

**Burden Sharing:
Estimating Global Demand and Supply Flows of Carbon Emission
Reductions for 2020 and 2050**

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Abstract

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Created under the Kyoto Protocol, the CDM mechanism represented a lower-cost solution for developed countries to reduce their GHG emissions. It is also believed to have positive spill-over effects for supplier countries, in general developing countries. In addition to receiving monetary transfers, the latter would benefit from technology transfers and energy efficiency improvements, which in the long term could help foster a more important commitment of developing countries and a fairer burden sharing.

On the basis of Marginal Abatement Cost Curves (MACCs) for different regions, our model assumes different possible evolutions of demand and supply of CO₂ emission reductions for the next four decades and their potential price, under two types of hypothesis. A first set of assumptions concerns the global reduction effort and a corresponding level of CO₂e concentration by 2020/ 2050. The second set of assumption is focusing on the sharing of the reduction effort between developed (Annex I) countries and developing countries. We develop two scenarios in this context: a more important role of the Annex I countries in mitigation and their financial support for its spread within developing nations and a more balanced sharing of emissions reductions regarding to each countries' population and its evolution by 2050.

According to the MAC curves constructed for the first scenario and the estimations for the second one, we can observe that for 2020, the second scenario is less demanding for the developing countries. Some can even increase their emissions. Potential flows are quite important. For 2050 instead, a great part of developing countries are obliged to import allocations in both scenarios.

Keywords: CDM, MACCs, developing countries, burden sharing.
JEL classification: O16, Q56.

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1. Introduction

Created under the Kyoto Protocol, the Clean Development Mechanism (CDM) mechanism represents a lower-cost solution for developed countries to reduce their GHG emissions. There are mainly three possibilities of mitigation for a country in order to meet its Kyoto-target: domestic CO₂ emission reductions in the European Trading Scheme (ETS hereafter) sectors or the trading of emission allowances; domestic reductions of CO₂-emissions in the sectors not covered by the ETS and/or reductions of other greenhouse gases (GHG hereafter) than CO₂ and emission reductions abroad possibly with CDM or Joint Implementations (JI).

The third option can be used by firms and/ or governments covered by the ETS to set less stringent domestic targets by avoiding emissions abroad. Beside that, it is also believed to have some positive spillover effects for recipient countries, which are generally developing countries². In addition to monetary transfers, this third option was supposed to allow technology transfer and energy efficiency improvements. All these transfers should help prepare developing countries for a more important commitment in the long term

Since its creation by the end of 2003, CDM has followed an important evolution, During the first three years very few projects were submitted for validation and registration, but this can be explained by the length of the required procedure. 2007 was the year of the highest level of Primary CDM transactions (see Table 1). Since then, the financial crisis has worsened the situation. Nevertheless, thanks to the rapid growth of the secondary CDM market, the total weight of CDM transactions has maintained its growing trend and represented almost one third of the allowances markets by 2008.

In 2008, the major buyer for Primary CDM was still the European Union, as Japan's share hasn't stopped declining since 2005 (see Figure 1). On the supply side, China maintained its prevailing importance with 84% of the supplied volumes (see Figure 2). The majority of the projects did not concern HFC reductions any more, but the implementation of renewable energies and energy efficiency tools (see Figure 3). The conclusion that can be made is that CDM projects are not longer focused only on fast returns on investment but also on opportunities of real improvement of existing energy systems.

² While CDM concern only developing countries without constraint on emissions, JI, are project based mechanisms used by countries in transition (from state based economy to market based economy) and countries or Annex I countries.

This brief overview of the current situation can be really useful to put in perspective our work and our findings. The present paper aims to determine the potential for CDM flows towards developing countries during the next four decades, focusing on the potential quantities and prices of CERs. Regardless of the fact that the current CDM architecture has met numerous criticisms, it is clear that some form of minimizing abatement costs through developed country – developing country collaboration will also be part of global efforts to reduce GHG emissions in the future.

We thus focus in the following paper on the potential demand and supply of CO₂ emission reductions and their potential price under different scenarios of burden- sharing.

In this study, we do not consider the particularities of CDM, but potential exports and imports of units of CO₂e between developing and developed countries with regard to their reduction commitment and to their respective effort. We choose to call them potential flows of CDM, because this is the current institutional framework. However, our results hold under any particular framework sharing the same principle arrangements for global burden sharing.

Several studies have focused on CDM importance within smaller time intervals. Section 2 will present an in-depth analysis of the available literature on this topic. Section 3 draws an overview of the model and its hypothesis. Details about data are shown in Section 4 and the results analyses are described in Section 5. The article ends by general conclusions and remarks.

2. Literature review

Up to now, two types of studies on CDM importance or on burden sharing between developed and developing countries exist: those going up to 2012 and those going beyond that time period. Nonetheless, most of them are based on Computable General Equilibrium (CGE) models and CO₂ prices and quantities are resulting from the construction of Marginal Abatement Cost Curves (MACCs).

Following the work of McKittrick (1999), the MAC links a firm's emission level with the cost of additional units of pollution reduction. In his findings he focuses on the duality of a firm's possible action in order to respect a mitigation cap: by reducing its emissions or by reducing its output. In our study we only focus on the case where firms invest in pollution control equipment to reduce their emissions.

As Klepper et Peterson (2004) define it, the marginal abatement cost in a CGE model, represents the shadow cost that results from a constraint on carbon emissions for a given region and a given time. It corresponds to the tax that would have to be levied on the emissions in order to achieve the targeted level. In our case of emissions trading, it

corresponds to the price of an emission permit. The more severe the constraint is, the more important the marginal abatement costs should be.

Before presenting our model, based on the MIT EPPA (Emission Prediction and Policy Analysis) model (Ellerman et Decaux, 1998; Jacoby *et alii* (2008)) we will focus on the existing competitive models and their findings about CDM.

There are five major models trying to represent the world economy and its environmental impact through MACCs: **POLES** (Criqui, Cattier, Menanteau, and Quido, 1996; Criqui et Mima, 2009), **CERT** (Haïtes; 2004), **DART** (Klepper et Peterson; 2004), **FEEM-RICE** (Buchner et Carraro, 2005) and **EPPA** (Ellerman et Decaux, 1998; Jacoby et alii; 2008). Ghersi (2001) uses also MACCs in an *ad-hoc* approach, but its methodology is not based on a CGE model, so we will not discuss it in this paper.

The **POLES** (Prospective Outlook on Long term Energy Systems) model is a bottom-up multi-regional model. It is not a General Equilibrium model as most of those that shall be presented, but a Partial Equilibrium model of the world's energy system. In its first version, it was representing the energy demand variations and the corresponding levels of emission reductions as a result of technological or behavioural changes.

In its latest version it allows a dynamic recursive simulation process, providing year-by-year projections until 2100. They describe the possible scenarios of energy development, fuel supply, GHG emissions, international and final consumer prices, from today to 2050. Projections are made on the basis of exogenous economic growth and demographic projections for each region. 47 world regions are identified, 22 economic and industrial sectors are defined as energy demanders, 40 energy technologies are represented (including “very low energy” end-use technologies).

There are no specified studies focusing on the possible burden-sharing between developing and developed countries, based on this model. Nevertheless, in their last publication Criqui and Mima (2009) are considering four types of scenarios for climate policies and their impacts on energy security. We chose to focus on them, given their similarity with our own scenarios.

The “Baseline” scenario is a Business-As-Usual case. The “Muddling Through” develops the idea of the lack of world coordination on abatement actions, only weak domestic policies are put in place. The “Europe Alone” case represents the situation, where the EU is undertaking the leading role in mitigation, while the rest of the world follows a “muddling through” attitude. Finally, the “Global Regime” scenario suggests an implication of all the world regions in the reduction effort.

The last mentioned scenario, corresponds to a concentration stabilization profile below 450 ppm CO₂ and 500 ppm CO_{2e} by 2050 which is equivalent to a global reduction of 50% of 2000 CO₂ emissions in 2050. This scenario is split into two variants. The first one (S3a) is considering a major implication of the Annex I countries in the mitigation process. They are responsible for 80% of global reductions and the non-Annex I countries are on charge of the residual part. According to the authors, in this case no use of flexibility mechanisms is allowed as Annex I countries have chosen a strong target and as this leaves the possibility for developing regions to have a less stringent constraint. However, in the second variant “S3b scenario”, the same world emission’s level is achieved, through the settlement of a global trading system or a world carbon tax.

