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Modelling emissions trading and abatement costs in FAIR 1.1

Case study: the Kyoto Protocol under the Bonn-Marrakesh Agreement

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Abstract

This report describes the cost model of the FAIR 1.1 model (Framework to Assess International Regimes for differentiation of future commitments). The cost model has been used in our earlier analysis of the evaluation of the environmental effectiveness and economic efficiency of the Kyoto Protocol after the Bonn-Marrakesh Agreement. The cost model includes Marginal Abatement cost (MAC) curves, which can be used to determine marginal and total abatement costs, to examine the gains of emissions trading in a competitive trading market. A MAC curve reflects the additional costs of reducing the last unit of carbon and differs per country. The default calculations in the cost model make use of the properties of the permit demand and supply curves, derived from MAC curves, in order to compute the market equilibrium permit price, abatement costs and emissions trading for the various regions, under different regulation schemes. These schemes could include constraints on imports and exports of emissions permits, non-competitive behaviour, transaction costs associated with the use of emissions trading and less than fully efficient supply (related to the operational availability of viable CDM projects). In order to illustrate the methodology we present the case study of the Bonn-Marrakesh Agreement in the first commitment period, i.e. 2008-2012. The case study confirms the main conclusions of our earlier policy report: the US withdrawal has by far the greatest impact in reducing the environmental effectiveness, lowering the price of traded emission permits and reducing Annex I abatement costs. Overall, Annex I CO_2-equivalent emissions without the US will come out at about ½ per cent below base-year level, but if sinks are seen as efforts additional to emission reductions to capture the overall decreasing effect on CO_2 built-up, this will increase to over 4 per cent. Without US participation, the emission permit price is estimated to be in a range up to US$10/tC. Hot air becomes increasingly dominant and may threaten the viability of the Kyoto Mechanisms, especially in lower baseline scenarios. Therefore, banking of hot air is of absolute importance to improve the environmental effectiveness of the Protocol at moderately higher costs, while enhancing the development of a viable emission trading market. A strategy of curtailing and banking permit supply is also in the interest of the dominant seller, Russia and the Ukraine.

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Contents

Samenvatting

Dit rapport beschrijft het kostenmodel van het FAIR model (Framework to Assess International Regimes for differentiation of commitments). Het kostenmodel is gebruikt voor eerdere analyses van de evaluatie van de milieueffectiviteit en kosten van het Kyoto Protocol na het Bonn-Marrakesh akkoord. Het kostenmodel bevat marginale kosten curves, die worden gebruikt voor de berekening van de marginale en totale kosten en de verkenning van de voordelen van emissiehandel in een internationale emissiemarkt. Een marginale kosten curve representeert de additionele kosten per eenheid te reduceren koolstof en verschilt per land. De berekeningen zijn gebaseerd op geaggregeerde vraag en aanbod curves, welke zijn afgeleid van deze marginale kosten curves. Deze vraag en aanbod curves worden gebruikt om de prijs op de internationale emissiemarkt te bepalen, alsmede de totale kosten en emissiehandel onder verschillende emissiehandel schema's. Deze schema's bevatten onder andere beperkingen op de toepassingen van de Kyoto Mechanismen, zoals plafonds op aan- en verkopen van emissie-eenheden, het uitoefenen van marktmacht, transactiekosten gekoppeld aan het gebruik van de Kyoto Mechanismen en geen volledige emissiehandel (beperking in het emissieaanbod door beperkte beschikbaarheid van CDM projectenen). Om de methode te illustreren presenteren we de case studie van het Bonn-Marrakesh Akkoord. De case studie bevestigt de conclusies van onze eerdere studies: het terugtrekken van de VS heeft verreweg de grootste invloed op de verminderde milieueffectiviteit van het Kyoto Protocol, de afname van de prijs op de internationale emissiemarkt en het verminderen van de totale emissiereductie-kosten van het Protocol. De Marrakesh Overeenkomst brengt de emissies van alle broeikasgassen van de Annex I landen in 2010 zonder de VS een ½ procent onder het niveau van het basisjaar; dit is *niet* hetzelfde vergeleken met het 1990-niveau. Als CO_2 opname door sinks wordt gezien als een additionele inspanning ten opzichte van emissiereducties om het gehele effect op de CO_2 concentratie in beeld te brengen, loopt de afname van een ½ procent op tot ruim 4 procent onder het niveau van het basisjaar. Zonder de VS echter zal de vraag naar emissierechten sterk dalen en daardoor de prijs op de internationale emissiemarkt (minder dan US$10/tC). Hot air wordt een zeer dominant probleem, met name in lagere groeiscenario's, en kan zelfs de ontwikkeling van de emissiemarkt ondermijnen omdat de prijs naar nul dreigt te gaan. Het banken van hot air van cruciaal belang is voor het versterken van zowel de milieueffectiviteit van het Protocol als de ontwikkeling van een internationale emissiemarkt. Een strategie gericht op het beperken en banken van het aanbod is ook in het voordeel van de belangrijkste aanbieder, dat is de Annex I FSU regio.

