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Is Kyoto Fatally Flawed?
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Johan Eyckmans, Denise Van Regemorter
and Vincent van Steenberghe

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Johan Eyckmans, *Katholieke Universiteit Leuven , CES*
Denise Van Regemorter, *Katholieke Universiteit Leuven, CES*
Vincent van Steenberghe, *Katholieke Universiteit Leuven, CORE*

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Summary

In this paper we present some numerical simulations with the MacGEM model to evaluate the consequences of the recent Marrakesh agreements and the defection of the USA for the Kyoto Protocol. MacGEM is a global marginal abatement cost model for carbon emissions from fossil fuel use based on the GEM-E3-World general equilibrium. Nonparticipation of the USA causes the equilibrium carbon price in Annex B countries to fall by approximately 50% since an important share of permit demand falls out. Carbon sinks enhancement activities enable Parties to fulfil their reduction commitment at lower compliance costs and cause the equilibrium permit price to decrease by 40%. Finally, it is shown that the former Soviet Union and central European countries have substantial monopoly power in the Kyoto carbon permit market. We conclude that the recent accords have eroded completely the Kyoto Protocol's emission targets but that they have the merit to have saved the international climate change negotiation framework.

Keywords: Environmental economics, climate change, permit trade, Kyoto Protocol, carbon sinks

JEL: H0, H2, H3

Address for correspondence:
Johan Eyckmans
Katholieke Universiteit Leuven ,
Centrum voor Economiche Studien, Energy, Transport and Environment
Naamsestraat 69
B 3000 Leuven
Belgium
Phone: + 32 - 16 - 326844
Fax: + 32 - 16 - 326910
E-mail: johan.eyckmans@econ.kuleuven.be

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1. INTRODUCTION

Since the failure of the Conference of the Parties COP 6 in The Hague in November 2000 and the declaration of nonratification of the Kyoto Protocol by the USA during spring 2001, it was feared that the Protocol would never come into force. However, during COP 6 Bis in Bonn in July 2001, Parties managed to agree on a political deal for the practical implementation of the Protocol. This deal has been worked out into a legal text at COP 7 in Marrakech in November 2001. Japan and Russia also confirmed their intention to ratify the Kyoto Protocol so that it is now more likely to come into force in 2002. The real question is however "what has remained of the original 1997 Kyoto Protocol, has it not been 'fatally flawed'[1] in Bonn and Marrakesh?" The main purpose of this paper is therefore to quantify and analyse the repercussions of first, the US withdrawal and secondly, the COP 6 Bis and COP 7 agreements on global carbon emissions and on the total amount and distribution of compliance costs.

First, concerning the withdrawal of the USA, it is well known that the USA has been, and still is, the major emitter of greenhouse gases among the Annex B countries, accounting for approximately 38% of total Annex B emissions in 1995. The US withdrawal therefore means that the world emission reduction objective is being weakened considerably. We thus expect a drastic fall of permit price and a significant decrease of the compliance costs for the other Annex B Parties of the Kyoto Protocol.

Secondly, the Bonn and Marrakesh accords cover mainly four topics: the use of Kyoto flexible mechanisms, the use of carbon sinks, funding provisions and compliance issues[2]. On the first topic, the Kyoto mechanisms and supplementarity issue, it has been agreed to put no cap on the use of the flexible mechanisms provided for in the Kyoto Protocol. Domestic actions should just constitute a "significant element" of the effort made by the Parties. It has also been agreed that each Party has to keep some specified amount of Assigned Amount Units (AAU) in its greenhouse gases account. This provision is called the *Commitment Period Reserve* (CPR) and is intended to limit the risk of permit overselling.

On the second topic, carbon sinks, rigorous definitions of concepts like afforestation, reforestation etc. have been agreed upon. In addition, limits have been set on the use of certain land use, land use changes and forestry (LULUCF) activities. For the details of the provisions on these LULUCF activities, see UNFCCC (2001a and 2001b).

Concerning funding provisions, three additional financial funds have been created. Two new funds were established under the UN Framework Convention on Climate Change UNFCCC (a special climate change fund and a least developed countries fund) and one new fund has been created under the Kyoto Protocol (Adaptation Fund).

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[1] In June 2001, President Bush called the Kyoto Protocol "fatally flawed" (http://www.whitehouse.gov/news/releases/2001/06/20010611-2.html). This phrase has ever since dominated much of the Kyoto discussion, see for instance *The Economist*, July 21 and 28, 2001

[2] For details on the Bonn agreement and on the Marrakesh accords, see UNFCCC (2001a) and UNFCCC (2001d) respectively or the Earth Negotiations Bulletin, IISD (2001).

Finally, a compliance committee has been created and one has agreed upon a non-binding obligation that says that excess emissions of a Party at the end of the first commitment period have to be compensated (augmented by 30%) during the following commitment period.

We will not deal in our analysis with all these four issues negotiated in Bonn and Marrakesh. Some of them are simply not quantifiable and others, like the 30% supplementary reduction to be done in case of non-compliance, would require information on the second commitment period. We rather concentrate on two major issues. The first issue is the use of *carbon sinks*. This issue is very much debated as there is no easy way to measure the carbon sequestered by changes in vegetation. Hence, there is a fear that emission credits obtained via these sinks are not real reductions and will not help to combat climate change. We approximate the repercussions of the use of carbon sinks on the Annex B permit market equilibrium and on the abatement efforts of the different Parties by assuming that land use changes and forestry activities constitute free carbon abatement options. Hence, we assumed that countries will try as much as possible to use existing projects without additional costs to be certified as carbon sink projects which can be used to meet their emission reduction obligation.

The second issue is the *Commitment Period Reserve* (CPR). Many signatories fear that, if no restrictions are put on permit sales, Russia and Ukraine would be tempted to sell large amounts of emission permits during the early years of the first commitment period (2008-2012) and will be found in non-compliance afterwards. The CPR mechanism tries to prevent this by requiring all permit exporters to maintain a certain number of permits in their accounts during the first commitment period. Hence, the CPR mechanism is similar to a (temporary) ceiling on permit exports and can be expected to have similar effects on the equilibrium permit price and on the costs of the different trading partners (see among others, Haites and Missfeldt (2001), Criqui et al. (1999), Ellerman and Wing (2000) or Eyckmans and Cornillie (2001)). Hence, this issue will be dealt in conjunction with those of restrictions on hot air, strategic behaviour and emissions abatement via Joint Implementation in countries from Eastern Europe.

In terms of methodology, we use in this paper the MacGEM model in order to quantify the repercussions of the US withdrawal from the Kyoto Protocol and of the Bonn and Marrakesh agreements. MacGEM consists of a set of marginal abatement cost functions for carbon emissions originating from fossil fuel use. The model aims at evaluating compliance costs and permit trading equilibria for the first commitment period of the UN Framework Convention on Climate Change UNFCCC. The approach is similar to Ellerman and Decaux (1998) and Criqui et al. (1999). Emission trading equilibria are computed by seeking a price for which total market excess permit supply is zero. Excess supply of every of the 15 world regions/countries in the model depends upon its marginal abatement cost function and assigned amount of emissions. The marginal abatement cost functions are estimated on data generated with the GEM-E3-World general equilibrium model (for detailed descriptions of GEM-E3-World, see Capros et al. (1997 and 1999). MacGEM also allows for the introduction of trading restrictions like for instance a Commitment Period Reserve (CPR, see further), transaction costs and limited accessibility of the Kyoto flexible mechanisms like Joint Implementation (JI) and Clean Development Mechanism.

This paper is organised as follows. Section 2 introduces the model and the reference scenario. This reference scenario represents the 'original' Kyoto Protocol as it assumes the participation of the USA and does not include the CPR nor does it account for sinks. Section 3 examines the effects of the US withdrawal on the world emissions reduction objective and on the effort to be done by each Party. In section 4, we approximate the net changes in carbon sinks that might be used by the Parties to meet their emission reduction objective. Section 5 emphasises the key role of Russia and Ukraine on the market and discusses the consequences of strategic behaviour by these countries under different scenarios including the CPR mechanism. Sensitivity analysis is reported in section 6. It bears on the efficiency of the domestic emission reductions, on the countries emissions baselines and on the use of the clean development mechanism. Finally, section 7 summarises our results and concludes.

2. MODEL STRUCTURE AND REFERENCE SCENARIO

2.1. MacGEM model structure

MacGEM is a numerical simulation model that aims at evaluating carbon emission abatement and permit trading equilibria for the first Commitment Period (i.e. 2008-2012) of the 1997 Kyoto Protocol. The model distinguishes between 15 main regions/countries in the world and allows for simulating the effects of the flexible mechanisms provided for in the 1997 Kyoto Protocol (Joint Implementation JI, Clean Development Mechanism CDM and International Emission Trading IET). The core of the model consists of a set of marginal abatement cost (MAC) functions that were derived from simulations with the GEM-E3-WORLD general equilibrium model (see Capros et al. (1997 and 1999). The MAC functions used in the main part of this paper were calculated under the assumption that emission abatement is allocated efficiently at the national level over the different economic sectors, i.e. marginal abatement costs are equalised across all sectors in every country, without distributional consideration. Implicitly, we also assume that the allocation of abatement efforts between the countries has no effect on the MAC function of an individual country[3].

The GDP in 2010 of country *i* is defined as $GDP_i = GDP_i^1 - C_i\left(R_i\right)$ where GDP_i^1 denotes the projected Business-As-Usual GDP level for 2010 and $C_i(R_i)$ denotes the emission abatement cost (AC) for country *i* for reducing its emissions with R_i tons compared to projected BAU emissions. Actual emissions in 2010 are defined as 2010 BAU emissions minus abatement: $E_i = E_i^1 - R_i$. The emission abatement cost function denotes the GDP loss incurred by country *i* if it has to curb its carbon

3 Simulation experiments with the GEM-E3-World model have shown that the estimated MAC function of a particular country is rather insensitive to the abatement efforts undertaken by the other countries. Hence, changes in the terms of trade as a result of different abatement effort allocations across countries, affect the MAC curves only very little.

emissions with R_i tons by 2010. These losses include, among others, the costs of fuel switching, the cost of investing in more efficient technologies, insulation costs to increase fuel efficiency in private houses and buildings etc. Since the MAC functions were estimated on data generated by a general equilibrium model, our approach incorporates indirect or general equilibrium effects. In this respect, our approach is the same as the one of Ellerman and Decaux (1998) who are using MAC functions that are estimated on data generated by the MIT-EPPA general equilibrium model or Criqui et al (1999) who are using partial equilibrium POLES data. The cost function is assumed to be twice continuously differentiable, strictly increasing ($C_i' > 0$ for $R_i > 0$) and strictly convex in abatement ($C_i'' > 0$). Hence marginal abatement costs are rising as more emissions are abated. Furthermore, it is assumed that the first unit of abatement is free ($C_i(0) = 0$ and $C_i'(0) = 0$) and that it is infinitely costly to abate the last unit of emissions ($\lim_{R_i \to E_i^1} C_i'(R_i) = +\infty$).

A market for carbon emission permits is created by assigning emission targets (Assigned Amount Units AAU_i) to every region and allowing them to trade emission reductions. The possibility of permit trading affects a country's GDP in the following way:

$$GDP_i = GDP_i^1 - C_i\left(R_i\right) + p\left[AAU_i - E_i\right] = GDP_i^1 - C_i\left(R_i\right) + p\left[AAU_i - E_i^1 + R_i\right] \quad (1)$$

Every country can choose between reducing its emissions more than required by the quotum AAU_i and selling the surplus in the permit market at unit price p, or reducing its emissions less than required and buying additional permits in the international market. Assuming price taking behaviour and ignoring constraints on the trading volumes[4], a free trade market equilibrium for permit trading is defined as a vector of emission reduction efforts such that every individual country maximises its expected GDP in 2010. The first-order necessary and sufficient condition for this maximisation problem says that every country should reduce its carbon emissions up to the point where its marginal abatement cost is exactly equal to the market price[5].

$$C_i'\left(R_i\right) = p \quad (2)$$

These first-order conditions define well-behaved, continuous and increasing emission reduction supply curves: $\rho_i(p) = C_i'^{-1}(p)$ since C_i' is strictly monotone, continuous and strictly increasing in abatement. Excess supply for permits is defined as follows:

$$XS_i\left(p\right) = AAU_i - E_i = AAU_i - E_i^1 + \rho_i\left(p\right) \quad (3)$$

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[4] Of course, some natural limits apply to the amount of emission reduction feasible. Emission abatement (relative to some Business-as-Usual scenario) is restricted to be nonnegative and cannot exceed the BAU emissions: $0 \le R_i \le \overline{E}_i$.