In Criqui and Mima (2009) the authors use these scenarios in order to define what shall be their impact on the energy consumption profile in the EU and their dependence. Thus, they focus on the existing interactions between climate policies and energy security issues. They conclude, that the last presented scenario, which is very similar to those that we are considering, allows achieving a double dividend situation. Indeed it shows clearly that a global coordination process helps reducing both emissions and fossil fuel dependence, through lower oil and gas production.

The authors do not consider the question of the repartition of the burden sharing in details; it is defined as one of the basic assumptions in the model. So, from that point it will not be possible to tempt a comparison on the on-going responsibility of each country/region and its evolution by 2020/2050. However, their last scenario is based on assumptions quite close to ours and a parallel of the resulting price levels of a tCO₂ can be considered.

The **CERT** (Carbon Emission Reduction Trade) model is based on some characteristics of the EPPA model and the GTEM model (Global Trade and Environment Model) developed by the Australian Bureau of Agricultural and Resource Economics. But it only covers energy-related CO₂ emissions and excludes the United States and Australia, which is quite restrictive in the case of estimations going further than 2010.

The CERT model proposes estimates of CDM market by 2010. It allows the determination of equilibrium prices and quantities after considering demand and supply side characteristics. However, as the model focuses on the horizon of 2010, estimates do not take into account a possible burden sharing between developing and developed countries.

The **DART** (Dynamic Applied Regional Trade) top-down model is a multiregional and multi-sector recursive dynamic CGE model developed by the Institute of World Economy in Kiel. A recursive dynamic model is solved for a sequence of static one-period equilibriums. Results are computed one-period-at-a-time, in contrast with fully intertemporal models where results are computed simultaneously for all periods. The term of “recursive” determines the fact that the model is solved on a year-to-year basis. It is also called

“dynamic” as the solutions are iterated for several years, starting from an initial time period and every new iteration takes into account the previously obtained results. However, the DART model neither take into account the use of renewable energies in electricity generation nor CCS technologies, which at the horizon of 2050 should have an impact on world economy and its global level of emissions.

Based on the DART model, Klepper and Peterson (2005) present a study on “Emissions Trading, CDM, JI, and More”. They focus on the climate strategy of the EU at the horizon of 2012, by comparing different scenarios of possible strategies to achieve its mitigation commitments. Those strategies include the use of project based mechanisms such as CDM and JI, in addition to National Allocation Plans (NAPs) included by European Trading System (EU ETS). Thus, the market potential of CDM and JI is determined only within their capacity of completing the European Units Allowance (EUA) credits issued by the EU ETS.

In their work, the authors find that all the gains achieved through international emissions trading (CDM and JI exchanges) were netted out by the distortions created between the ETS and the non-ETS sectors within each economy. Therefore, they recommend reducing the costs of the European climate strategies by reducing the burden for the non-ETS sectors. They consider that this most optimal strategy can be achieved by setting stricter targets for the ETS installations and by restricting the use of CDM and JI for the ETS installations.

As one may understand the paper does not consider an eventual burden sharing between developing and developed countries, but how the EU should optimise the use of CDM and JI in order to achieve its commitments. Therefore, we will not be able to compare further, this study’s results with ours.

The **FEEM-RICE** (Fondazione Eni Enrico Mattei –RICE) model is a regional dynamic model in which technical change is considered as endogenous (evolving with the model and the assumptions of environmental requirements). It represents an extended version of the RICE model of Nordhaus and Yang (1996): an optimal growth model with a single sector and a multi-regional approach. The advantage of this model is that it allows quantifying international technological spillovers.

The last model has been used after the US decision not to comply with its Kyoto commitments. Buchner and Carraro, (2005) have presented a study on the effects of this withdraw on the effectiveness of the Kyoto Protocol and on its on-going GHG emissions cuts. Here the role of China (major recipient for CDM) is considered only through the perspective of what might be the impact of its participation on the US willingness to take part in the Kyoto Protocol. Conclusions focus on US strategy regarding different scenarios of China’s behaviour and consider the participation of the US in a climate regime quite unlikely

in the short term. The authors suggest that the US policies may more likely focus on adopting unilateral policies than joining the Kyoto coalition, even if a two bloc regime would be the most preferred option in the case of cooperation on GHG emission control.

Thus, even though this study considers the same topic, the different perspective does not allow a fair comparison with our findings.

The **EPPA** (Emissions Prediction and Policy Analysis) model represents a part of the MIT Integrated Global Systems Model (IGSM) focused on human systems. It is a recursive-dynamic multi-regional and multi-sector CGE model built on the base of the Global Trade Analysis Project (GTAP) dataset and data for greenhouse gas and urban gas emissions. The EPPA model can provide projections of economic growth and the on-going anthropogenic greenhouse gas and aerosols emissions. It is solved recursively at 5-year intervals. In its last version (Jacoby *et alii*, 2008) it takes into account different advanced electric generation technologies and provides estimations for GHG emissions by 2050.

As the EPPA model is the only one providing estimates for burden-sharing at a horizon of 2020/2050, we shall focus more deeply on it. Indeed, since 1998, several studies have been issued based on that model and they were first considering the impact of the implementation of the Kyoto protocol in Annex I countries on developing countries' economy (Ellerman, Jacoby and Decaux (1998); Babiker et Jacoby (1998)). More recently, with the rising importance of developing countries emissions and the issues about a possible burden sharing, Jacoby *et alii* (2008) have worked on the potential role of developing countries.

In their last article, Paltsev *et alii* (2008) focus on different scenarios of possible burden sharing considering different levels of developing countries' implication. As this article presents some findings close to our topic, a detailed analysis of their subsequent assumptions is necessary.

The authors consider seven scenarios of possible burden sharing and compensation of developing countries.

The first one (named: "30-70") suggests a fixed percentage reduction for Annex I and non- Annex I countries of respectively 70% vs. 30%. The second one (named: "Pop based") assumes allocations based respectively on each countries population, as a share of world total population in 2000, while the third one (named: "GDP based") focuses on allocations based on inverse share of year 2000 GDP per capita.

Scenarios 4 (named: "Full comp-equal alloc") and 5 (named: "Full comp-equal cost") explore the possibility of developing countries' full compensation and the distribution of this responsibility. Thus, the authors evaluate a full compensation of all costs in developing

countries with respectively two possibilities for sharing this effort: an equal repartition in accordance with the year 2000 emissions or as equal percentage costs. In this case the “full compensation” integrates all costs associated with emissions mitigation, which implies a zero welfare cost (no loss in national consumption) for Non-Annex I parties.

The last two scenarios present only partial participation of developing countries: either by allowing up to a 3% loss for them through compensation (sc. 6 “3% cost cap”) or by compensating for developing countries` direct mitigation costs but not for their indirect ones (i.e. terms-of-trade effects).

From the above mentioned scenarios we chose to consider those that are more close to our assumptions, i.e.: “Pop based”; Partial Participation of Developing Countries- “Direct mitigation costs”; “Full compensation for developing countries” scenarios.

After this literature review we shall present our model and our suggestions for improvement.

3. Model description

The model assumes different scenarios of possible evolution of CDM flows due to two types of hypothesis. A first set concerns the global reduction effort and a corresponding level of CO₂ concentration by 2020 and 2050. The second set of hypothesis is focusing on the sharing of the reduction effort between developed (Annex I) countries and developing countries.

Thus, the first set of assumptions determines three benchmarks for final global reductions by 2050 in order to achieve the following three atmospheric concentration scenarios:

- 450 parts per million (ppm hereafter) ppm CO₂e, 70% of reductions by 2050 compared to global emissions in 2005
- 500 ppm CO₂e, 50% of reductions by 2050 compared to global emissions in 2005
- 550 ppm CO₂e, 25% of reductions by 2050 compared to global emissions in 2005

An intermediate set of assumptions allows determining the reduction effort by 2020:

- 450 ppm CO₂e, 12.5% of average reduction of Annex I emissions compared to their emissions in 1990 (IPCC recommendations are 25- 40%)
- 500 ppm CO₂e, 20% of average reduction of Annex I emissions compared to their emissions in 1990 (IPCC recommendations are 10-30%)
- 550 ppm CO₂e, 32,5% of average reduction of Annex I emissions compared to their emissions in 1990 (IPCC recommendations are 0-25%)

The assumptions concerning the global reduction effort by 2050 are inspired directly by the Stern Review: The Economics of Climate Change (2006) (See Figure 4); those for 2020 are resulting from an average suggestion based on the 4th report of IPCC (See Figure 5).