1 Introduction

This report describes the cost model in FAIR 1.1, which has been used in our earlier evaluation of the environmental effectiveness and economic efficiency of the Kyoto protocol after the Bonn Agreement and the Marrakesh Accords (UNFCCC, 2001a), as described in Den Elzen and De Moor (2001a; 2001b; 2002a; 2002b). The report functions as the background of this earlier evaluation as it examines in detail the Kyoto Protocol under the Bonn-Marrakesh Agreement for the first commitment period, i.e. 2008-2012, as an illustration of the methodology of the cost model.

The cost model includes Marginal Abatement Cost (MAC) curves, which can be used to determine marginal and total abatement costs. More importantly, they can indicate the gains of emissions trading for various Parties. A MAC curve reflects the additional costs of reducing the last unit of carbon and differs per country in a perfectly competitive trading market. The default calculations in the cost model make use of the properties of the permit supply and demand curves, derived from MAC curves, in order to compute the market equilibrium permit price under different regulation schemes, based on the same emission-trading methodology of Ellerman and Decaux (1998) and Criqui et al. (1999). Given the obligations of Parties and this permit price, the model calculates the abatement costs, the permit trading between regions, as well as the net benefits gained by the purchasers and sellers on the market for the first commitment period, i.e. 2008-2012 and the next commitment periods till 2030. The cost model of FAIR focuses so far on CO_2 emissions only, and does not consider the emissions reductions of the other greenhouse gases (GHGs) of the Kyoto Protocol.[1]

This report is organised as follows. Chapter 2 describes the FAIR 1.1 model. Chapter 3 briefly describes the MAC curves used in the model. Chapter 4 presents the methodology of the calculation of the emissions trading and abatement costs using MAC curves. Chapter 5 illustrates the methodology for the case study. Chapter 6 comprises the conclusions.

[1] As CO_2 is the major greenhouse gas, we assume that the main conclusions of the study will hold if the other GHGs are included. Current work-in-progress focuses on incorporating the other GHGs in the model.

2 The FAIR 1.1 model

The FAIR model is designed to quantitatively explore a range of alternative climate regimes for differentiation of future commitments in international climate policy and link these to targets for climate protection (Den Elzen et al., 2001). The FAIR model is a simulation tool with a graphic interface allowing for changing and viewing model input and output in an interactive way.

Here, version 1.1 of FAIR is used (Den Elzen, 2002a; Den Elzen and Lucas, 2002), which differs from FAIR 1.0 (Den Elzen et al., 2001) in the following major elements:
1. the inclusion of the climate model meta-IMAGE 2.2, which corresponds with the stand-alone version of the Atmosphere-Ocean System (AOS) of IMAGE 2.2 (Eickhout et al., 2002). This climate model calculates the greenhouse gas concentrations, temperature increase, rate of temperature increase and sea level rise for the different emissions scenarios;
2. an improved climate 'attribution' module for the calculation of the regional contributions to various categories of emissions, concentrations of greenhouse gases, and temperature and sea-level rise (especially developed for the evaluation of the Brazilian Proposal) (Den Elzen and Schaeffer, 2002a; Den Elzen and Schaeffer, 2002b).
3. an updated methodology of the Triptych approach, as described in Den Elzen (2002a; 2002b);
4. updated global emissions profiles for stabilising the atmospheric CO_2 and CO_2 -equivalent concentrations based on the IPCC Third Assessment Report, as well as new IMAGE 2.2 calculations, as being used in the differentiation of future commitment calculations;
5. the inclusion of the cost model (as described in this report).
6. the inclusion of the IMAGE 2.2 implementation of the IPCC SRES emissions (IMAGE-team, 2001).
7. the IMAGE 2.2 regional aggregation of 17 world regions is used. [2]

The FAIR 1.1 model consists of an integration of three models: a simple integrated climate model, a burden-sharing model for calculating regional emission allowances or permits for various options for the differentiation of future commitments, and a cost model for the calculation of emissions trading and abatement costs. More specifically FAIR 1.1 includes:

1 *Scenario construction & evaluation*: The climate impacts in terms of the global climate indicators: greenhouse gas concentrations, temperature increase, rate of temperature increase and sea level rise of global emission profiles for greenhouse gases are calculated using the simple climate model meta-IMAGE 2.2 (Den Elzen and Schaeffer, 2002a). This climate model reproduces the IMAGE 2.2 projections of these climate indicators (IMAGE-team, 2001). The meta-IMAGE 2.2 model is supplemented with a climate 'attribution' module to calculate the regional contributions to various categories of emissions, concentrations of greenhouse gases, and temperature and sea-level rise (especially developed for the evaluation of the Brazilian Proposal) (Den Elzen and Schaeffer, 2002b).