[5] Because of the assumptions on the limit behaviour of the marginal abatement cost functions we need not consider corner solutions.

If $XS_i(p) < 0$, this implies that for region *i* actual emissions in 2010 are higher than the Assigned Amount Units, and hence, that it has to import emission permits in order to comply with its emission reduction commitment. Similarly, if $XS_i(p) > 0$, country *i* is exporting emission permits since its actual emissions are lower than its Assigned Amount Units.

A permit market equilibrium for the set of countries S is defined as a price level $p^* \geq 0$ for which total excess supply is nonnegative[6]:

$$\sum_{j \in S} XS_i(p^*) \geq 0 \tag{4}$$

The excess supply framework can easily be extended to account for transaction costs and limited accessibility for, e.g. CDM and/or JI projects, by altering the reduction supply functions as follows:

$$\rho_i(p) = \alpha C_i'^{-1}([1-\beta]p) \tag{5}$$

where α denotes the accessibility rate (for instance 30%) and β the proportional transaction cost (for instance 20%) that is incurred when implementing a bilateral JI or CDM project.

2.2. Reference scenario: the 1997 Kyoto Agreement

Since we want to compare the recent Bonn and Marrakesh agreements with the original Kyoto Protocol, we first have to define what we mean exactly with the Kyoto Protocol. For the Kyoto reference scenario we made the following assumptions:

- the USA are participating in the agreement
- Annex B countries engage in unrestricted permit trading among each other
- “hot air” (i.e. if $E_i^1 < AAU_i$) is allowed to be traded without restrictions
- CDM accessibility is limited to 30% and CDM transaction costs amount to 20%

The limited accessibility of CDM means that only 30% of projects eligible for CDM and which would have been realised given the international permit/credit price, are actually carried out because of practical, legal and administrative reasons. The transaction costs, which complement this limited accessibility, are a cost for the host countries[7].

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6 Existence of a unique free trade market equilibrium is always guaranteed for $\sum_{i \in S} AAU_i \leq \sum_{i \in S} E_i^1$ because of the limit assumptions on the marginal abatement cost functions. The inequality in the market equilibrium condition refers to the case in which total permit supply would be larger than the sum of all AAUs in equilibrium (for instance if there would be more "hot air" than total reduction obligations) which implies that carbon permits have no value, i.e. the equilibrium price is zero.

7 We follow here the approach chosen by Criqui (2000) and Manne and Richels (2001) who use similar numbers for CDM accessibility. Note that the 2% share of proceeds on CDM projects that has been agreed in Bonn (see UNFCCC (2001c), p.18) is assumed to be embodied in the accessibility and transaction costs factors.

The following Table shows the main features of the reference scenario.

Table 2.1: the 1997 Kyoto Protocol[8]

	E	ΔE/E0	XS/AAU	MAC	AC	PC	TC
EU15	3.613	12.283	-22.046	21.963	0.033	0.122	0.155
OEU	0.099	26.330	-31.320	21.963	0.006	0.071	0.078
AUZ	0.327	12.855	-15.986	21.963	0.091	0.173	0.264
JAP	1.345	26.297	-34.359	21.963	0.011	0.103	0.114
CAN	0.500	16.119	-23.531	21.963	0.110	0.262	0.372
Annex B*	***5.885***	***15.793***	***-24.568***		***0.029***	***0.120***	***0.149***
CEU	2.997	-33.585	32.642	21.963	0.560	-2.674	-2.113
USA	5.370	9.414	-17.649	21.963	0.108	0.171	0.279
Annex B	**14.252**	**-1.731**	**-3.739**		**0.073**	**0.035**	**0.108**
MED	0.487	39.232	2.146	4.111	0.004	-0.045	-0.041
MEA	1.084	66.299	3.190	3.895	0.008	-0.096	-0.088
AFR	0.620	50.462	2.531	3.693	0.005	-0.062	-0.057
CHI	3.656	51.622	6.792	2.457	0.017	-0.400	-0.383
IND	0.941	56.361	7.353	1.904	0.010	-0.319	-0.309
ASIA	1.625	95.044	1.770	4.242	0.002	-0.026	-0.024
SAM	1.484	52.329	1.808	4.101	0.002	-0.022	-0.020
ROW	0.760	-7.146	6.575	2.083	0.010	-0.281	-0.271
World	**24.908**	**15.557**	**0.000**		**0.058**	**0.000**	**0.058**

p = 21.963 \$1995/tonCO_2 (= 80.531 \$1995/tonC)

Due to the unrestricted nature of emission trading within the Annex B group, marginal abatement costs are equalised and amount to 21.96 $\$_{1995}$/ton$CO_2$ which is the equilibrium permit price in the first commitment period. However, the Annex B group buys some of its reduction in non-Annex B countries by means of CDM projects. The CDM mechanism is however imperfect due to limited accessibility (30%) and transaction costs (20%). The accessibility restriction causes marginal abatement costs to differ between CDM host countries.

Within Annex B, only CEU exports permits. Its unrestricted permit sales amount to more than 32% of its Kyoto assigned emissions. Approximately half of these sales stand for genuine emission abatement, the other half stems from hot air, i.e. the amount of emissions in surplus of its baseline emissions. Overall, CEU gains more than 2% of its 2010 GDP from engaging in emission trading. All other Annex B regions are net permit importers. High cost regions like Japan and Other Europe import for more than 30% of their assigned amount. The USA and EU15 import approximately 20% of their Kyoto assigned amount. Compliance costs for Annex B together amount to 35.255 billion US$\$_{1995}$

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8 Legend for all tables:

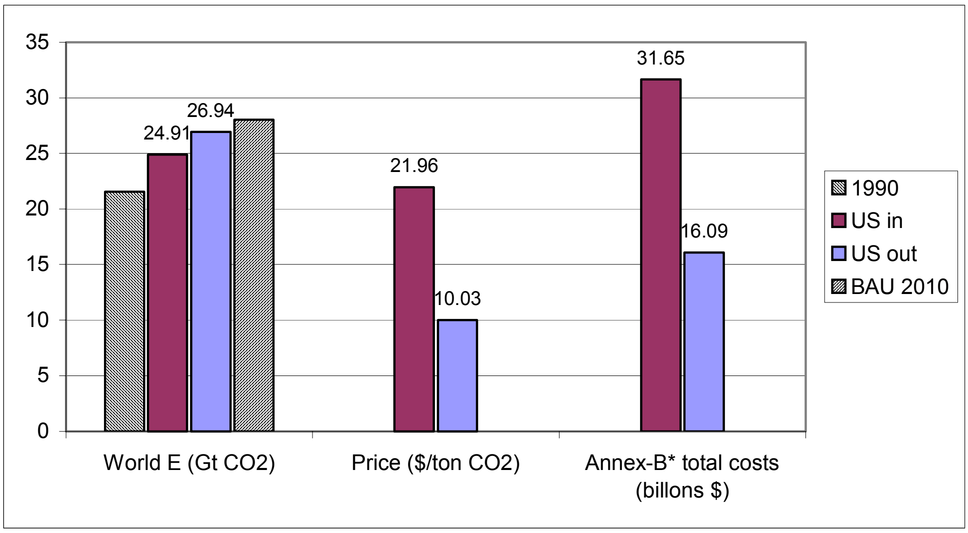
- The name and the composition of the regions and countries are provided in appendix (see Table A.1); Annex B* includes all Annex B countries except USA and CEU.
- E denotes 2010 emissions (in GtCO_2)
- ΔE/E0 denotes the change in emissions between 2010 and 1990, divided by 1990 emissions (in percentage)
- XS/AAU denotes excess supply for permit (exports (+) or imports (-)) as a fraction of Kyoto target emissions or Assigned Amount Units AAU (in percentage)
- MAC denotes marginal carbon abatement cost (in $\$_{1995}$ per ton of CO_2)
- AC stands for the abatement cost (in percentage of 2010 GDP)
- PC stands for the permit costs, i.e. the equilibrium permit price times the volume of permits imported or exported (in percentage of 2010 GDP)
- TC denotes total costs, i.e. AC + PC (in percentage of 2010 GDP).

which represents about 0.108% of 2010 GDP. Total world compliance costs amount to 24.526 billion US$$_{1995}$ or 0.058% of 2010 GDP.

3. THE NON-PARTICIPATION OF THE USA

By now it has become clear that the USA will not observe the emission target it had been assigned in the 1997 Kyoto Protocol. In July of this year, the remaining Parties of the Kyoto Protocol decided during COP 6 bis to pursue the implementation of the Protocol in spite of the nonparticipation of one of the most important carbon emitting Parties. As depicted in Figure 3.1, the nonparticipation of the USA changes things significantly. First, global carbon emissions in 2010 increase by almost 25% instead of 15.5% w.r.t. 1990 emission levels (see Table A.3 in appendix for detailed figures). Compared to the emissions increase under the BAU scenario, which amounts to 30.1% (see Table A.2 in appendix), the global emission reduction objective is drastically weakened by the US withdrawal.

Figure 3.1: World emissions, permits price and total costs with and without US



Secondly, and consequently, the price of the permits decreases by more than 50% (10.03 versus 21.96 $\$_{1995}$/ton$CO_2$) since an important share of permit demand falls out. As the world total emissions objective falls, it is not surprising to observe that compliance costs for the Annex-B* countries (EU15, OEU, AUZ, JAP and CAN, i.e. countries with real emission reduction objectives) decrease by a factor of 2 (see Figure 3.1, for detailed figures, see Table A.3 in appendix). Because of the sharp reduction in the equilibrium permit price, all permit exporting countries lose from the nonparticipation by the US. The biggest looser in absolute terms is CEU whose benefits decrease from 2.113% to 0.819% of GDP in 2010. Permit sales revenues of CDM hosting countries are even cut by a factor four. At the same time, world total costs decrease drastically, from 0.058 % to 0.008 % of 2010 GDP.

For comparison, Böhringer (2001) reports equilibrium carbon prices of 16.9 $\$_{1995}$/ton$CO_2$ when US participates and only 1.9 $\$_{1995}$/ton$CO_2$ when it does not for the original Kyoto emission reduction targets. We will come back to this comparison later.

4. SINKS

The general principle that net changes in carbon sinks can be used by Annex B countries to meet their greenhouse gas emission reduction commitment was already accepted in the Kyoto Protocol (in particular the Articles 3.3 and 3.4). However, the precise definitions of carbon sinks and the way to account for them has been one of the major discussion points during CoP 6 (The Hague), CoP 6 Bis (Bonn) and COP 7 (Marrakesh). In the final documents issued by the Bonn and Marrakesh meetings (see FCCC (2001a,d)), different kinds of land use, land use changes and forestry (LULUCF) activities which result in net changes in carbon sinks are distinguished. Each of these activities is subject to different rules and constraints. In the following section we summarise the essentials.

4.1. Activities that give rise to changes in carbon sinks

It is important to distinguish activities that fall under Article 3.3 of the Kyoto Protocol (i.e. only deforestation, afforestation and reforestation) and other activities which are mentioned in Article 3.4 of the Protocol (i.e. sinks in agriculture land, land use and forestry). The text of the recent Bonn agreement contains precise definitions of the basic concepts (we only report general definitions in order to give an idea of the agreement's content, we refer the interested reader to the official document FCCC (2001)):

- *afforestation (article 3.3)*: planting new forest on sites that were not forested for at least 50 years
- *deforestation (article 3.3)*: converting forested into non-forested land
- *reforestation (article 3.3)*: planting forest on sites that have been deforested in the past and that were not replanted on December 31, 1989
- *revegetation (article 3.4)*: establishing vegetation that does not meet the criteria of afforestation and reforestation
- *forest management (article 3.4)*: practice of stewardship of forests taking into consideration the (nationally defined) principle of sustainable development
- *cropland management (article 3.4)*: management practices on land used for production of agricultural crops
- *grazing land management (article 3.4)*: management practices on land used for livestock production

4.2. Sinks in Annex B countries

Both Article 3.3 (afforestation and deforestation) and Article 3.4 (revegetation, forest management, cropland management, grazing land management) LULUCF activities can give rise to net additions to the assigned amount of an Annex B country. There are in principle no limits on Article 3.3 activities, except for the general principles of eligibility, reporting etc. For Article 3.4 activities however, and in particular for forest management, data are largely lacking and negotiators were afraid that the LULUCF credits would erode the general emission targets of the Kyoto Protocol. Therefore, the amount of credits that can be obtained from forest management activities under Article 3.4 has been limited to the total of all credits obtained under Article 3.3 activities. Further activities of forest management eligible under Article 3.4 should be such that total forest management activities of each party do not exceed the levels listed in Annex Z of the Bonn agreement[9]. Moreover, if net sources are incurred by a Party under Article 3.3, this Party may account for GHG emissions under forest management (Article 3.4).