Within those benchmarks two scenarios of burden sharing are used. One is based on a more important role of the Annex I countries in mitigation and its spread within developing nations (a). The other one assumes the implication of developing countries in the reduction effort in a more important manner and thus proposes a fairer sharing of emissions reductions with regard to the weight of each countries population and its evolution at the horizon of 2050 (b).

a) Annex I countries leading role scenario

This scenario is based on the hypothesis that all the financial effort is supported by developed countries. That assumption implies that both developed and developing countries are reducing their emissions, but that 100% of Certified Emissions Reductions (CERs) issued as a result of GHG reductions in developing countries are “sold” on carbon markets. Thus, all the countries are physically making efforts to reduce their emissions, but developing countries are encouraged to do so *via* the potential flows of capital that those CERs represent.

The model for this scenario can be summarised as:

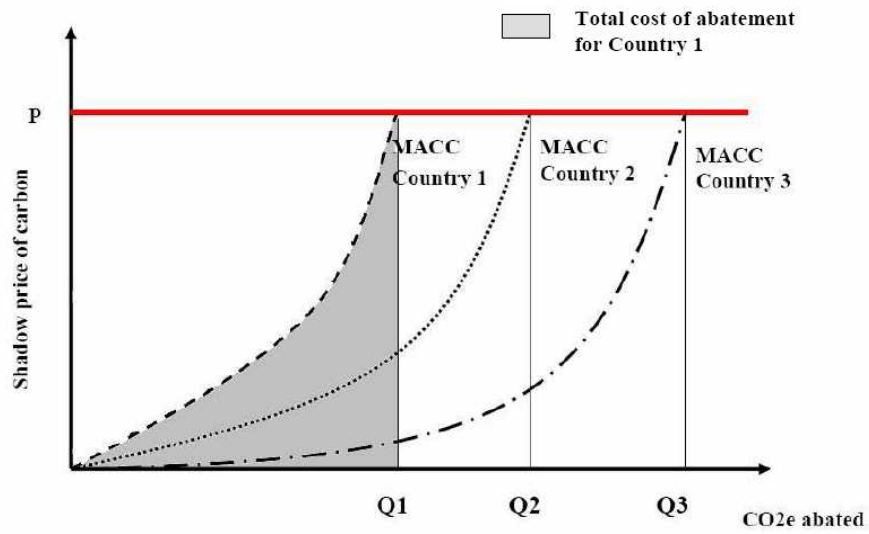
$$\begin{aligned}
 P^* &= a_1 Q_1^2 + b_1 Q_1 = a_2 Q_2^2 + b_2 Q_2 = \dots = a_n Q_n^2 + b_n Q_n \\
 P^* &= P_1 = P_2 = \dots P_n \\
 \text{s.t. } \sum_{i=1}^n Q_i &\geq \text{BAU Total Emissions 2020/2050} - (\text{admitted 2020/2050 benchmark} \\
 &\text{emission level for 450/500/550ppm})
 \end{aligned} \tag{1}$$

Where P is the shadow price of the abatement of 1t CO₂e; Q_i stands for the emission reduction of a given country *i* in Mmt³ CO₂e; a and b are technology coefficients (for more details on their values, see Section 4).

Equation (1) represents an open market situation, where flows are unconstrained within country’s borders. The exchange of emission reduction units is unconstrained as it is supposed that a global cap and trade market is operating. Within this global market, there is one price which is the equilibrium price at which the optimal reduction effort Q*_i of each country *i* is attained.

³ Million Metric Tones

Figure 6 : Theoretical representation of Annex I countries leading role scenario



The program optimization is under the constraint that the total amount of reductions should enable to attain at least the targets of global reductions for 450 ppm, 500ppm and 550ppm.

b) Per capita equalization scenario

The second scenario considers a more balanced effort sharing, i.e. assuming parity of per capita GHG emissions in developed and developing countries by 2050. This scenario follows the idea that some developing countries should be involved in a more important manner in the reduction process, given their raising importance in global emissions balance.

This also allows adjusting for demographic growth, in particular in China and India. Population has to be taken into account in order to give a more objective and fair representation of the emission capacity of a given country. However, in the case of global climate change, the importance of total emissions is more than evident.

The corresponding model to this scenario is:

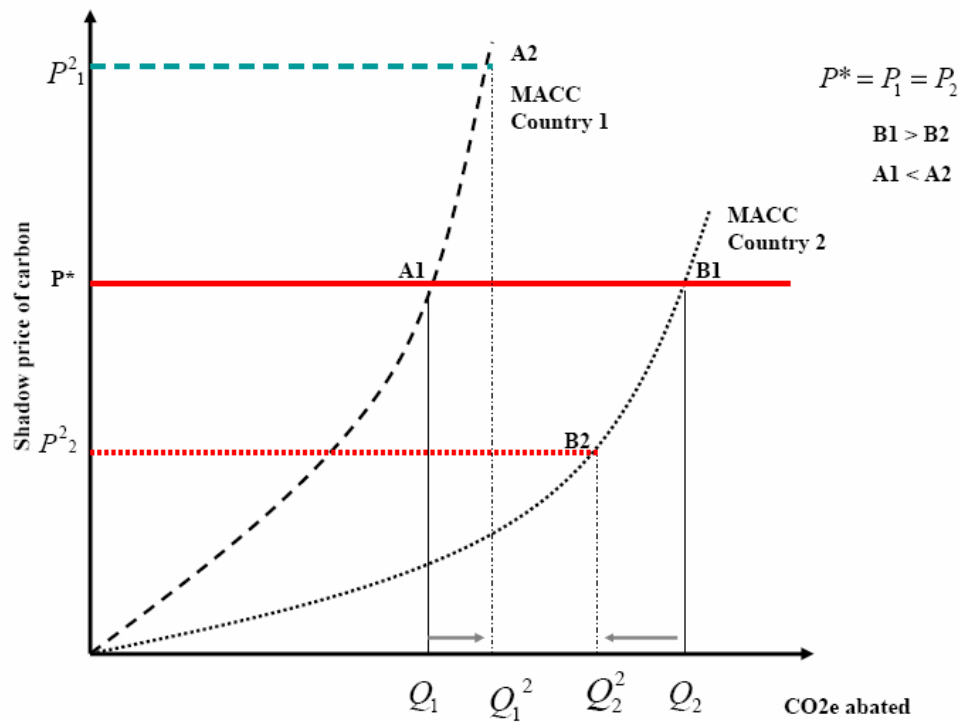
$$\begin{aligned}
 (Q_{BAU_1} - Q_1) / Pop_1 &= (Q_{BAU_2} - Q_2) / Pop_2 = \dots = (Q_{BAU_n} - Q_n) / Pop_n \\
 s.t. \sum_{i=1}^n Q_i &\geq BAU \text{ Total Emissions } 2020/2050 - (\text{admitted } 2020/2050 \text{ benchmark} \\
 &\text{emission level for } 450/500/550 \text{ ppm})
 \end{aligned} \tag{2}$$

Where Q_{BAU_i} represents the BAU emissions level of country i for 2020 or 2050; Q_i the reduction at that time and their difference gives the final emission rate for 2020 or 2050. Pop_i stands for the population weight of country i in 2020 or 2050.

Regarding to the first presented scenario, which can be assumed as the base case, this one can be considered as the normative one. While in the first model, the market is at equilibrium, in the second one, we are confronted to a situation where the implementation of the new norm (per capita equalization of emissions) implies a reorganisation of the market situation and no optimal price is defined at that stage. In comparison, if one considers the first scenario, he will notice that there is only one optimal price corresponding to the optimal emission reduction quantities for each country/region. In order to attain again the equilibrium again, an exchange of the thus-created supply and demand flows will be necessary.

