0.4%	-0.2%
India	0.1%	-0.2%	-0.4%	-1.4%	-0.5%	-0.5%
World	-0.3%	-0.7%	-0.8%	-0.5%	-0.9%	-1.0%
	GHG Emissions compared to baseline			GHG Emissions compared to 1990		
2020	Perfect market	Gradual market	No market	Perfect market	Gradual market	No market
EU27	-6.3%	-20.9%	-25.3%	-8.5%	-22.8%	-27.1%
USA	-20.9%	-31.6%	-37.7%	-1.0%	-14.3%	-22.0%
Japan	-14.8%	-23.9%	-31.0%	-7.4%	-17.3%	-25.0%
Commonwealth of Independent States	-24.9%	-26.1%	-20.4%	-46.7%	-47.5%	-43.5%
China	-32.9%	-20.8%	-16.2%	70.3%	100.9%	112.6%
Brazil	-18.8%	-12.3%	-9.3%	80.7%	95.2%	102.0%
India	-23.5%	-10.7%	-7.8%	143.1%	183.6%	192.9%

The Commonwealth of Independent States, as the only developed country, reduces beyond their target when emission trading is allowed. Interestingly, they reduce less in the perfect global market case than in the gradual global carbon market case. As we did not assume any transaction costs for this developed country, they were outcompeted when all reduction potential is available on the international carbon market. Similarly, oil-producing middle income countries like Venezuela, Mexico and the Middle East change from net sellers to net buyers when the international carbon market becomes more mature, and hence, decreasing carbon values.

Carbon prices for the ETS-sectors in developed countries range from € 71 per ton of CO_2eq in case of the need to achieve the 30% internally to € 27 per ton of CO_2eq in the case of a perfect global carbon market, with an intermediate € 40 per ton of CO2eq as a price level in case of the gradual carbon market.

Table **8** shows clearly for the three cases the role of a carbon market for welfare and GDP impacts. For all regions and countries the welfare is the highest for the case with a perfect global carbon market, and the lowest for the case with no carbon market. The gradually developing carbon market has an intermediate outcome.

For the GDP, however, the outcome is mixed. With a perfect global carbon market the GDP of the developed countries is the highest, whereas the developing countries have a higher GDP with no global carbon market. Due to the transfer of credits, consumers in developing countries receive a higher income which they decide to spend rather on more consumption and leisure, as such maximising welfare. The world GDP in general is better off with a perfect global carbon market.

World	-21.4%	-21.4%	-21.4%	18.3%	18.3%	18.3%

6 CONCLUSIONS

A key issue in the international negotiations for the post-2012 period relates to the economic effects of alternative mitigation targets across developed countries. The distribution of mitigation costs across countries makes necessary to consider not only efficiency but also equity issues. This article uses the GEM-E3 model in order to explore the economic implications of alternative emissions allocations methods of global climate scenarios. They are based on readily available indicators that are easy to understand for policy makers.

The single indicators to prescribe alternative burden-sharing allocation are GDP/capita, GHG/GDP, Early action and population trends. The GEM-E3 model has assessed the effects in developed countries of the allocation of targets according to each single indicator. Given that a single indicator leads often to disproportional costs or gains in single countries (e.g. for the case of the GDP per capita high income countries undergo very large GDP losses), it seems unlikely that comparable allocation of targets will be based on a single indicator. Therefore, a 'Central Scenario' is built which combines the four indicators and is consistent with the 2°C target. The impacts on welfare, GDP, employment and private consumption which are between the extremes of the impacts of any single indicator allocation method, as such underlining that reasonable comparability will require a multiple set of indicators.

Further, the study discussed the role of a carbon market for reducing the economic costs of climate policies. Particular attention was paid to the gradually developing carbon market, facing (gradually diminishing) transaction costs. The results show that the carbon market can reduce the carbon prices for the ETS-sectors in developed countries range from € 71 per ton of CO_2eq to € 27 per ton of CO_2eq in the case of a perfect global carbon market, with € 40 per ton of CO_2eq as a price level in case of the gradually developing carbon market. Moreover, even an imperfect carbon market may reduce the GDP costs significantly compared to the case were all GHG reductions are obtained domestically. Given that perfect markets with full flexibility on where, when and what kind of reductions are done is practically inconceivable, it is exactly the scenario with gradually developing carbon market that emphasizes the importance and benefits of efforts to further developed the international carbon markets where country specific carbon trading mechanisms gradually are developed and linked.

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Abstract

The distribution of the mitigation burden across countries is a key issue regarding the post-2012 global climate policies. This article explores the economic implications of alternative allocation rules, an assessment made in the run-up to the COP15 in Copenhagen (December 2009). We analyse the comparability of the allocations across countries based on four single indicators: GDP per capita, GHG emissions per GDP, population growth, and the GHG emission trend in the recent past. The multi-sectoral computable general equilibrium model of the global economy, GEM-E3, is used for that purpose. Further, the article also compares a perfect carbon market without transaction costs with the case of a gradually developing carbon market, i.e. a carbon market with (gradually diminishing) transaction costs.

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