4.3. Sinks in CDM projects (Article 12 of Kyoto Protocol)

For CDM projects, things are relatively clear and simple. In the framework of CDM projects, the only LULUCF activities that can give rise to net additions to the donor country's assigned amount of greenhouse gases are afforestation and reforestation. However, the net total of these LULUCF activities under CDM projects should not exceed one percent of the donor country's base year (i.e. 1990 for most parties) emissions.

4.4. Sinks in the MACGEM model: a first approximation

As comprehensive data on carbon sinks and costs of LULUCF activities are rare and not reliable, we adopted a rough approximation by assuming that *all Parties will use sinks in CDM projects and forest management activities up to the maximal levels specified by the Bonn agreement and that this represents a zero cost abatement option*. This is clearly a strong assumption since converting agricultural land into forest has an important opportunity cost (loss of agricultural production) for instance. Still we believe that Parties will try as much as possible to get their current and planned LULUCF activities recognised as carbon sink credits. These projects can be considered as zero cost greenhouse gas abatement options since they will be undertaken anyway (for instance in the case of commercial forestry projects because they are expected to generate future profits, or in the case of nature conservation, because the expected recreational and existence value are estimated higher than the opportunity cost of the land).

One might argue that our assumption that sinks are zero cost abatement opportunities, is unrealistic and overestimates the role of sinks in the Bonn and Marrakesh agreements. However, we believe that Parties will try as much as possible to use these carbon sinks provisions to limit their compliance costs. Moreover, and in contrast to our simulations, the Bonn-Marrakesh accords do not cap all LULUCF activities. In partiuclar, there exist several other low cost LULUCF activities (e.g. grazing land management etc) which will, beyond doubt, be used by Parties to obtain emission credits.

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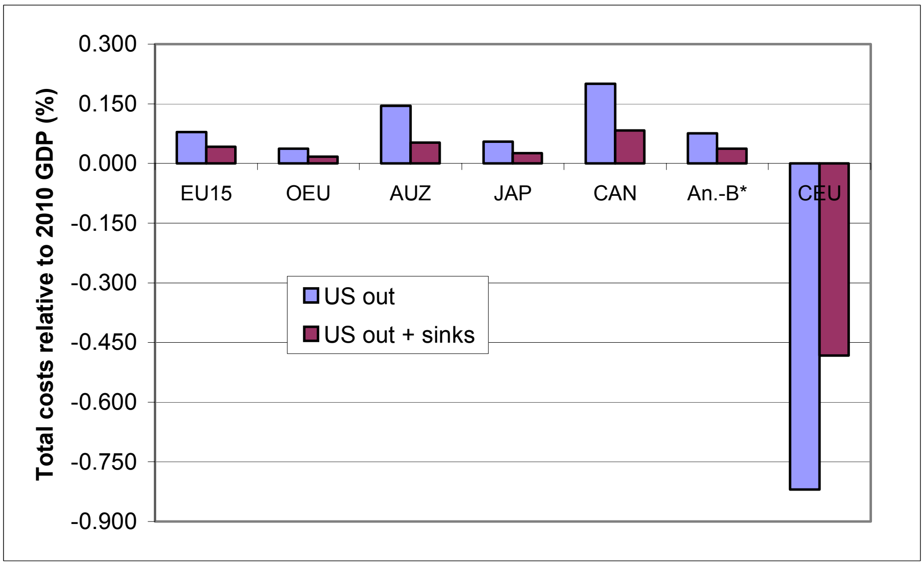
[9]Annex Z of the Bonn agreement must by modified by the following decision taken in Marrakech : "The Conference of the Parties […] decides that, for the first commitment period, additions to and subtractions from the assigned amount of the Russian Federation, resulting from forest management under Article 3.4 after the application of paragraph 10 of the annex to decision -/COP.7, and resulting from forest management projects under Article 6, shall not exceed 33 megatons of carbon per year, times five." See UNFCCC (2001,d).

Practically speaking, we adapted the Kyoto assigned amounts for the regions of the MACGEM model in two consecutive steps: first we augmented the Annex B Parties assigned amounts with one percent of their base year emissions to account for the upper limit in CDM projects. Secondly, we added the Appendix Z data and the potential net credits under Article 3.3[10]:

$$AAU_i^S = AAU_i + 0.01E_i^0 + E_i^Z + E_i^{3.3} \quad (6)$$

Figure 4.1: Total costs relative to 2010 GDP for selected regions with and without sinks (US out)



As sinks represent very low cost carbon abatement options, their introduction causes the permits price to fall from 10.03 to 5.36 $\$_{1995}$/ton$CO_2$ (see Table A.4 in appendix for detailed figures). Böhringer (2001) obtains a zero equilibrium carbon price for a similar scenario, Manne and Richels (2001) a small but positive price. Figure 4.1 shows how this affects the compliance costs of some selected participating countries. Compliance costs for total Annex-B* are cut by half. Among these Annex B* countries, we observe that CAN, AUZ and to a lesser extent JAP, benefit proportionately more than the other countries from the inclusion of sinks. In our opinion, this reflects their high negotiation power during CoP 6 Bis in Bonn since their approval was necessary to saveguard the future ratification of the Kyoto Protocol. Relative to their 2010 GDP, their costs are however still the highest. Finally, all permit exporters emission trading gains decrease as a consequence of the fall in permits price.

[10]The potential net sources under Article 3.3 are presented in appendix (see Table A.2). They come from National Communications (http://www.unfccc.int/resource/natcom/index.html) and from United Nations Food and Agriculture Organisation (FAO) data as reported in Pronk (2001).

5. COUNTRIES OF EASTERN EUROPE: STRATEGIC BEHAVIOUR, THE COMMITMENT PERIOD RESERVE AND HOT AIR

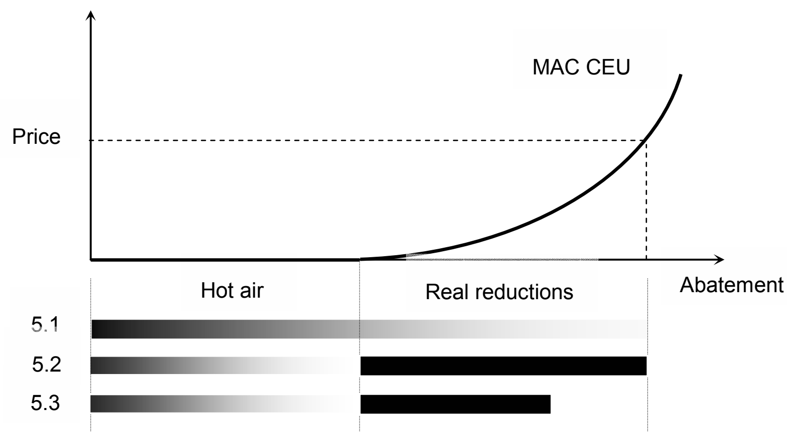
As mentioned in the above sections, Central and Eastern European countries CEU play a key role in the determination of abatement efforts since (i) their AAU are larger than their 2010 BAU emissions (hence they possess so called "hot air") and (ii) they are the only permit exporters among Annex-B countries. This raises several issues that are linked to the Commitment Period Reserve provision negotiated in Bonn and which we deal with in three steps.

Firstly in section 5.1, we analyse the impact of strategic restrictions of permits exports by CEU and show that the Commitment Period Reserve may be interpreted as a step towards such a strategic behaviour. For that purpose, we assume that CEU is free to sell first all the permits which entail the lowest abatement costs. As depicted in Figure 5.1 (scenario "5.1"), CEU will sell first its permits from hot air as these permits do not imply any abatement costs. If all hot air is sold and if sales restrictions have not been reached yet, CEU will start selling permits that correspond to costly emission reduction projects. For any binding permit export restriction, the marginal abatement cost of CEU will therefore lie below the market price of carbon. At the prevailing price, CEU would like to sell more permits but is prevented from doing so by the export ceiling.

Secondly, restrictions on the sales of hot air have been very much debated because this hot air does not correspond to genuine abatement of emissions. We evaluate in section 5.2 the effect of different *restrictions on the sale of hot air* by assuming that *real* emission reductions take place up to equalisation of CEU marginal abatement cost to the international price of carbon. Hence, we assume that CEU does not restricts its sales of real emission reductions as depicted in Figure 5.1 (scenario "5.2").

Thirdly in section 5.3, we conjecture that CEU might not themselves implement domestic policies aiming at reducing emissions and that CEU domestic abatement may only come from Joint Implementation (JI) projects. In this scenario, genuine emission reductions will take place but to a lower extent than in the previous scenario because JI does not perform as well as emissions trading (see Figure 5.1, scenario "5.3"). This is accounted for by introducing a JI accessibility factor, which drives a wedge between the equilibrium permit price and CEUs marginal abatement cost. In this third scenario, we will also analyse the consequences of a possible limit on CEUs sales of hot air.

Figure 5.1: alternative assumptions on CEU sales restrictions



5.1 Strategic behaviour by CEU and the Commitment Period Reserve

5.1.1. Restrictions on permit exports by CEU

As CEU are the only countries which are expected to export AAU in the Kyoto carbon permit market, a restriction on their exports is likely to affect the price of the permits and, consequently, the total compliance costs of every country. In order to analyse this issue, we compute the total abatement cost (relative to GDP) for some selected regions including CEU and the equilibrium permit price for different levels of restrictions on CEU permits exports. As mentioned above, we assume that CEU sells first the emission reductions which entail the lowest costs. Practically, it means that CEU will sell its hot air before turning to genuine emission reductions. If the export restriction is binding, we therefore expect the marginal abatement cost of CEU to be lower than the one of the Annex-B* countries.

The export restriction is introduced in MacGEM by modifying expression (3) for excess permit supply:

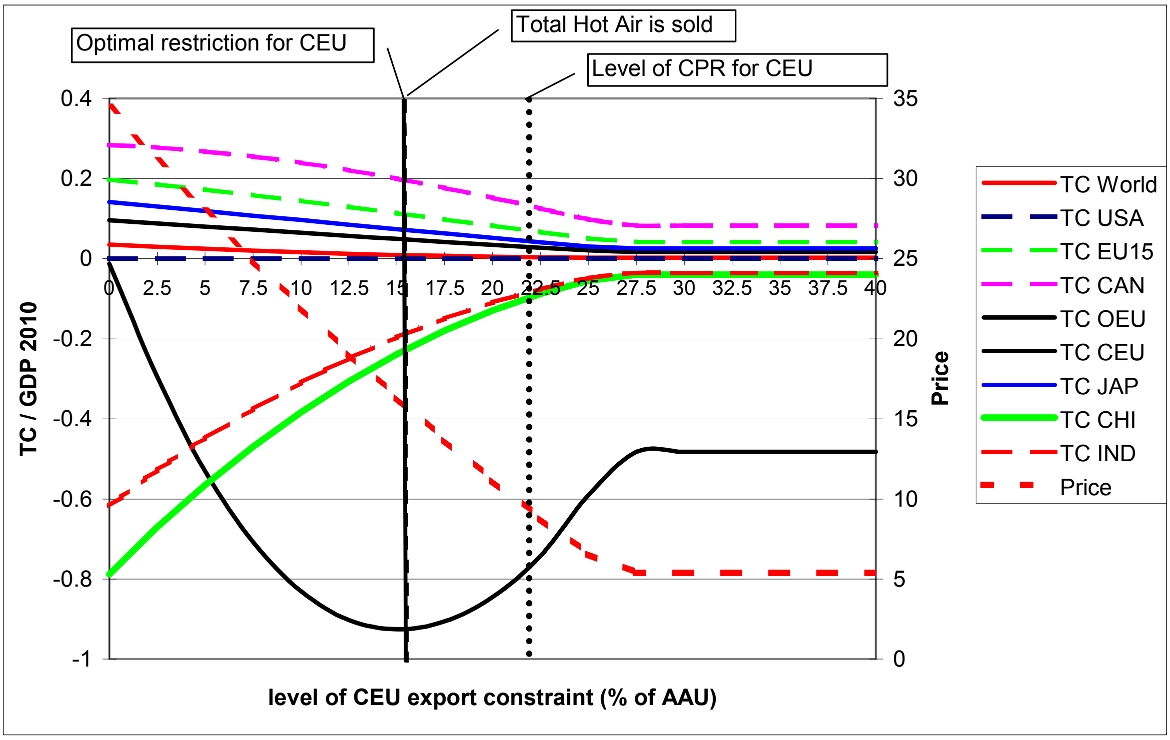
$$XS_i\left(p\right) = \min\left\{AAU_i - E_i\ ,\ L_i\right\} \tag{7}$$

where L_i stands for the export limit and $L_i \in \left[0, AAU_i\right]$.