We have tried to illustrate this situation by the following figure.

Figure 7 : Theoretical representation of Per capita equalization scenario

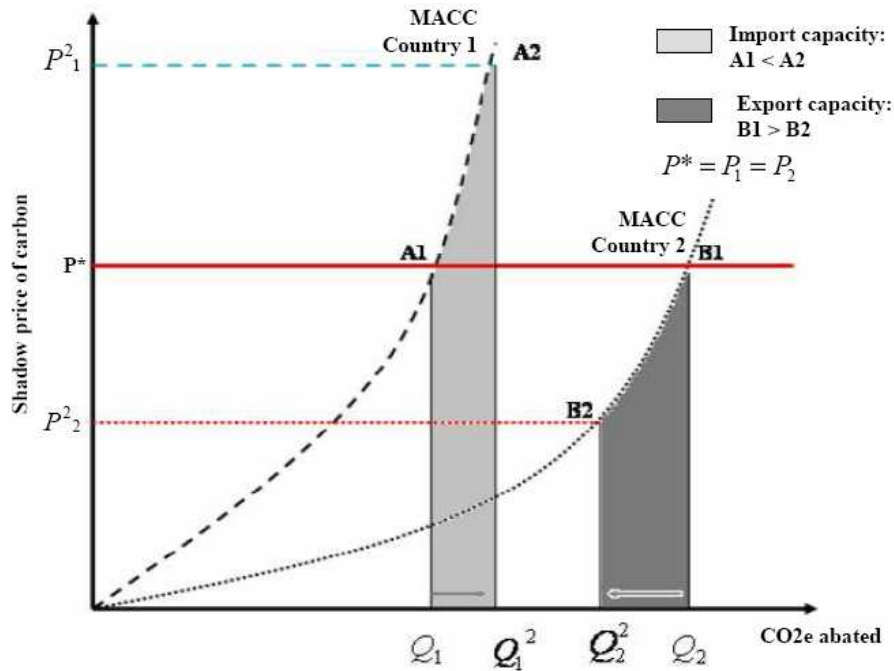


c) Determining the flows

Thus, the above mentioned two scenarios of reduction effort sharing will allow us to determine the magnitude and the character (imports or exports) of the CERs flows between developing and developed countries. Indeed, the first scenario describes a situation that can be considered as the base case. The second one can be considered as the normative case. The

observed variation in the second case regarding to the base case gives the trends of the needs of each country or region in importing or exporting emissions reductions units.

Figure 8: Theoretical representation of supply and demand flows



In short, in the first case, a given developing country is not implicated to reduce its emissions further than the financial perspective counter parts provided by the Annex I countries. So, its reduction effort is corresponding only to the possible financial motivation.

In the second case, its reduction effort is obviously more considerable comparing to the first case, even though we focus on per capita emissions, which allows a better repartition of the effort and a slightly minor effort regarding to the total emissions case. Thus, if the country regarding to its demographic weight is supposed to be more implicated in the mitigation effort, in comparison with the first less constraining case, should import emissions reductions units in order to achieve its level of commitments.

Considering the literature review already presented in Section 2, one can notice that some similarities exist between our scenario assumptions and some of those taken into account by Paltsev et alii (2008). More precisely, their “Population based allocation” and “Partial compensation direct only” cases can allow us an interesting comparison with ours and therefore a verification for the on-going robustness of our results.

4. Data analysis

The study concerns the following countries and regions: United States, Canada, Japan, European Union, Australia & New Zealand, Former Soviet Union, Eastern Europe, India, China, Indonesia, Higher Income East Asia, Mexico, Central & South America, Middle East, Africa and Rest of World. The used data for possible BAU emissions levels in 2050 and 2020 for those regions is resulting from the MIT EPPA 4 model's estimations (Jacoby, Babiker, Paltsev, and Reilly, 2008). The estimations are evaluated in CO₂e as they consider the following gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, sulphur dioxide, nitrogen oxides, black carbon, organic carbon, ammonia, carbon monoxide and non-methane volatile organic compounds.

The MIT emissions estimations are inherently depending on the particularities of the model and the technology level of each country. Indeed the model takes into account the use of gas and coal with Carbon Capture and Storage (CCS) and renewables such as solar, wind and biomass within electricity generation. Liquids from Biomass and Oil from Shale are used as fuels within the world economy. In order to define the technology coefficients corresponding to each country, we proceed to an Ordinary Least Square (OLS) estimation, following a previously used formula in the EPPA Model by Ellerman and Decaux (1998). We have applied the same tests as the authors and our findings are coherent with theirs (for further details see Table 2 and 3 in Annex).

Population projections are issued from World Bank (2009).

5. Empirical analysis

5.1. Results description and analysis

Following the two policy scenarios described in the second part we have proceeded to the estimation of each countries' emission reductions. The first set of results concerns the scenario, where all the effort of reduction is supported by the developed countries. It gives detailed information about the reduction effort that each country should support and the ongoing equilibrium price if a global cap and trade system is put in place.

Beside these results describing a full compensation system for developing countries effort, we have focused on the second scenario which implies an equalization of the emissions per capita between all the considered regions by the end of 2020 and 2050. Thus the reduction effort of a country by the end of a period is proportional to its population at the end of that same period.

These two sets of results are evaluated for the period of 2020 and 2050. But beside that, we take into account the recommendations of the Stern Review Report (2006) about the different reduction efforts corresponding to the different possibilities of GHG's atmosphere concentration, inherently linked to the temperature rise.

Thus, each set of results for the two periods are declined in three reduction effort schemes tempting to achieve the global emission reductions for 450 ppm, 500 ppm and 550ppm.

In order to determine the equilibrium prices and quantities for the first policy scenario, we have proceeded to the construction of each country's MAC curve and tried to represent the potential carbon market situation, if a global cap and trade system is put in place. Of course, the results concern both of the periods and all the three reduction effort schemes (see Figure 9, 10 and 11).

Figure 9 : Marginal Abatement Cost Curves for 450ppm

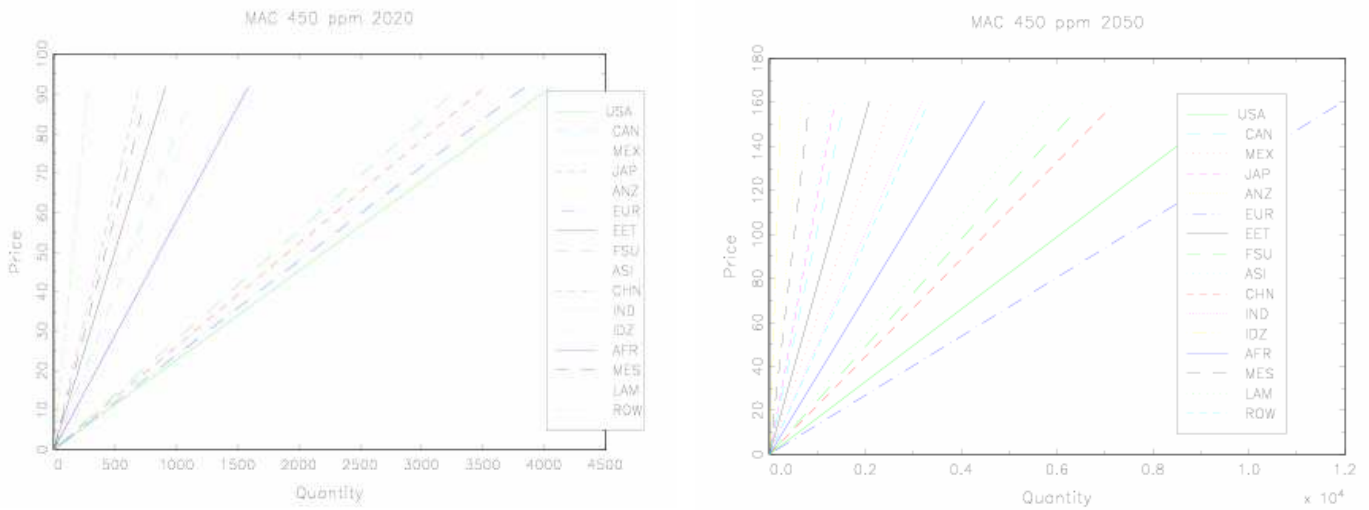


Figure 10 : Marginal Abatement Cost Curves for 500ppm

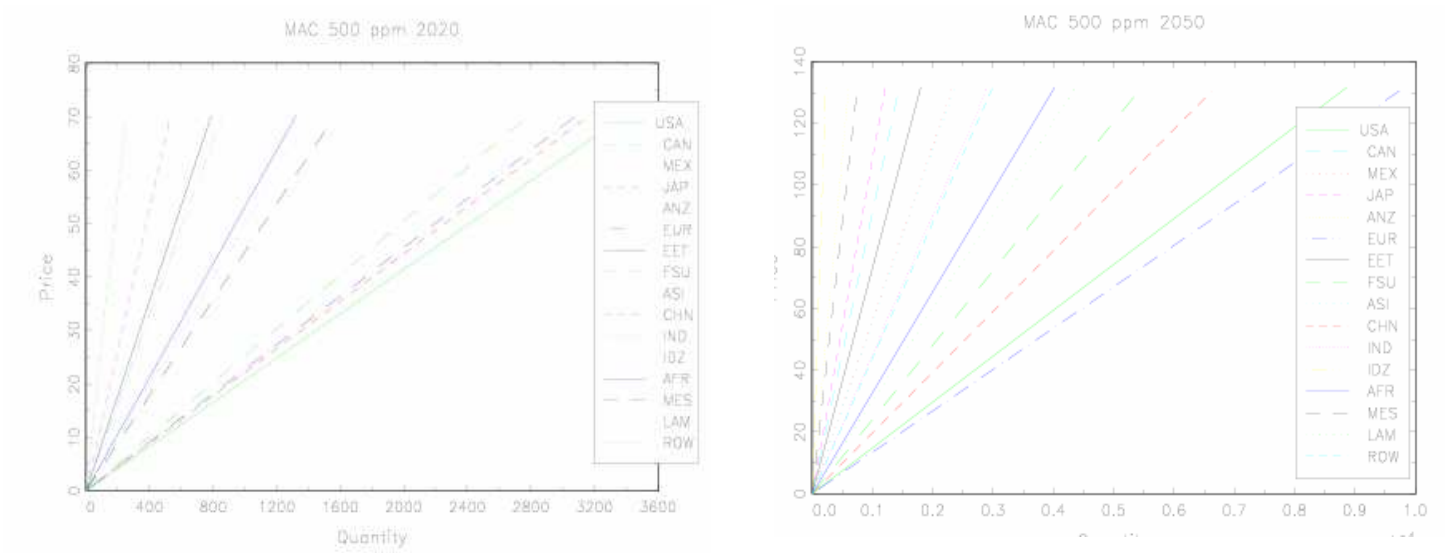
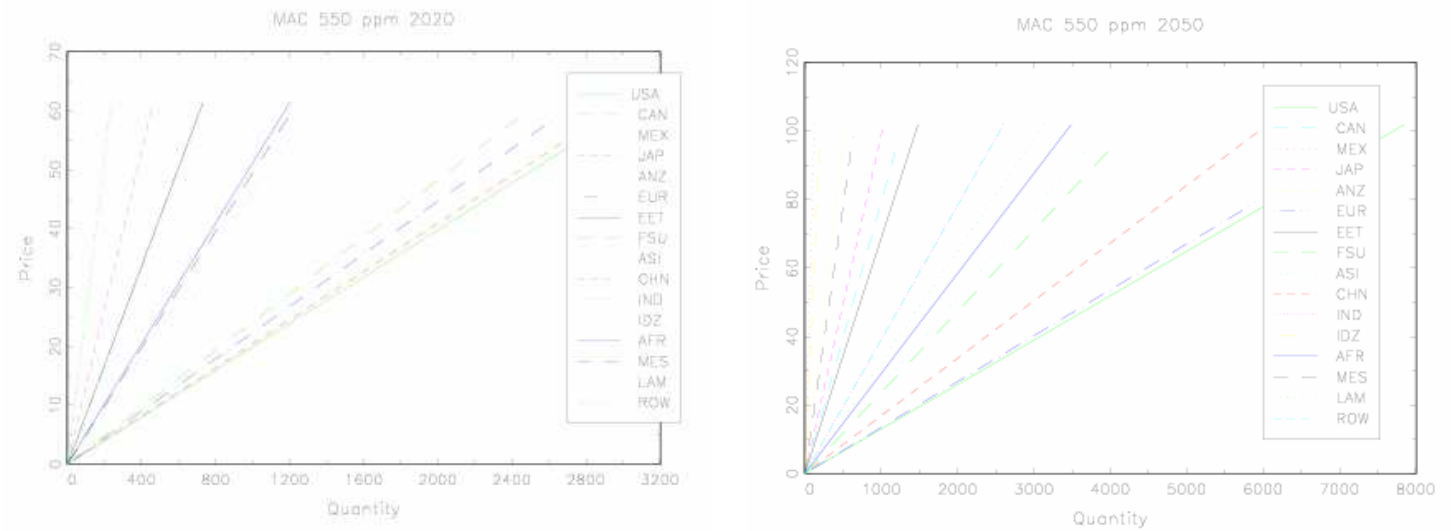


Figure 11 : Marginal Abatement Cost Curves for 550ppm



The corresponding equilibrium prices for these scenarios are:

Table 4 : CO2e Price evolution through the different scenarios (in 2000 US\$/tCO2e)

	450ppm	500 ppm (2050/2005)	550ppm	500ppm Criqui and Mima (2009) POLES (2050/2000)	500ppm Paltsev et alii (2008) EPPA 4 (2050/2000) 500 ppm (2050/2000)
Price 2020	91,8	70,21	61,445	-	75
Price 2050	160,7	131,7	101,82	380 (295*)	360- 450 136,7

* Value in 2000 US\$. The conversion factor used is 1.287

As one can see in Table 3, the more stringent the constraint is the higher the price, as more reduction efforts should be made and that least expensive reduction opportunities are done first. On that point, we find Klepper`s definition of marginal abatement costs, that we have already mentioned in Section 2. The considerable difference between 2020 and 2050 values is due to the more important magnitude of the reduction effort by 2050.

On that stage we have tempted a comparison with the results obtained within the POLES and EPPA4 model. As one can notice, our result for 2020 seems quite close to the projection obtained with the EPPA model. However, for 2050, the difference is quite important even when we are considering the same global concentration limit with the same reference year.

But there is another point that should be also taken into account: the interval of values suggested by Paltsev *et alii* (2008) corresponds to the following scenarios: “30-70”, “Pop based”, “GDP based”. Only the “Pop based” scenario can be considered as potential candidate for comparison, but as it is considering the allocation of permits based respectively on each countries population, as a share of world total population in 2000 it doesn’t seem so similar to our “population based scenario”.

Nevertheless, this point shows the necessity to integrate a robustness check of the obtained results. The method to follow is to reproduce the presented alternative scenarios by the competing literature and to apply our methodology in order to observe if the obtained difference is due on the scenario definition particularities. Unfortunately, in this version we will not be able to present a section on that point, but it will be done in our further developments.