As depicted in Figure 5.2, CEU can exert considerable market power by restricting its permit export. If CEU exports are fully restricted, the equilibrium permit price reaches 34.46 $\$_{1995}/tonCO_2$. The equilibrium price progressively decreases and stabilises at 5.38 $\$_{1995}/tonCO_2$ when the export constraint becomes non binding. This occurs at an export limit of about 30% of CEUs AAU. We observe that CEU maximises its gains by selling only 15% of its AAU, which corresponds approximately to its hot air[11]. It would therefore be optimal for CEU to sell exactly all its hot air and not to engage in any additional costly emission reduction. It should however be noted that the overall magnitude of CEUs monopoly gains is relatively small. Furthermore, both trade gains of the CDM regions and compliance costs of permit importing regions increase monotonically because of the increasing permit price.

[11]Sensitivity analysis however shows that this is a pure coincidence. For other BAU baseline assumptions for CEU the amount of permit exports which maximises CEU gains may well differ from its hot air.

Figure 5.2: Total costs and permits price for different levels of CEU exports



Compared to Böhringer (2001), our results are less dramatic since, even if the CEU would sell all of its hot air, we still find a positive equilibrium carbon price. In Böhringer (2001), the equilibrium permit price would fall to zero because the hot air of the CEU countries is sufficient to cover the reduction obligations of the other Annex-B countries in a scenario which takes into account the nonparticipation of the US and the use of carbon sinks. The results between our and Böhringer (2001) results stem from the difference in the BAU baseline projections we use for CEU. In section 6 (sensitivity analysis), we will come back to this issue of CEU baseline projections.

5.1.2. The CPR: a step towards strategic behaviour

The goal of the commitment period reserve (CPR) is to prevent the risk of overselling of emission permits by Parties by requiring each of them to maintain a certain amount of permits in their account. According to the negotiation text, the CPR is defined as follows[12]: “each Party included in Annex I shall maintain, in its national registry, a commitment period reserve which should not drop below [*a*] 90 per cent of the Party’s assigned amount calculated pursuant to Article 3, paragraphs 7 and 8, of the Kyoto Protocol or [*b*] 100 per cent of five times its most recently reviewed inventory, whichever is lowest.” Therefore, if all countries comply, the CPR works as a (temporary) constraint on the sales—the

[12]See UNFCCC (2001a), page 10.

exports—of permits during the commitment period (see Baron (2001) and Haites and Missfeldt (2001) for a detailed description and analysis of the CPR) [13] [14].

Computation of the CPR permit export ceilings under option [*a*] (90% of AAU) is straightforward. However, computing the CPR export ceilings under option [*b*] requires knowledge of future emissions. For this purpose, we use the 2005 business-as-usual emissions derived from the GEM-E3-World model. These emissions should be interpreted as an upper estimate of the actual 2005 emissions as countries might decide to reduce their emissions before the start of the First Commitment Period and therefore depart from the BAU trajectory.

Among the two options determining the CPR, option [*b*] is the less restrictive for CEU as it is allowed to export approximately 22% of its AAU when considering the 2005 BAU emissions as the most recently reviewed inventory for CEU against only 10% for option [*a*]. However, in the scenario without participation of the USA and with sinks, CEU wishes to export 26.42% of its AAU (see Table A.4). Hence, CEU would like to sell more permits but is prevented from doing so by the CPR mechanism.

In Figure 5.2, the vertical dotted line indicates the 22% export restriction induced by the CPR mechanism under option [*b*][15]. In this situation, CEU permit trading gains rise by about 45% compared to a situation without export restrictions (compare Table A.5 and Table A.4 in appendix for detailed figures). However, as suggested before, CEU would maximise its gains by restricting its supply of permits even more: a CPR of 85% (corresponding to an export restriction of 15%) would be optimal from the CEU's point of view. If the CPR becomes higher than 94%, CEU starts loosing compared to the unrestricted scenario because the effect of the export ceiling dominates the price effect.

We can conclude that the CPR mechanism is not a bad deal for CEU as its permit trading gains increase. However, CEU countries could do even better by behaving strategically and restricting its sales of permits even further.

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[13] Because our model considers only net transfers of permits between countries and because the first commitment period is modelled as only one period, we cannot simulate the potential effect of shifting abatement from the beginning towards the end of the first commitment period. For instance, if a permit importing country believes the permit price will decrease during the first commitment period, it might wish to sell early in the commitment period some of its permits while purchasing a large amount of permits later when the market price is low. Because the CPR mechanism forbids it to sell more than a certain amount of permits, this country might fail to benefit from favourable market conditions and the liquidity of the permits market would be reduced.

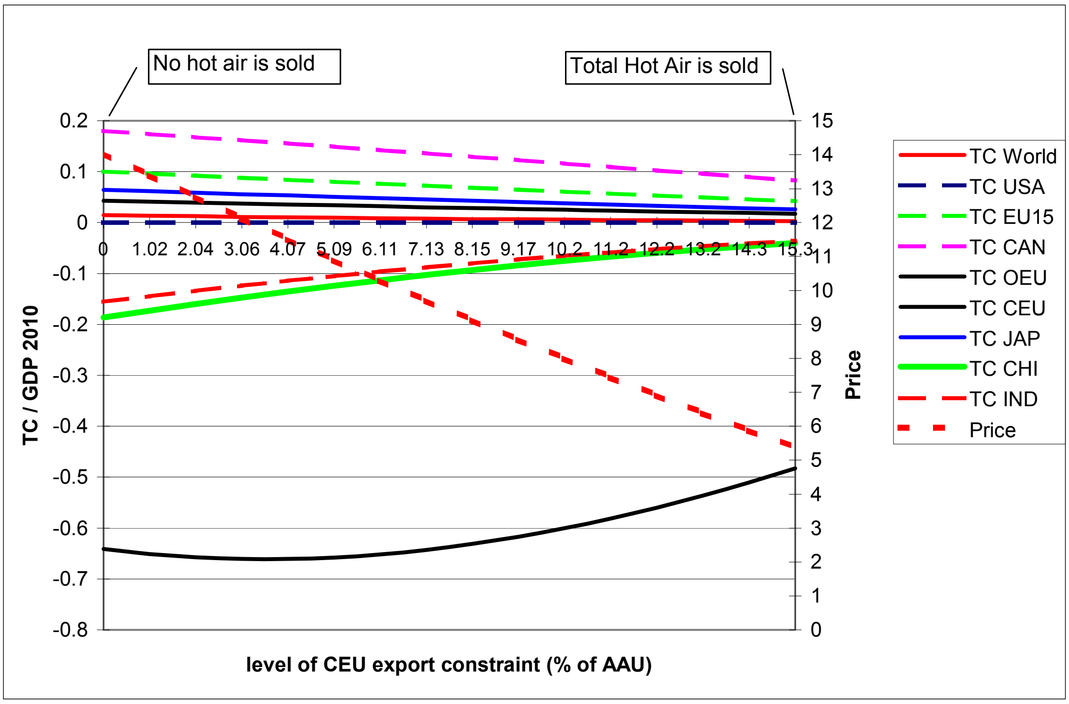
[14] After compliance has been established for the first commitment period, a country which is left with unsold permits because it has been restricted in its exports by the CPR, may use or sell these permits during the second commitment period. This would have an impact on world emissions and on the permit price in the second commitment period. However, this impact is not dealt with here as we concentrate on the first commitment period. Manne and Richels (2001) consider this option explicitly. Note that Parties may also trade their unsold permits during the 'true-up period', which we do not deal with since we assume that all countries comply and since we work in static model.

[15] Recall that option [b] is based on the 2005 BAU emissions which are an upper estimate of the most recently reviewed inventories that will be used to determine the CPR during the commitment period. Therefore, the actual export restriction might well stand on the left of the vertical dotted line, which would reduce the effect of the CPR on CEU gains and on world costs.

5.2 Restrictions on Hot Air

As CEU are the only countries which export AAU, a restriction on their exports is likely to affect the price of the permits and, consequently, compliance costs of every country. In order to analyse this issue, we compute in Figure 5.3 the total abatement cost (relative to GDP) for some selected regions including CEU and the equilibrium permit price for different levels of hot air exports. Whatever this restriction on hot air sales, it is assumed that CEU reduces its emissions up to equalisation of its marginal abatement costs to the permits price[16].

Figure 5.3: Total costs and permits price for different levels of hot air exports (US out with sinks)



In case of full restriction on hot air sales (0% of AAU), the permits price is 14.00 $\$_{1995}$/ton$CO_2$. When all hot air is allowed to be exported (15.3% of AAU), the price reaches its level of 5.38 $\$_{1995}$/ton$CO_2$. In the former case, total compliance costs for Annex-B* countries are two times higher than in the latter case. The intuition for this cost increase is that more costly abatement projects have to be undertaken when hot air sales are forbidden in order to satisfy the Kyoto commitments. When no hot air is sold, global carbon emissions are lower and amount to 26.63 GtCO_2 rather than 27.33 GtCO_2. Note also that non-Annex-B countries, like China and India, benefit very much from a restriction on the sale of hot air. Their gains increase by a factor of, respectively, 4 and 3 since the demand of permits by Annex-B* countries shifts towards CDM credits as a result of the lower permits supply by CEU.

[16] This analysis may also serve as a very rough assessment of the "environmental reinvestment proposal" put forward by CEU at COP6. These countries propose to reinvest the revenues from sales of hot air into special projects that reduce the same amount of emissions as those sold (see Grubb et al., 2001 for a detailed presentation of the proposal). It means that if permits are sold, they schould correspond to genuine emission reductions. In our model, the reinvestment proposal (if applied in this form) would therefore correspond to a situation of full restriction of hot air sales.

5.3 Restrictions on hot air and a conjecture: Joint Implementation rather than domestic policies in CEU

Up to now we have assumed that emission reductions in CEU take place via domestic measures such as a cap-and-trade system or a carbon tax. These measures allow CEU to produce genuine emission abatement and to sell more permits than the difference between its AAU and its business-as-usual emissions, i.e., to sell more than its hot air. However, we believe that CEU may not have the capacity, or may not be willing, to implement such domestic instruments during the first commitment period. Rather, the only emission reductions taking place in CEU could be realized via Joint Implementation projects (Article 6 of the Kyoto Protocol) set up and financed by other Annex B countries. The emission reduction units (ERUs) obtained under these projects would be used by these importers to meet their reduction commitment and would automatically be deduced from CEUs permit account.

In the present subsection, we consider a rather extreme case where CEU does not engage in any domestic action to reduce its emissions. Emission reductions in CEU only take place via Joint Implementation projects. In this scenario, CEU would still be free to sell all or only part of its hot air. We therefore consider that CEU exerts market power, but only by means of its hot air. As it has been done for CDM projects, we introduce a JI accessibility factor which accounts for the impossibility to carry all profitable and eligible projects. In the simulations described below, we choose an accessibility factor of 60%[17]. A sensitivity analysis on this JI accessibility factor is performed because on the one hand, the value of this parameter is highly conjectural, and, on the other hand, CEU may take administrative or legal rules which either favour or discourage JI on its territory.

CEUs behaviour can then be described as choosing the amount of hot air to be sold, H_{CEU}, such that its net costs of abatement and permit demand are minimised:

$$\begin{aligned} &\min_{H_{CEU}} \; C_{CEU}\left(R_{CEU}\right) - pXS_{CEU}\left(p\right) \\ &s.t. \quad \sum_{i\in S} XS_i\left(p\right) \geq 0 \quad ; \quad p \geq 0 \\ &\qquad 0 \leq H_{CEU} \leq AAU_{CEU} - E^1_{CEU} \end{aligned}$$

with $XS_{CEU}\left(p\right) = AAU_{CEU} - E^1_{CEU} + \rho_{CEU}\left(p\right) = H_{CEU} + \rho_{CEU}\left(p\right)$ and $\rho_{CEU}\left(p\right) = \gamma C'^{-1}_{CEU}\left(p\right)$

with γ being the accessibility factor of JI projects in CEU.

The detailed results are presented in appendix (see Table A.6). The main findings are summarised below in Figures 5.4a and 5.4b.

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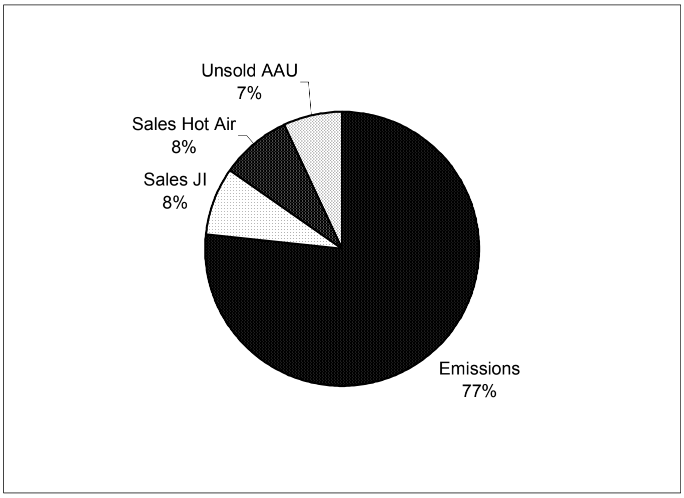
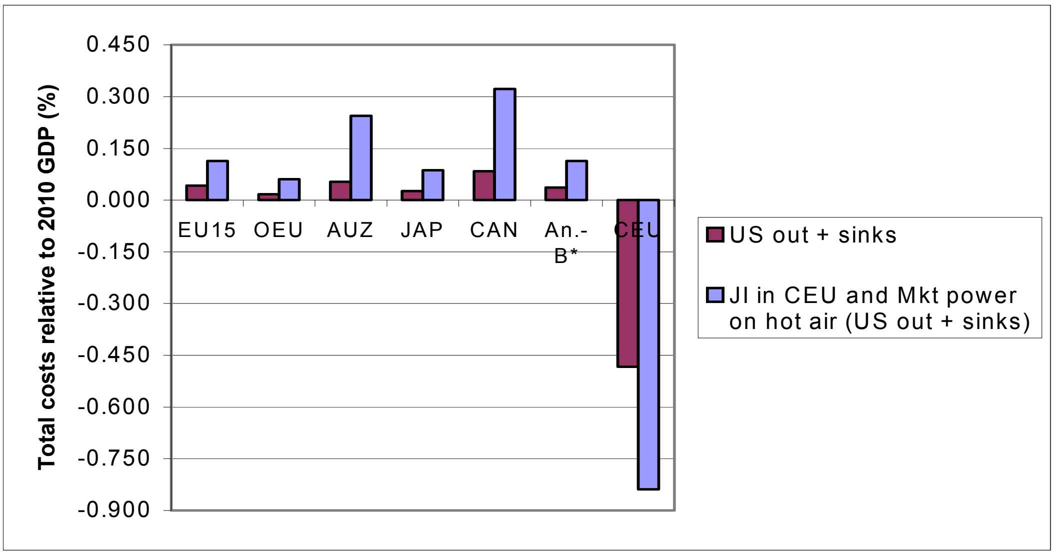
[17] Recall that we use a 30% CDM accessibility factor in all simulations.

Figure 5.4a: Distribution of the use of AAU by CEU (%): JI in CEU and market power on hot air (without USA + sinks)



A first observation is that the CPR is not binding. CEU only exports 16% of its AAU: 8% are exports of ERUs (i.e., emission reductions which stem from JI projects) and 8% are from hot air sales[18]. As CEU only sells 55% of its hot air (0.373 $GtCO_2$), this has an influence on the CO_2 emissions of these countries, and thus also on the world emissions which increase by 23.57% w.r.t. their 1990 level (26.80% in the case of US non participation and with sinks).

Figure 5.4b: JI in CEU and market power on hot air (without USA + sinks)



A second observation is that the total costs are higher than in the scenario without USA and with sinks (see Figure 5.4b). This increase in not only due to the market power of CEU, but also–and mainly—to

[18] The Bonn agreement stipulates that exports of ERUs are not subject to the CPR (see UNFCCC (2001 c), p14, §38). Therefore, only the hot air exports (8% of AAU) are subject to the CPR. The latter is thus *a fortiori* satisfied. However, exports from sinks absorption activities should also be taken into account, but this does not lead the CPR to be binding since these activities only account for 4.2% of CEU AAU.

the restricted accessibility of JI. At the same time, the price increases from 5.38 $\$_{1995}$/ton$CO_2$ to 14.80 $\$_{1995}$/ton$CO_2$.

Table 5.1: Bonn agreement with different JI accessibility in CEU

JI access. (%)	Price ($\$_{1995}$/t$CO_2$)	CEU Hot Air (%)	CEU EXP/EK	CEU TC	Annex B* TC	World E
90	12.66	50	18.517	-0.712	0.099	26.601
60	14.80	55	16.450	-0.839	0.113	26.636
30	16.02	72	15.310	-0.910	0.121	26.756

A sensitivity analysis on the JI accessibility factor is presented in Table 5.1. With a JI accessibility factor of 90%, CEU minimises its costs by selling 50% of its hot air. When the accessibility factor goes down to 30%, CEU sells 74% of hot air. In each case, the CPR is satisfied. From this we observe that CEU might find profitable to discourage JI projects in their region, if possible. Its gains are indeed slightly higher when the JI accessibility factor equals 30%. The reason is that CEU benefits from restricting its total exports of permits (as it increases the price). Then, for a given limit on exports, the lower the JI accessibility, the higher the amount of hot air that can be sold and therefore the lower the reductions, that is the abatement costs, for CEU. However, world emissions are higher with a low JI accessibility factor as more hot air is sold.

6 SENSITIVITY

In this final section, we illustrate the sensitivity of our simulation results w.r.t. the basic parameters and assumptions. As a central case, we assume non-participation of the USA, inclusion of sinks and introduction of the Commitment Period Reserve[19]. In particular we will investigate the effect of:

- an increase in the cost estimates resulting from imperfect *domestic* policies in Annex-B countries
- a change in the 2010 baseline emissions
- more flexible implementation of CDM projects

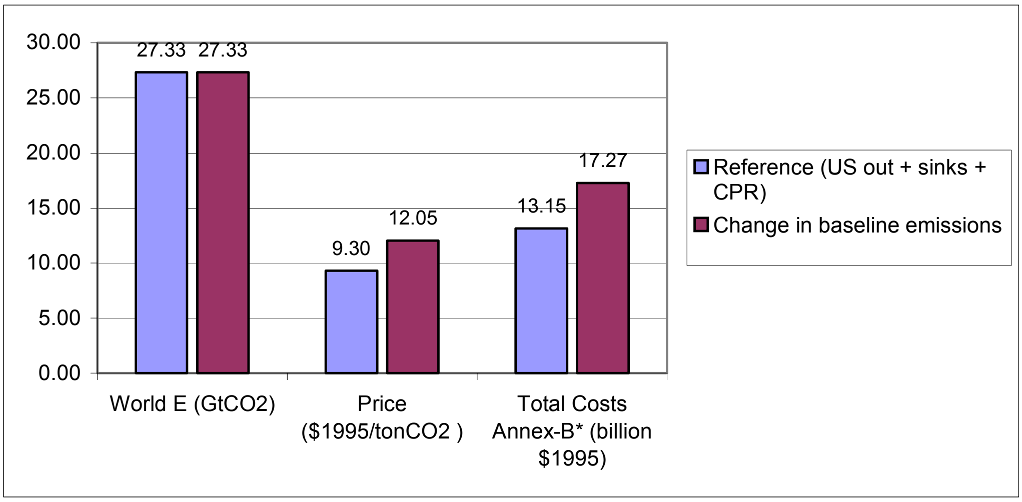
6.1 Imperfect domestic policies in Annex-B countries

Up to now, we have been working with a set of marginal abatement cost functions derived from the GEM-E3-World model under optimistic assumptions W.r.t. the efficiency of domestic carbon reduction measures. In particular, it was assumed that all regions implement their abatement policy by choosing a cost efficient allocation of reduction efforts over the 18 different sectors in the GEM-E3-World model. For instance, they achieve the target by setting a uniform carbon tax in all sectors (without exception!) or by allowing for unrestricted permit trading.

However, full cost efficiency is rarely achieved in environmental policy making, for instance because some sectors are exempted from the carbon tax or because of transaction costs. We therefore estimated an alternative set of marginal abatement cost functions that incorporate some degree of inefficiency in the national implementation of reduction efforts. We assumed that within every region 5 isolated clubs of sectors can be distinguished: energy sector, energy intensive sector, other industries, services, and households. The national authority allocates uniformly its emission abatement target (x% abatement w.r.t. 1990 emission levels) over the five sector clubs but within each club, abatement efforts can be reallocated in order to achieve equalisation of marginal abatement costs. Hence, we assume that within every region, marginal abatement costs are equalised only partially. Only within the clubs, marginal abatement costs are equal, across clubs and countries, they can differ[20].

We used this new set of MAC functions only for Annex B countries since the for the non-Annex B regions, accessibility constraints and transaction costs of CDM projects already incorporate a certain degree of local inefficiency. Results are shown in Figure 6.1.

Figure 6.1: World emissions, permits price and Annex-B* costs under imperfect domestic policies in Annex-B countries



For this new set of MAC functions, the equilibrium price of permits and global compliance costs are obviously higher than in the central case. Since domestic abatement is more expensive, Annex B* countries are making more use of the CDM mechanism. CDM host countries are therefore better off compared to the central case. Compliance costs in Annex B* countries increase by almost 25%. The degree of inefficiency in the national implementation of a carbon policy has strong repercussions for the equilibrium permit price and overall compliance costs although global carbon emissions do not change.

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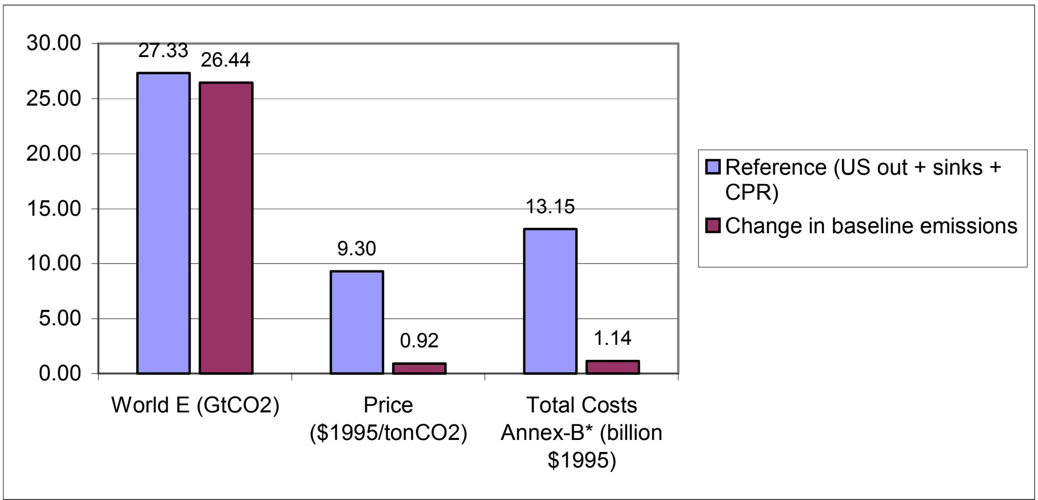
[19] The detailed results of this central case are presented in Table A.R5.2 in appendix.