Table 5 : Comparison of the mitigation effort through the different scenarios

Region	2020					
	450 ppm		500ppm		550ppm	
	Qi Sc I	Qi Sc IIa	Qi Sc I	Qi Sc IIa	Qi Sc I	Qi Sc IIa
USA	4057	7691	3388	7523	3091	7423
CAN	1151	933	850	915	735	904
MEX	1253	535	866	475	734	439
JPN	698	1094	530	1033	463	996
ANZ	299	594	265	580	250	571
EUR	3850	4608	3084	4405	2755	4283
EET	912	1169	788	1123	732	1096
FSU	3313	3671	2785	3534	2549	3451
ASI	1693	1762	1282	1631	1117	1552
CHN	3521	2685	3167	1977	3008	1552
IND	1570	-330	1409	-990	1336	-1385
IDZ	277	41	248	-86	235	-162
AFR	1587	-345	1320	-948	1202	-1310
MES	773	1328	1567	1226	1242	1165
LAM	1947	1328	1622	1002	1478	806
ROW	277	415	248	19	235	-219
Region	2050					
	Qi Sc I	Qi Sc IIa	Qi Sc I	Qi Sc IIa	Qi Sc I	Qi Sc IIa
	Qi Sc I	Qi Sc IIa	Qi Sc I	Qi Sc IIa	Qi Sc I	Qi Sc IIa
USA	9742	12816	8863	12505	7848	12115
CAN	1571	1337	1441	1303	1281	1259
MEX	2548	1109	2327	1003	119	870
JPN	1369	2122	1210	2039	1027	1936
ANZ	667	929	600	902	523	869
EUR	11985	7721	9824	7400	7597	6999
EET	2082	1794	1799	1733	1481	1657
FSU	6561	5823	5461	5629	4293	5387
ASI	1292	3661	2361	3423	3958	3126
CHN	7250	9575	6694	8470	6057	7090
IND	3174	3475	2906	2209	2597	626
IDZ	239	476	221	251	202	-30
AFR	4483	3642	4019	2122	3485	223
MES	830	1612	746	1380	650	1089
LAM	5888	3830	4362	3220	3130	2456
ROW	3330	3094	2990	2239	2598	1170

Where Qi ScI stands for the emission reduction of a given country i under Annex I countries leading role scenario; Qi ScII stands for Per capita equalization scenario

Figures in red: Slowing reduction trend compared to I countries leading role scenario

Figures in blue: Raising reduction trend compared to I countries leading role scenario

When one compares the reduction effort under policy scenarios I and II (Table 4), he can notice that the last one is more advantageous to the majority of the developing countries.

Indeed, for 2020, this scenario could give the possibility to some of them to raise their emissions instead of reducing them.

However, it is important to point out that this opportunity is greater in the laxer scenarios of mitigation (550ppm) and is not a long term trend. In 2050, a great majority of developing countries (China, India, Indonesia, Middle East countries) are forced to raise their reductions, especially for the more constraining case (450ppm). This more important implication of developing countries, contributes for a redistribution of the burden sharing between the European Union, the US and Japan. In result, the EU seems to be favoured.

Nevertheless, these results should be considered with great caution for several reasons. First of all, in our model EU has a leading role in mitigation in the first scenario case. Thus, through the technology coefficients (a,b), EU is supposed to have put in place by 2050 the more innovative technologies in order to slow down its emissions. Beside that, its decreasing population weight by 2050 and the repartition of the reduction effort among the other countries can explain the observed results.

Secondly, the more important weight of the US as a global emitter implies its greater responsibility. Thirdly, the evolution of China's per capita value for 2020 and 2050 shows the importance of the demographic evolution. In order to respect the fixed level of per capita emission, one should reduce its emissions when its population is decreasing, which implies an increase of its reductions. This increase coupled with the more important level of needed reduction comparing to 2020, can explain the values for China's mitigation. The same reasoning could be applied to Japan.

Finally, one should not forget that the presented results are issued from a worldwide general equilibrium model. This means that it represents a system in equilibrium. When for an exogenous reason (Developing countries commitments of emission reduction) the equilibrium (Annex I countries bearing all the reduction effort) is not maintained, the effects are dispatched through the existing countries/regions such as to reach a new equilibrium. Thus, the new generated results should not be considered per se, but regarding to the previous situation (first case scenario). In the case of EU, its mitigation effort by 2050, under scenario II, should be reduced, considering its pioneer role in the previous scenario.

Table 6 : Comparison of the flow levels in imported (-) or exported (+) emissions of tCO2e (imports in blue)

Partial comp in Mmt CO2e			
2020			
Region	450 ppm	500ppm	550ppm
USA	-3633,47	-4135,48	-4332,08
CAN	217,78	-64,38	-169,19
MEX	718,02	391,38	295,02
JPN	-395,97	-502,59	-533,32
ANZ	-294,60	-314,63	-321,52
EUR	-757,71	-1320,69	-1527,89
EET	-257,02	-335,70	-364,16
FSU	-358,36	-749,24	-901,99
ASI	-68,77	-348,78	-434,53
CHN	836,05	1189,92	1456,32
IND	1899,62	2398,24	2721,98
IDZ	236,29	334,09	397,14
AFR	1932,61	2268,35	2511,81
MES	-555,67	340,14	76,75
LAM	618,73	619,87	671,50
ROW	-137,85	229,43	454,16
Total	12918,52	15542,90	17169,35
2050			
Region	450 ppm	500ppm	550ppm
USA	-3073,97	-3641,8	-4266,79
CAN	233,58	138,1	21,56
MEX	1439,34	1324,4	-751,54
JPN	-752,76	-829,5	-908,61
ANZ	-261,87	-302,1	-346,06
EUR	4264,30	2424,5	598,17
EET	287,80	65,4	-176,45
FSU	738,25	-168,0	-1093,67
ASI	-2368,77	-1062,3	831,86
CHN	-2325,06	-1775,9	-1032,89
IND	-300,60	697,4	1971,09
IDZ	-237,63	-29,7	232,01
AFR	840,74	1896,9	3262,32
MES	-782,17	-633,2	-438,98
LAM	2057,92	1142,7	673,74
ROW	236,48	751,5	1428,29
Total	20201,24	16883,4	18034,04

As one can notice, potential flows towards developing countries are quite important and most of the developed countries are importers and developing countries are exporters for the first period.

On one hand, these financial flows can impact positively their local economic activity. But on the other hand, through technology transfers they can improve the energy

efficiency of the existing industrial installations and thus allow for more important emissions reductions.

For the second period, in the more constrained mitigation effort case (450ppm), a great part of developing countries: China, India, Indonesia, Higher Income East Asia countries seem to be more involved in the reduction process and are obliged to import allocations.

This result demonstrates that the nowadays fast-growing major recipients of CDM (China and India) will be replaced by African and Latin American countries. Their situation can be explained by their decreasing population growth by 2050, which implies greater mitigation effort shared by less people. Beside that, following the environmental Kuznets curve, the more one country's income per capita is growing, the more its emission level is rising up to a turning point when this trend is inversed. It seems that in 2050, China and the all above mentioned countries wouldn't have improved enough their energy efficiency and wouldn't have reached that point yet.

The case of China is particular as coal has a great importance in its energy mix and its fossil fuels reserves. Another possibility may be summarised by the extension of car use by a greater part of population. The cost of a more sustainable and responsible growth seems to pass through the import of allocations.

The Middle East countries are for the two periods net importers and this could be explained by their energy mix and the abundance of not so expensive fossil fuels which may not help decisions about the implementation of more energy efficient technologies.

However, all these results, should be taken into account as the evolution of a country's commitment if the population based policy scenario is chosen, regarding to their commitment in the case when only the developed countries are implied financially in the reduction effort.

5.2. Comparison with the competing literature

As mentioned above, a comparison is possible with the "Population based" and "Partial participation direct only" scenarios described by Paltsev *et alii* (2008). However, within the last mentioned scenario, no estimation of the market equilibrium price is proposed and the analysis does not consider the needed mitigation effort. It does not go beyond a definition of the welfare impact on the different regions.

As for the first cited scenario, no comparison is possible as Paltsev and alii (2008) consider the allocation based on each country's share of the total world 2000 population. In

our analysis, we take also into account the importance of the population weight. Nevertheless, we consider an equalization of the emissions per capita and not a reduction proportional to population. Beside that, in our population based scenario, we prefer to consider not only the weight of population, but also the demographic evolution as the studied period is quite large and as some population trends are going to be inversed as shown by the available projections; especially for China, most Asian economies and Russia (World Bank, 2009).

Thus, finally, as Paltsev et alii (2008) consider also the possible evolution of flows at the horizon of 2020 and 2050, even though they are taking into account the full compensation of developing countries we have tried a comparison.

In our assumptions we take under consideration only the compensation of direct costs, as they are more easily accounted and we present the physical flows while Paltsev *et alii* (2008) present the financial flows. But the last mentioned point may be solved quite easily. However, as our price results (Table 4) mark an important difference with theirs, we choose only to compare the global trends. This means that we are going to search for the similarities or differences in the behaviour of developing countries.

Indeed, one can notice that for the first period our results seem quite similar: developed countries are importing and developing countries are exporting.