[20] An even more inefficient scenario would be to allocate the national abatement target uniformly over all 18 sectors without cost efficiency consideration at all.

6.2 Lower baseline emissions for 2010

Baseline emissions estimates are based on numerous assumptions concerning GDP growth rate, rate of technological progress etc. The uncertainty on each of these parameters is compounded in the final baseline emission estimate. We therefore present a simulation in which all regions baseline emissions are lower by 5% (E2010 = 0.95 E2010) compared to the central case[21]. Though there is little reason to believe that uncertainty would affect all regions in the same way, we have chosen this counterfactual scenario to illustrate the strong sensitivity of the simulation model for baseline emission data.

Figure 6.2: World emissions, permits price and Annex-B* costs under a 5% decrease in baseline emissions



The relative small error of 5% in the projection of the 2010 baseline emissions has a strong impact on the simulation results. Since projected future emissions are lower, CEU's hot air decreases, which leads to a lower level of global carbon emissions. It nevertheless becomes easier to comply with the Bonn Agreement. The equilibrium permit price falls below 1 $\$_{1995}$/ton$CO_2$. If we would decrease the baseline emissions with 10% instead of 5%, total hot air by CEU would suffice to cover all abatement requirements and the permit price falls to zero. There would simply be no reason to abate emissions, all necessary abatement for the Bonn Agreement would stem from the CEU's hot air. A similar result is obtained by Böhringer (2001) who finds a zero permit prices for a scenario in which CEU sells all of its hot air, the US do not participate in the Kyoto Protocol and carbon sinks are used to meet emission reduction obligations. Again, this exercise illustrates the strong sensitivity of the simulation model for one of its basic parameters, the projected baseline emissions.

6.3 Higher accessibility and lower transaction costs for CDM

Finally we look at the effect of higher accessibility (60% instead of 30%) and lower transaction costs (10% instead of 20%) for CDM projects compared to the central case. Figure 6.3 shows that the

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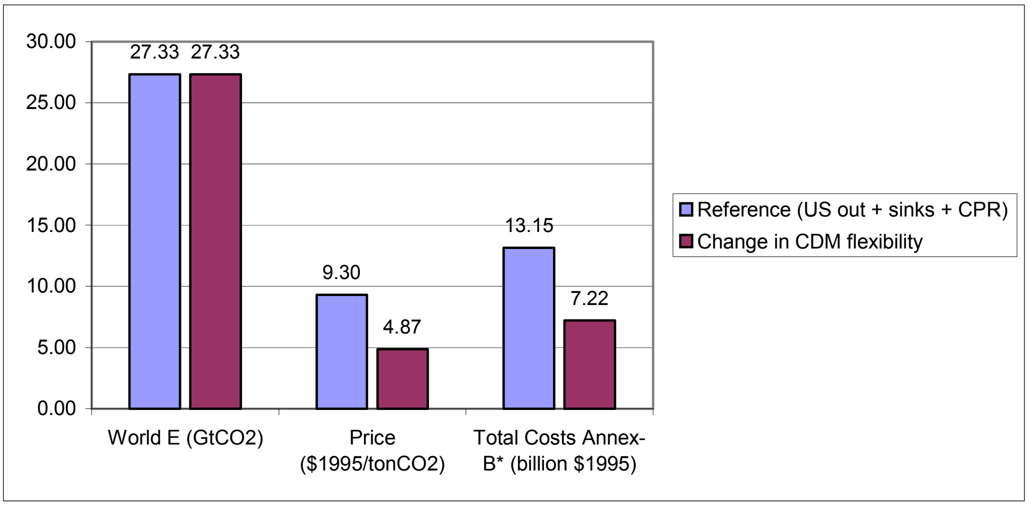
[21] We also decrease baseline emissions in 2005 by the same factor. This might affect the level of the CPR whenever CEU chooses option [b] (see section 5.1).

equilibrium permit price and compliance costs would fall sharply when CDM projects become easier and cheaper to implement.

Figure 6.3: World emissions, permits price and Annex-B* costs under higher accessibility and lower transaction costs for CDM

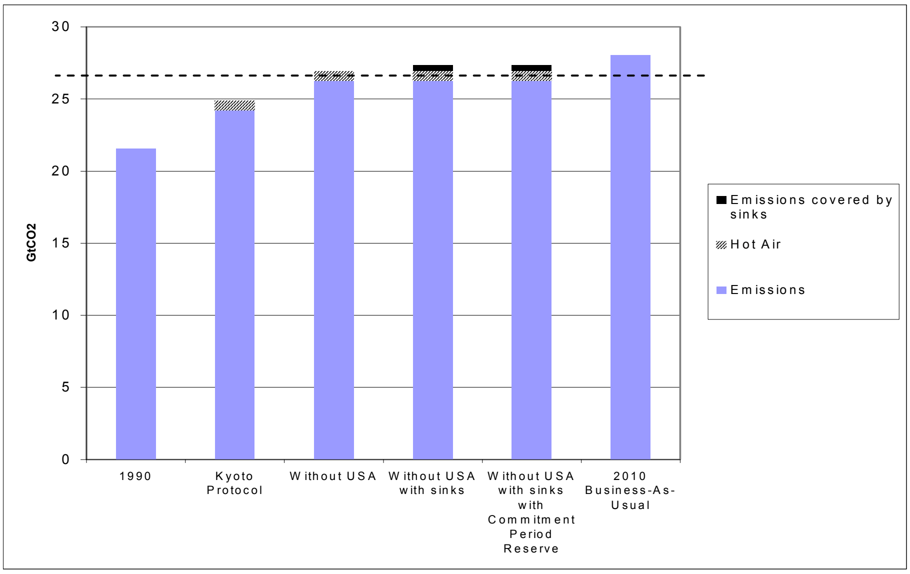


7 CONCLUSIONS

In this paper we have performed a quantitative assessment of the recent US withdrawal from the Kyoto Protocol and of the Bonn/Marrakesh agreement adopted in November 2001. The analysis was carried out using the MacGEM model which is based on a set of marginal abatement cost functions derived from the GEM-E3-World general equilibrium model.

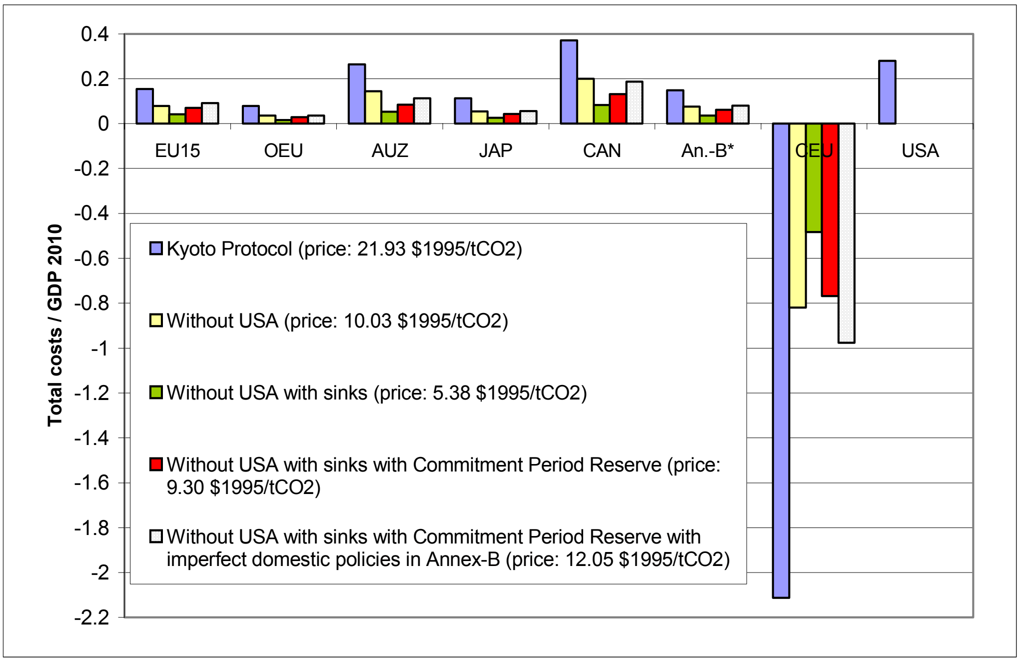
While in the absence of an agreement on CO_2 emission reductions, world carbon emissions would increase by about 30.1% compared to 1990, the ‘original’ 1997 Kyoto Protocol would have limited this increase to 15.5%. However, non participation by the USA causes world emissions to increase by 25.5% in 2010 (see Figure 7.1). The equilibrium carbon permit price and Annex-B* (EU15, OEU, AUZ, JAP and CAN) total costs fall by 50% (see Figure 7.2).

Figure 7.1: World CO_2 emissions under alternative scenarios



The introduction of activities enhancing carbon sinks should in principle not modify world net-CO_2 emissions since the discounts on emission reduction obligations are, in priciple, compensated by the uptake of CO_2 by sinks. Although this issue is being very much debated, it is clear that the introduction of such activities leads to a further decrease of carbon emission abatement efforts. Given the non-participation of the US, our results show that accounting for carbon sinks enhancement activities will lead to a further decrease of Annex-B* total costs by more than 45% (55% and 60% for CAN and AUZ respectively).

Figure 7.2: Total costs for Annex-B countries under alternative scenarios



Another element of the Bonn and Marrakesh agreements, the commitment period reserve (CPR), plays in an opposite direction. On the one hand, our analysis suggests that the CPR has been well designed in the sense that it limits as much as possible the risk of overselling while not imposing further costs to CEU. On the other hand, it also emphasises the central role played by CEU, particularly when the accessibility to emission reductions in non-Annex B countries via CDM projects is low. In this case, CEU has ample opportunities to behave strategically either by applying the CPR rule strictly or by restricting its sales of permits. This causes an increase in the permit price of about 50% and, as a consequence, of the compliance costs (about 55% for all Annex B* countries taken together). This effect continues to play but is weakened if we assume that emission reductions can only take place via JI projects in CEU. Thought the market power effect is relatively small compared to the consequences of the US withdrawal and the inclusion of sinks, our simulations suggest to pay attention to the market behaviour and to the way emission reductions take place in the CEU countries.

Our analysis also suggests that these results are very sensitive to the performance of domestic abatement policies, the 2010 baseline emissions and the degree of CDM flexibility. When countries do not succeed domestically in equalising the marginal abatement costs of their carbon emitting sectors, the equilibrium permit price and Annex-B* total costs may increase by more than 25%. Sensitivity analysis on baseline emissions illustrates the role of Russia and Ukraine.Given the US withdrawal and the inclusion of sinks activities, lowering baseline emissions of all countries by 10% implies that no more emission reductions are needed to satisfy the Protocol's emission targets. Hot air does all the job and the permit price falls to zero.

Hence, the US withdrawal and the Bonn and Marrakesh agreements reduce total compliance costs to 0.062% of Annex B* countries 2010 GDP, while this number would reach 0.149% under the 'original' Kyoto Protocol. At the same time, world CO_2 emissions will rise to 26.943 $GtCO_2$ (plus 0.388 $GtCO_2$ which should in principle be absorbed by sinks) instead of 24.908 $GtCO_2$ if the 'original' Protocol were to come into force. It is clear that the recent agreements have completely eroded the 1997 Kyoto Protocol GHG abatement target for the first commitment period. The nonparticipation of the USA plus the rather generous way in which sinks can be used to meet one's reduction commitment, indeed cause the Kyoto Protocol to become "fatally flawed". However, together with many others like for instance Grubb and Depledge (2001), we believe that this negative conclusion should not be interpreted as the death of the international climate negotiations. It is important to recall the status of the Kyoto Protocol, it is only one of the instruments of implementation of the more general and ambitious 1992 UN Framework Convention on Climate Change UNFCCC. Therefore we believe that the Bonn-Marrakesh agreements have the merit to save this international negotiation framework, even if the first step (the Kyoto Protocol) will bring about only very little reduction in GHG emissions. The UNFCCC foresees that talks should start soon on quantified emission reduction targets for the second commitment period (2013-2017). In our opinion, the international climate negotiators face the challenge to persuade some of the big developing countries to commit to quantified emission reductions for the future. This might create the appropriate conditions for making the USA reconsider its position and for meeting the ultimate long term goal of the UNFCCC, i.e. to stabilise GHG emissions at a level to prevent irreversible damage to natural and human ecosystems.

Our analysis is incomplete as not all elements of the Bonn and Marrakesh agreements have been analysed, notably because some of them are of a qualitative nature. However, the 30% supplementary reductions to be done in case of non compliance during the first commitment period is likely to have a significant impact on emission reductions and on abatement efforts, as well as on the enforcement of the Protocol. Indeed, anticipating a decrease in the permit price at the second commitment period by, for instance, putting high hopes in the development of low cost abatement technologies, some countries might choose not to comply in the first commitment period and rather bear the 30% discount penalty. An excessive use of this rule could then jeopardise the credibility on the enforcement. Moreover, delaying emission reduction efforts has a non-negligible impact on future climate. Conversely, since our analysis has shown that the first commitment period abatement objectives are flawed and that the permit price will be relatively low, countries might rather choose to bank permits in order to use them in the second commitment period. Determining whether countries will not comply and pay de 30% penalty or rather bank permits requires the conversion of the static MacGEM model into a dynamic one. Various second commitment period emission reduction objectives will then need to be considered.

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9. APPENDIX

9.1 GEM-E3-WORLD

GEM-E3-World model is a full scale, global general equilibrium model consisting of 18 inter-linked world country/region-modules and is based on the GTAP database. The model results from a collaborative efforts by a consortium, involving the National Technical University of Athens (NTUA), the Centre for Economic Studies of the Katholieke Universiteit Leuven and the Centre for European Research (ZEW) as the core modelling team. Other participants in current projects for a further developing of the model are ERASME (Ecole Centrale de Paris), MERIT (University of Maastricht), the Paul Scherrer Institute (PSI) and the University of Budapest of Economic Science. Its development has mainly been financed by the European Commission through research projects within the Joule Programme and the 5th Framework Programme.

The GEM-E3 model has been frequently used in the past by the project partners for policy-oriented research activities for National Authorities and for Directorate Generals of the European Commission. The multi-purpose nature of GEM-E3 (national, EU-wide, world wide applications, endogenous innovation, alternative assumptions about expectations of agents, new instruments etc.) makes it an appropriate tool for the evaluation of policies in many domains, also outside energy and environment.

GEM-E3 provides details on the macro-economy of the 18 World regions and its interaction with the environment and the energy system. GEM-E3 is a dynamic, recursive over time, model, involving dynamics of capital accumulation and technology progress, stock and flow relationships and backward looking expectations. A more detailed description of MacGEM can be found in Capros et al. (1997 and 1999).

9.2 MacGEM

MacGEM is a global marginal abatement cost simulation model. MacGEM aims at evaluating carbon emission abatement and permit trading equilibria for the first commitment period (i.e. 2008-2012) of the 1992 UN Framework Convention on Climate Change. The model distinguishes between 15 main regions/countries in the world and allows for simulating the effects of the flexible mechanisms provided for in the 1997 Kyoto Protocol (Joint Implementation JI, Clean Development Mechanism CDM and International Emission Trading IET).

Table A.1: geographical coverage MacGEM

label	name	Composition
EU15	European Union	
OEU	other Europe	Iceland, Norway, Switzerland
CEU	Eastern Europe and former Soviet Union	Bulgaria, Czech-Rep, Hungary, Poland, Romania, Slovak-Rep, Slovenia, former Soviet Union
AUZ	Australazia	Australia, New Zealand
JAP	Japan	
CAN	Canada	
USA	USA	
MED	Mediterranian	Turkey, Morocco, Algeria, Egypt, Libya, Tunisia
MEA	Middle East	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen
AFR	Africa	Angola, Benin, Botswana, Burkina-Fasso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Republic of Congo, Djibouti, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Ivory Coast, Kenya, Leshoto, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Senegal, Seychelles, Sierra-Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe
CHI	China	China, Hong Kong
IND	India	
ASIA	Asia	South Korea, Indonesia, Malaysia, Philippine, Singapore, Thailand, Vietnam, Taiwan, Sri-Lanka, Bangladesh, Nepal, Pakistan
SAM	South America	Costa-Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Antilles, Nicaragua, Panama, Trinidad-Tobago, Venezuela, Colombia, Bolivia, Ecuador, Peru, Argentina, Brazil, Chile, Uruguay, Paraguay
ROW	rest of world	

Table A.2: MacGEM basic data[22]

	E0	E1	AAU	EZ	E3.3	GDP0	GDP1	a	b
EU15	3.218	4.006	92.00	18.96	10.27	7850.433	11766.24	241.278	1.426
OEU	0.078	0.103	96.20	3.30	0.15	405.313	725.44	291.825	1.426
AUZ	0.290	0.381	97.30	0.73	28.27	393.723	572.69	423.325	1.206
JAP	1.065	1.424	94.00	47.67	0.00	3463.125	7374.34	290.224	1.251
CAN	0.431	0.598	94.00	44.00	0.00	662.370	802.71	251.330	1.538
Annex B*	***5.082***	***6.512***	***92.96***	***114.66***	***38.69***	***12774.964***	***21241.42***		
CEU	4.513	3.770	98.60	141.50	0.00	1345.646	1167.91	694.559	1.100
USA	4.908	6.599	93.00			6400.874	10371.89	373.612	1.220
Annex B	**14.503**	**16.881**				**20521.480**	**32781.22**		
MED	0.350	0.498				361.168	521.53	432.421	1.296
MEA	0.652	1.120				503.246	1412	269.217	1.279
AFR	0.412	0.636				335.96	573.04	525.051	1.097
CHI	2.411	3.922				500.657	1457.15	199.020	1.634
IND	0.602	1.016				347.876	512.86	235.499	1.846
ASIA	0.833	1.654				959.373	2454.29	496.158	1.180
SAM	0.974	1.511				1331.117	2688.14	523.793	1.209
ROW	0.818	0.813				143.138	416.78	258.486	1.771
non Annex B	**7.052**	**11.170**				**4482.539**	**9440.36**		
World	**21.555**	**28.051**				**25004.019**	**42221.58**		
	$GtCO_2$	$GtCO_2$	%	$MtCO_2$		billion \$1995	billion \$1995		

Data for this table were compiled using IEA (1997), UNFCCC (2001b) and data from the GEM-E3-World model.

9.3 Marginal abatement cost MAC functions

The core of the MacGEM model is given by a set of marginal abatement cost (MAC) functions that were derived from simulations with the global GEM-E3-WORLD general equilibrium model under different hypothesis concerning the national allocation of abatement targets or permits. The cost functions used for the simulations in the main part of the paper were calculated under the assumption that emission abatement is allocated efficiently at the national level over the different economic sectors, i.e. marginal abatement costs are equalized across all sectors in every country.

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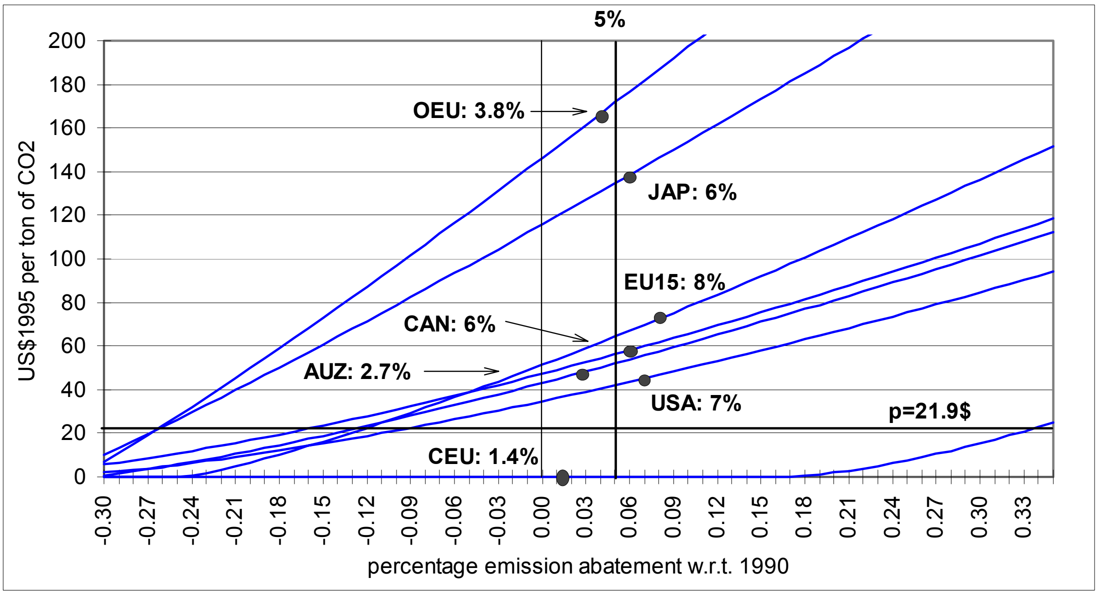
[22] Table legende

- E0 1990 carbon emissions from fossil fuel use ($GtCO_2$)
- E1 2010 carbon emissions from fossil fuel use ($GtCO_2$)
- AAU Assigned Amount Units in per cent of 1990 emissions E0
- EZ Appendix Z limits on forest management activities for Annex B ($MtCO_2$) including the Marrakesh decision modifying the limit for Russia (121 $MtCO_2$ instead of 64.64 $MtCO_2$)
- E3.3 Net sources under Article 3.3 of the Kyoto Protocol
- GDP0 1990 GDP (billion $US\$_{1995}$)
- GDP1 2010 GDP (billion $US\$_{1995}$)
- a intercept MAC function
- b exponent MAC function

Figure A.1: MAC functions Annex B



On the horizontal axis we plot percentage emission reduction w.r.t. 1990 reference emissions, on the vertical axis the marginal abatement cost in US$$_{1995}$ per ton of CO_2. The intersection of the MAC functions with the horizontal axis denotes the expected growth (or decline in the case of CEU) of baseline emissions without abatement policies. For instance, EU15 emissions are expected to increase by about 24% between 1990 and 2010, CEU emissions are expected to be about 18% below 1990 emission levels. The black dots indicate the abatement commitment by the individual regions under the original 1997 Kyoto Protocol, for instance 8% reduction for EU15. The solid horizontal line stands for the efficient market outcome for Annex B (with specific CDM accessibility of 30% and transaction costs of 20%), the solid vertical line for the uniform abatement allocation of 5% across all Annex B Parties. Clearly, there exist substantial differences marginal abatement costs if no trade of abatement efforts were allowed for.