Table 7: Comparison of the flow levels in imported (-) or exported (+) emissions of CO₂e

Region	Partial comp in Mmt CO ₂ e			Full comp in 2000 US\$billion	
	2020			2020	
	450 ppm	500ppm	550ppm	equal alloc	equal cost
USA	-3633,47	-4135,48	-4332,08	-196,7	-264,5
CAN	217,78	-64,38	-169,19	-20,0	4,5
MEX	718,02	391,38	295,02	16,4	14,6
JPN	-395,97	-502,59	-533,32	-44,8	-118,9
ANZ	-294,60	-314,63	-321,52	-18,5	-8,8
EUR	-757,71	-1320,69	-1527,89	-116,9	-86,3
EET	-257,02	-335,70	-364,16	-9,9	3,2
FSU	-358,36	-749,24	-901,99	-26,7	44,6
ASI	-68,77	-348,78	-434,53	-13,8	-14,9
CHN	836,05	1189,92	1456,32	73,9	74,4
IND	1899,62	2398,24	2721,98	51,8	52,3
IDZ	236,29	334,09	397,14	8,0	8,2
AFR	1932,61	2268,35	2511,81	81,2	79,3
MES	-555,67	340,14	76,75	119,4	116,5
LAM	618,73	619,87	671,50	62,7	61,3
ROW	-137,85	229,43	454,16	33,9	34,4
Total	12918,52	15542,90	17169,35		

Region	2050			2050	
	450 ppm	500ppm	550ppm	equal alloc	equal cost
USA	-3073,97	-3641,8	-4266,79	-1239,4	-1715,5
CAN	233,58	138,1	21,56	-148,8	2,1
MEX	1439,34	1324,4	-751,54	108,4	110,1
JPN	-752,76	-829,5	-908,61	-358,6	-942,1
ANZ	-261,87	-302,1	-346,06	-120,5	-78,6
EUR	4264,30	2424,5	598,17	-866,1	-985,3
EET	287,80	65,4	-176,45	-146,9	7,1
FSU	738,25	-168,0	-1093,67	-434,3	299,9
ASI	-2368,77	-1062,3	831,86	355,8	363,8
CHN	-2325,06	-1775,9	-1032,89	589,0	578,3
IND	-300,60	697,4	1971,09	176,4	189,5
IDZ	-237,63	-29,7	232,01	85,0	91,2
AFR	840,74	1896,9	3262,32	543,0	558,7
MES	-782,17	-633,2	-438,98	761,1	797,3
LAM	2057,92	1142,7	673,74	536,8	556,7
ROW	236,48	751,5	1428,29	159,1	167,0
Total	20201,24	16883,4	18034,04		

Nevertheless, the difference between these two studies is more evident for the second period. Three major points stand out and they concern respectively China's, EU's and Middle East countries' positions. Regarding to Paltsev and alii's results, in 2050 the trend of global repartition of the mitigation effort presented in 2020 should remain unchanged.

Beside the fact that the MIT team chooses 2000 as the reference year for reductions, while the Stern Review Report, on which we are basing our policy scenarios uses 2005, there are some other differences in our approaches that could explain the controversy of the results.

First of all, as explained above, the presented figures are the result of the comparison between each country's situation when only Annex I countries should bear the financial effort of mitigation and the case where developing countries are more deeply engaged in that process by taking into account their population weight. In the last mentioned case the burden sharing is redistributed and thus the responsibility of the EU diminished regarding to the first case and those of China and the Middle East countries are inversely rising.

Secondly, the MIT full compensation scenario is more preoccupied by the difference between the repartition of the burden sharing within the Annex I countries. And mostly, they consider a full compensation of direct and indirect costs, while we focus only on direct costs, which are easier to be accounted for. Again, the "Partial compensation direct only scenario" would have been more appropriate for such a comparison. Unfortunately, no studies on financial transfers for that case are available up to now.

6. Conclusions

Considering the obtained results, about potential flows of CDM or other similar kind of mechanism, towards developing countries in 2020 and 2050, one can observe that countries like China and India may not have the role of major recipients that they have actually.

Indeed, in 2050 they may have a more important role in the mitigation process and risk to even import reduction units. This finding shows that developing countries should not only count on financial flows such as CDM in order to prepare themselves for a more constraining mitigation. Indeed, at the last COP-15 meeting in Copenhagen a decision to create a Multilateral Climate Fund was taken.

This fund “shall provide substantial, new, additional, adequate, predictable and sustained public funding additional to and different from the ODA to meet the agreed full costs and/or incremental costs incurred by developing country Parties to effectively implement their commitments under the Convention, taking into consideration that other sources of finance like private sector and carbon market can play a supplementary role” (The Copenhagen Decisions, UNFCCC, 12 December 2009).

As it is pointed out, private sector should also play a role and developing countries should find the right incentives in order to benefit from all the positive spill-over effects.

Finally, the presented results should be considered keeping in mind that they are issued from a global economy model, under assumptions such as the existence of a global cap and trade market within 2020/2050 and the use of some innovative technologies in electricity generation.

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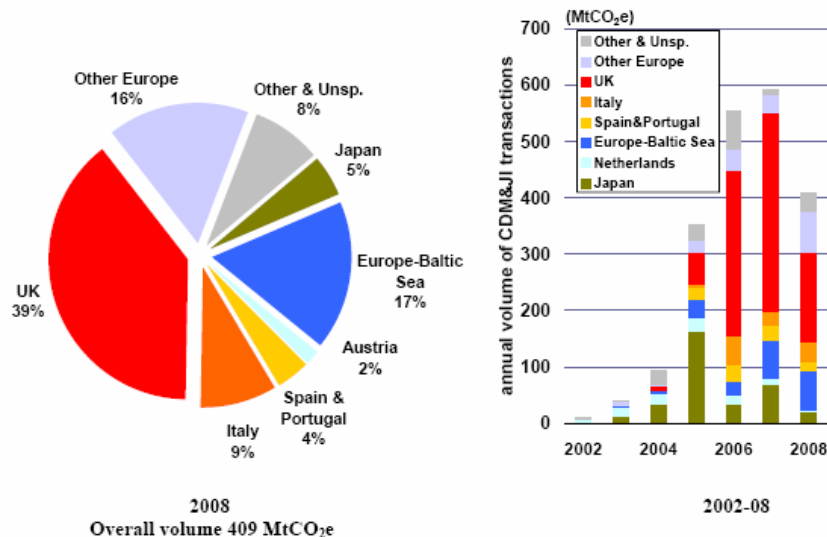
Annexes

Table 1: Carbon Market at a Glance, Volumes & Values in 2007-08

	2007		2008	
	Volume (MtCO ₂ e)	Value (MUS\$)	Volume (MtCO ₂ e)	Value (MUS\$)
Project-based Transactions				
Primary CDM	552	7,433	389	6,519
JI	41	499	20	294
Voluntary market	43	263	54	397
Sub total	636	8,195	463	7,210
Secondary CDM				
Sub total	240	5,451	1,072	26,277
Allowances Markets				
EU ETS	2,060	49,065	3,093	91,910
New South Wales	25	224	31	183
Chicago Climate Exchange	23	72	69	309
RGGI	na	na	65	246
AAUs	na	na	18	211
Sub total	2,108	49,361	3,276	92,859
TOTAL	2,984	63,007	4,811	126,345

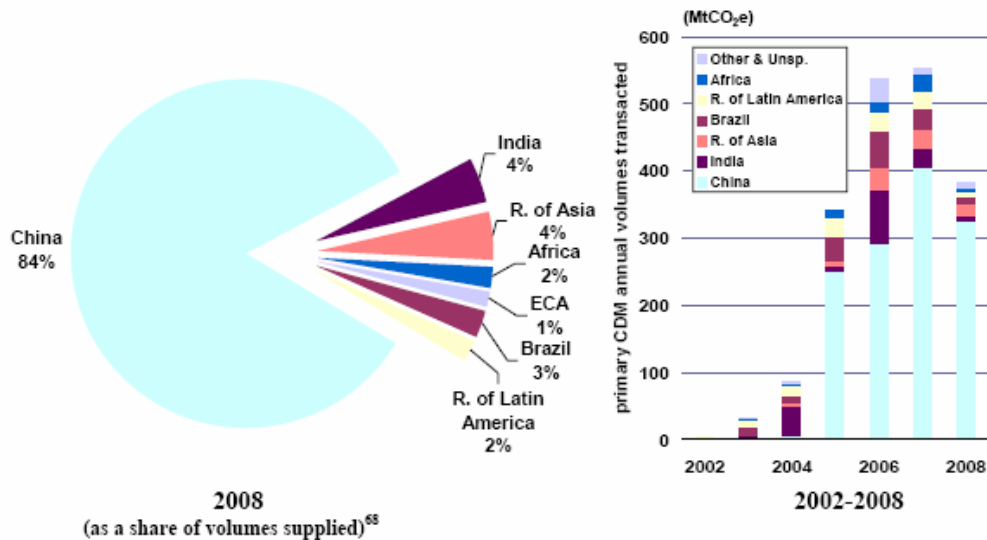
Source: WB Carbon Markets Sate and Trends, Capoor and Ambrosi (2009)

Figure 1: Primary CDM&JI Buyers (as shares of volumes purchased, vintages up to 2012)



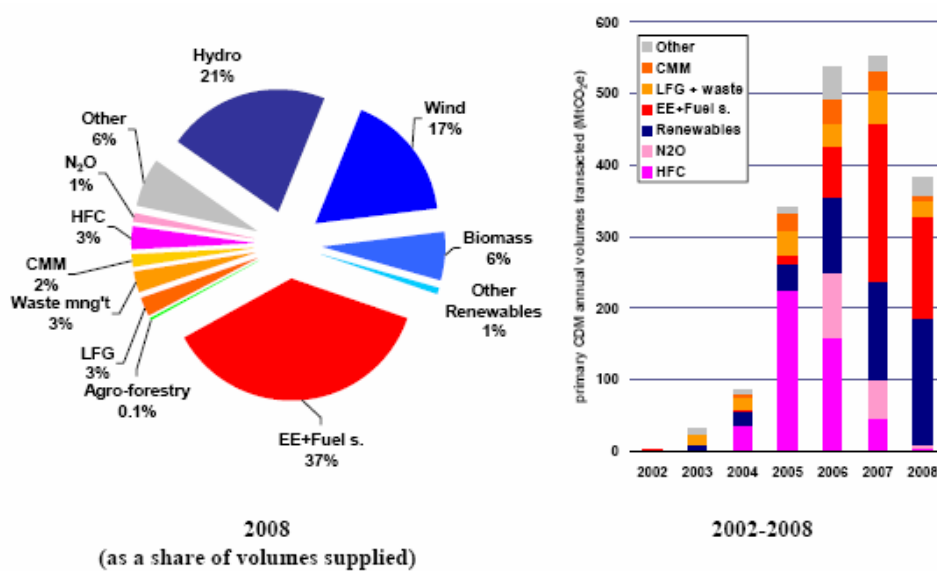
Source: WB Carbon Markets Sate and Trends, Capoor and Ambrosi (2009)

Figure 2: Location of CDM Projects



Source: WB Carbon Markets Sate and Trends, Capoor and Ambrosi (2009)

Figure 3: CDM Project Types



Source: WB Carbon Markets Sate and Trends, Capoor and Ambrosi (2009)

Figure 4: Levels of CO₂e emission reductions in 2050 compared to 2005 values for stabilisation levels of: 450, 500, 550 ppm.

Stabilisation Level (CO ₂ e)	Date of peak global emissions	Global emissions reduction rate (% per year)	Percentage reduction in emissions below 2005* values	
			2050	2100
450 ppm	2010	7.0	70	75
	2020	-	-	-
500 ppm (falling to 450 ppm in 2150)	2010	3.0	50	75
	2020	4.0 - 6.0	60 - 70	75
	2030	5.0[1] - 5.5 [2]	50 - 60	75 - 80
	2040	-	-	-
550 ppm	2015	1.0	25	50
	2020	1.5 - 2.5	25 - 30	50 - 55
	2030	2.5 - 4.0	25 - 30	50 - 55
	2040	3.0 - 4.5 [3]	5 - 15	50 - 60

Source: Stern Review: The Economics of Climate Change (2006)

Figure 5: Levels of CO₂e emission reductions in 2020 compared to 1990 values for stabilisation levels of: 450, 500, 550 ppm

Box 13.7 The range of the difference between emissions in 1990 and emission allowances in 2020/2050 for various GHG concentration levels for Annex I and non-Annex I countries as a group^a

Scenario category	Region	2020	2050
A-450 ppm CO ₂ -eq ^b	Annex I	-25% to -40%	-80% to -95%
	Non-Annex I	Substantial deviation from baseline in Latin America, Middle East, East Asia and Centrally-Planned Asia	Substantial deviation from baseline in all regions
B-550 ppm CO ₂ -eq	Annex I	-10% to -30%	-40% to -90%
	Non-Annex I	Deviation from baseline in Latin America and Middle East, East Asia	Deviation from baseline in most regions, especially in Latin America and Middle East
C-650 ppm CO ₂ -eq	Annex I	0% to -25%	-30% to -80%
	Non-Annex I	Baseline	Deviation from baseline in Latin America and Middle East, East Asia

Notes:

^a The aggregate range is based on multiple approaches to apportion emissions between regions (contraction and convergence, multistage, Triptych and intensity targets, among others). Each approach makes different assumptions about the pathway, specific national efforts and other variables. Additional extreme cases – in which Annex I undertakes all reductions, or non-Annex I undertakes all reductions – are not included. The ranges presented here do not imply political feasibility, nor do the results reflect cost variances.

^b Only the studies aiming at stabilization at 450 ppm CO₂-eq assume a (temporary) overshoot of about 50 ppm (See Den Elzen and Meinshausen, 2006).

Source: See references listed in first paragraph of Section 13.3.3.3

Source: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change : Policies, Instruments and Co-operative Arrangements, In Climate Change (2007)

Table 2: Technology coefficients for 2020 and 2050

Region	2020			Region	2050		
	a	b	R2		a	b	R2
USA	2.8E-06	1.1E-02	0.98	USA	1.9E-06	-0.002	0.99
CAN	-9.3E-06	9.0E-02	0.99	CAN	-1.2E-04	0.149	0.98
MEX	-2.0E-05	9.8E-02	0.97	MEX	-4.8E-05	0.105	0.97
JPN	-5.5E-06	1.4E-01	0.97	JPN	5.3E-05	0.044	0.98
ANZ	1.2E-03	-6.4E-02	0.98	ANZ	3.2E-04	0.025	0.98
EUR	1.4E-06	1.8E-02	0.98	EUR	1.4E-09	0.013	0.98
EET	9.3E-05	1.6E-02	0.99	EET	1.4E-05	0.048	1.00
FSU	4.7E-06	1.2E-02	1.00	FSU	3.4E-07	0.022	0.96
ASI	-1.4E-06	5.6E-02	0.98	ASI	-4.6E-06	0.044	0.97
CHN	1.1E-05	-1.3E-02	0.99	CHN	4.5E-06	-0.010	0.98
IND	5.4E-05	-2.6E-02	0.96	IND	2.0E-05	-0.012	0.98
IDZ	1.7E-03	-1.4E-01	0.95	IDZ	4.6E-03	-0.420	0.98
AFR	1.7E-05	3.0E-02	0.99	AFR	6.7E-06	0.006	0.99
MES	-2.0E-05	7.5E-02	0.99	MES	2.1E-04	0.023	0.95
LAM	1.2E-05	2.4E-02	0.98	LAM	-1.9E-06	0.038	0.99
ROW	1.7E-03	-1.4E-01	0.95	ROW	1.2E-05	0.007	0.98

Table 3: Technology coefficients for 1998, (Ellerman, Decaux; 1998)

Region	Technology coeff. 1998 (Ellerman, Decaux; 1998)		
	a	b	R2
USA	0.00	0.04	0.992
JPN	0.02	1.82	0.994
EEC	0.00	0.15	0.995
OOE	0.01	0.10	0.998
EET	0.01	0.05	0.997
FSU	0.00	0.00	0.994
EEX	0.00	0.30	0.998
CHN	0.00	0.02	0.999
IND	0.00	0.08	0.997
DAE	0.00	0.38	1.000
BRA	0.56	8.50	1.000
ROW	0.00	0.08	0.997