9.4 Detailed results for each scenario

Table A.3: Kyoto Protocol without USA

	E	ΔE/E0	XS/AAU	MAC	AC	PC	TC
EU15	3.799	18.065	-28.332	10.033	0.008	0.072	0.080
OEU	0.101	29.244	-34.350	10.033	0.001	0.036	0.037
AUZ	0.352	21.338	-24.705	10.033	0.022	0.122	0.145
JAP	1.385	30.079	-38.382	10.033	0.003	0.052	0.055
CAN	0.542	25.682	-33.704	10.033	0.029	0.171	0.200
Annex B*	***6.179***	***21.587***	***-30.801***	***10.033***	***0.007***	***0.069***	***0.076***
CEU	3.306	-26.750	25.710	10.033	0.156	-0.975	-0.819
USA	6.599	34.454	0.000	0.000	0.000	0.000	0.000
Annex B	**16.084**	**10.900**	**-2.264**	**10.033**	**0.010**	**0.010**	**0.020**
MED	0.492	40.690	1.121	1.878	0.001	-0.011	-0.010
MEA	1.101	68.849	1.706	1.779	0.002	-0.024	-0.022
AFR	0.627	52.235	1.383	1.687	0.001	-0.015	-0.014
CHI	3.757	55.830	4.205	1.122	0.005	-0.113	-0.109
IND	0.967	60.653	4.810	0.870	0.003	-0.096	-0.093
ASIA	1.639	96.749	0.912	1.938	0.001	-0.006	-0.006
SAM	1.497	53.667	0.946	1.873	0.001	-0.005	-0.005
ROW	0.779	-4.810	4.225	0.951	0.003	-0.083	-0.080
World	**26.943**	**24.996**	**0.000**	**10.033**	**0.008**	**0.000**	**0.008**

p = 10.033 $\$_{1995}$/ton$CO_2$ (= 36.788 $\$_{1995}$/tonC)

Table A.4: Nonparticipation of USA, with sinks

	E	ΔE/E0	XS/AAU	MAC	AC	PC	TC
EU15	3.882	20.636	-29.142	5.375	0.003	0.039	0.042
OEU	0.102	30.459	-29.980	5.375	0.000	0.017	0.017
AUZ	0.363	25.214	-17.382	5.375	0.007	0.046	0.053
JAP	1.402	31.654	-34.232	5.375	0.001	0.025	0.026
CAN	0.562	30.311	-26.705	5.375	0.010	0.073	0.083
Annex B*	***6.311***	***24.178***	***-28.123***	***5.375***	***0.002***	***0.035***	***0.037***
CEU	3.461	-23.319	26.424	5.375	0.056	-0.539	-0.483
USA	6.599	34.454	0.000	0.000	0.000	0.000	0.000
Annex B	**16.370**	**12.875**	**-1.477**	**5.375**	**0.004**	**0.003**	**0.007**
MED	0.495	41.335	0.668	1.006	0.000	-0.003	-0.003
MEA	1.108	70.000	1.036	0.953	0.001	-0.008	-0.007
AFR	0.631	53.051	0.854	0.904	0.000	-0.005	-0.005
CHI	3.809	58.002	2.870	0.601	0.002	-0.042	-0.040
IND	0.981	62.982	3.430	0.466	0.001	-0.037	-0.035
ASIA	1.645	97.493	0.537	1.038	0.000	-0.002	-0.002
SAM	1.503	54.258	0.564	1.004	0.000	-0.002	-0.002
ROW	0.789	-3.564	2.970	0.510	0.001	-0.031	-0.030
World	**27.331**	**26.796**	**0.000**	**5.375**	**0.003**	**0.000**	**0.003**

p = 5.375 $\$_{1995}$/ton$CO_2$ (= 19.708 $\$_{1995}$/tonC)

Table A.5: Commitment Period Reserve (without USA + sinks)

	E	ΔE/E0	XS/AAU	MAC	AC	PC	TC
EU15	3.812	18.450	-26.766	9.304	0.007	0.063	0.070
OEU	0.101	29.430	-28.910	9.304	0.001	0.028	0.029
AUZ	0.354	21.914	-13.990	9.304	0.020	0.064	0.084
JAP	1.388	30.321	-32.814	9.304	0.002	0.042	0.044
CAN	0.545	26.355	-22.496	9.304	0.026	0.106	0.131
Annex B*	***6.199***	***21.975***	***-25.849***	***9.304***	***0.006***	***0.056***	***0.062***
CEU	3.660	-18.909	21.952	1.102	0.004	-0.772	-0.768
USA	6.599	34.454	0.000	0.000	0.000	0.000	0.000
Annex B	**16.457**	**13.476**	**-2.091**	**9.304**	**0.004**	**0.008**	**0.013**
MED	0.493	40.787	1.053	1.741	0.001	-0.009	-0.009
MEA	1.102	69.021	1.606	1.650	0.002	-0.021	-0.019
AFR	0.628	52.356	1.304	1.564	0.001	-0.014	-0.013
CHI	3.765	56.139	4.015	1.041	0.004	-0.101	-0.096
IND	0.969	60.978	4.617	0.806	0.003	-0.085	-0.082
ASIA	1.640	96.862	0.855	1.797	0.001	-0.005	-0.005
SAM	1.498	53.756	0.888	1.737	0.000	-0.005	-0.004
ROW	0.780	-4.635	4.049	0.882	0.003	-0.073	-0.071
World	**27.331**	**26.796**	**0.000**	**9.304**	**0.004**	**0.000**	**0.004**

p = 9.304 $\$_{1995}$/ton$CO_2$ (= 34.115 $\$_{1995}$/tonC)

Table A.6: JI in CEU and market power on hot air (without USA + sinks)

	E	ΔE/E0	XS/AAU	MAC	AC	PC	TC
EU15	3.663	13.830	-23.728	18.615	0.025	0.089	0.113
OEU	0.096	22.636	-27.480	37.997	0.018	0.042	0.060
AUZ	0.310	6.771	-9.734	31.584	0.173	0.071	0.244
JAP	1.311	23.061	-30.916	32.686	0.024	0.062	0.086
CAN	0.476	10.380	-17.425	30.319	0.191	0.131	0.322
Annex B*	***5.855***	***15.204***	***-22.955***	***18.615***	***0.034***	***0.079***	***0.113***
CEU	3.411	-24.411	16.450	6.747	0.081	-0.920	-0.839
USA	6.599	34.454	0.000	0.000	0.000	0.000	0.000
Annex B	**15.865**	**9.391**	**-2.812**	**18.615**	**0.025**	**0.018**	**0.043**
MED	0.490	40.084	1.548	2.770	0.002	-0.022	-0.020
MEA	1.094	67.782	2.327	2.625	0.004	-0.047	-0.044
AFR	0.624	51.488	1.866	2.489	0.002	-0.031	-0.028
CHI	3.713	53.993	5.335	1.656	0.009	-0.212	-0.203
IND	0.956	58.750	5.938	1.283	0.005	-0.174	-0.169
ASIA	1.633	96.043	1.267	2.859	0.001	-0.013	-0.012
SAM	1.491	53.110	1.304	2.763	0.001	-0.011	-0.010
ROW	0.770	-5.841	5.262	1.403	0.005	-0.152	-0.147
World	**26.636**	**23.574**	**0.000**	**18.615**	**0.020**	**0.000**	**0.020**

p = 14.800 $\$_{1995}$/ton$CO_2$ (= 54.267 $\$_{1995}$/tonC)

Table A.7: Bonn Agreement with high cost estimates for Annex B

	E	ΔE/E0	XS/AAU	MAC	AC	PC	TC
EU15	3.842	19.386	-27.783	12.047	0.007	0.084	0.091
OEU	0.101	29.076	-28.542	12.047	0.002	0.036	0.037
AUZ	0.358	23.287	-15.402	12.047	0.020	0.092	0.112
JAP	1.388	30.338	-32.832	12.047	0.002	0.054	0.056
CAN	0.564	30.779	-27.202	12.047	0.021	0.166	0.187
Annex B*	***6.252***	***23.019***	***-26.927***	***12.047***	***0.006***	***0.075***	***0.081***
CEU	3.660	-18.909	21.952	2.076	0.008	-0.998	-0.990
USA	6.599	34.454	0.000	0.000	0.000	0.000	0.000
Annex B	**16.510**	**13.842**	**-2.465**	**12.047**	**0.004**	**0.013**	**0.017**
MED	0.492	40.429	1.305	2.255	0.001	-0.015	-0.014
MEA	1.098	68.388	1.974	2.136	0.003	-0.033	-0.030
AFR	0.626	51.911	1.592	2.026	0.002	-0.021	-0.020
CHI	3.738	55.020	4.703	1.348	0.007	-0.152	-0.146
IND	0.962	59.807	5.311	1.044	0.004	-0.127	-0.123
ASIA	1.636	96.446	1.064	2.327	0.001	-0.009	-0.008
SAM	1.494	53.427	1.100	2.249	0.001	-0.007	-0.007
ROW	0.775	-5.267	4.685	1.142	0.004	-0.110	-0.106
World	**27.331**	**26.796**	**0.000**	**12.047**	**0.004**	**0.000**	**0.004**

p = 12.047 $\$_{1995}$/ton$CO_2$ (= 44.172 $\$_{1995}$/tonC)

Table A.8: Bonn Agreement with lower baseline emissions

	E	ΔE/E0	XS/AAU	MAC	AC	PC	TC
EU15	3.778	17.401	-25.624	0.922	0.000	0.006	0.006
OEU	0.098	25.144	-24.455	0.922	0.000	0.002	0.002
AUZ	0.358	23.335	-15.451	0.922	0.000	0.007	0.007
JAP	1.349	26.632	-28.890	0.922	0.000	0.004	0.004
CAN	0.558	29.482	-25.823	0.922	0.001	0.012	0.013
Annex B*	***6.140***	***20.817***	***-24.655***	***0.922***	***0.000***	***0.005***	***0.005***
CEU	3.488	-22.709	25.806	0.922	0.003	-0.091	-0.088
USA	6.269	27.731	0.000	0.000	0.000	0.000	0.000
Annex B	**15.897**	**9.613**	**-0.466**	**0.922**	**0.000**	**0.000**	**0.000**
MED	0.472	34.962	0.155	0.173	0.000	0.000	0.000
MEA	1.061	62.777	0.253	0.163	0.000	0.000	0.000
AFR	0.603	46.329	0.219	0.155	0.000	0.000	0.000
CHI	3.690	53.030	0.976	0.103	0.000	-0.002	-0.002
IND	0.953	58.217	1.320	0.080	0.000	-0.002	-0.002
ASIA	1.569	88.404	0.121	0.178	0.000	0.000	0.000
SAM	1.434	47.184	0.131	0.172	0.000	0.000	0.000
ROW	0.764	-6.617	1.098	0.087	0.000	-0.002	-0.002
World	**26.443**	**22.675**	**0.000**	**0.922**	**0.000**	**0.000**	**0.000**

p = 0.922 $\$_{1995}$/ton$CO_2$ (= 3.381 $\$_{1995}$/tonC)

Table A.9: Bonn Agreement with more CDM flexibility

	E	ΔE/E0	XS/AAU	MAC	AC	PC	TC
EU15	3.892	20.936	-29.467	4.870	0.002	0.036	0.038
OEU	0.102	30.596	-30.122	4.870	0.000	0.015	0.016
AUZ	0.364	25.672	-17.853	4.870	0.006	0.043	0.049
JAP	1.404	31.831	-34.420	4.870	0.001	0.023	0.023
CAN	0.564	30.876	-27.305	4.870	0.009	0.067	0.076
Annex B*	***6.326***	***24.480***	***-28.435***	***4.870***	***0.002***	***0.032***	***0.034***
CEU	3.660	-18.909	21.952	1.102	0.004	-0.406	-0.402
USA	6.599	34.454	0.000	0.000	0.000	0.000	0.000
Annex B	**16.585**	**14.354**	**-2.989**	**4.870**	**0.001**	**0.006**	**0.008**
MED	0.491	40.353	1.358	2.367	0.001	-0.006	-0.005
MEA	1.096	68.166	2.103	2.313	0.003	-0.014	-0.011
AFR	0.625	51.693	1.733	2.261	0.002	-0.009	-0.008
CHI	3.694	53.223	5.808	1.902	0.011	-0.076	-0.065
IND	0.946	57.073	6.931	1.707	0.008	-0.067	-0.059
ASIA	1.636	96.391	1.092	2.398	0.001	-0.004	-0.003
SAM	1.494	53.355	1.146	2.364	0.001	-0.003	-0.002
ROW	0.764	-6.580	6.005	1.773	0.008	-0.057	-0.050
World	**27.331**	**26.796**	**0.000**	**4.870**	**0.002**	**0.000**	**0.002**

p = 4.870 $\$_{1995}$/ton$CO_2$ (= 17.857 $\$_{1995}$/tonC)

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(xlii) This paper was presented at the International Workshop on "Climate Change and Mediterranean Coastal Systems: Regional Scenarios and Vulnerability Assessment" organised by the Fondazione Eni Enrico Mattei in co-operation with the Istituto Veneto di Scienze, Lettere ed Arti, Venice, December 9-10, 1999.
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(xlix) This paper was presented at the International Conference "Knowledge as an Economic Good", organised by Fondazione Eni Enrico Mattei and The Beijer International Institute of Environmental Economics, Palermo, April 20-21, 2001
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