2. *Differentiation of future commitments*: Next, the burden-sharing model calculates regional emission allowances or permits on the basis of the three different commitment regime approaches (Berk and Den Elzen, 2001; Den Elzen, 2002b; Den Elzen et al., 2001):
   a. Multi-stage approach, with a gradual increase in the number of Parties involved and their level of commitment according to participation and differentiation rules, such as per capita

[2] The 17 IMAGE 2.2 world-regions are: Canada, USA, Central America, South America (SAM), Northern Africa, Western Africa (WAF), Eastern Africa, Southern Africa, OECD Europe (WEUR), Eastern Europe, Former USSR (CIS), Middle East, South Asia (incl. India), East Asia (incl. China), South East Asia, Oceania and Japan.

income, per capita emissions, or contribution to global warming (including the Brazilian Proposal) (Den Elzen et al., 1999).

b. Convergence approach, in which all Parties participate in the regime, with emission allowances converging to equal per capita levels over time. Three types of convergence methodologies are included: (i) 'Contraction & Convergence' approach, convergence towards equal per capita emission allowances. (ii) Contraction & convergence approach with basic sustainable emission rights as suggested by the Centre of Science and Environment (CSE). (iii) Convergence of emission intensities of the economy (emissions per unit of economic activity expressed in GDP (Gross Domestic Product) terms).
c. Triptych approach, a sector and technology-oriented approach in which overall emission allowances are determined by different differentiation rules applying to different sectors (e.g. convergence of per capita emissions in the domestic sector, efficiency and de-carbonisation targets for the industrial and the power generation sector).

The calculated emissions allowances (without emissions trading) of a selected climate regime form the input for the cost module, as described in this report, i.e.:

3. *Emissions trading and abatement costs:* this model calculates the tradable emissions permits, international permit price and abatement costs for the first commitment period, i.e. 2008-2012, and the second and third commitment periods up to 2030, with or without emissions trading. Marginal Abatement cost (MAC) curves are used to this end. The default calculations in the cost model make use of the properties of the permit supply and demand curves, derived from MAC curves, in order to compute the market equilibrium permit price under different regulation schemes in any emission trading market. These schemes could include constraints on imports and exports of emissions permits, non-competitive behaviour, transaction costs associated with the use of emissions trading and less than fully efficient supply (related to the operational availability of viable CDM projects).

3 Marginal Abatement Cost curves

This Chapter starts with a brief introduction to Marginal Abatement cost (MAC) curves, i.e. what are MAC curves and what do they represent? How are MAC curves constructed from the macro-economic model WorldScan and the energy system model TIMER and used in the cost model of the FAIR 1.1 model?

3.1 What are Marginal Abatement Cost (MAC) curves?

A Marginal Abatement Cost (MAC) curve reflect the additional costs of reducing the last unit of carbon. The MAC curves are upward sloping: marginal costs rise with the increase of the abatement effort. Figure 3.1 shows a stylised marginal Abatement Cost Curve. One point (*q,p*) on the curve represents the marginal cost *p* for a region of abating an additional unit of carbon emissions at quantity *q*. The integral under the curve (hatched area) represents the total abatement cost of carbon emission reduction *q*.

In general, Marginal Abatement Cost Curves differ by region. In some countries abatement options may be less expensive than in others. For instance, in a highly energy-inefficient economy, it takes less effort to reduce emissions. Given a certain emission reduction, the marginal costs can thus differ.

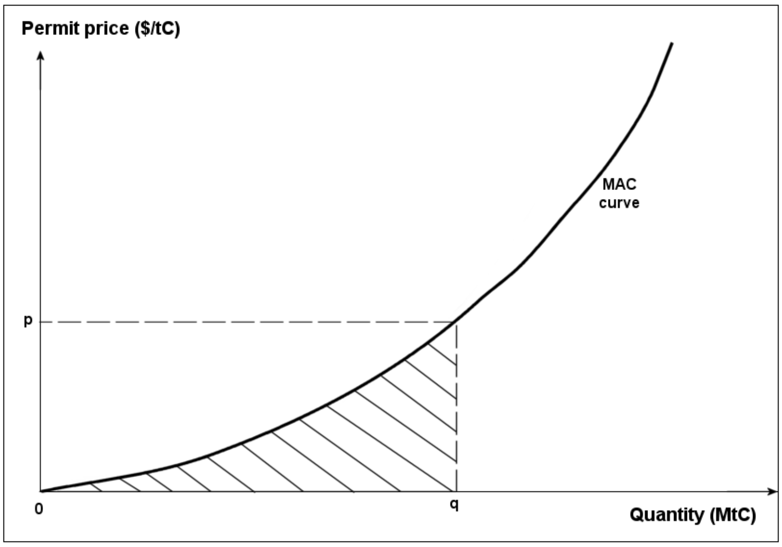

Figure 3.1: Marginal Abatement Cost Curve. Shaded area indicates the total cost of abatement under constraint q abated.

The MAC curves can be used as an indication of abatement costs per region, given a certain reduction target. The curves can also be used to model the effects of international emissions trading by comparing the marginal costs of different regions and constructing demand and supply curves (see Chapter 4). The use of MAC curves in models such as FAIR has a number of advantages; they allow to calculate the costs and revenues of permit trading and determine the sellers and buyers. Furthermore they clearly show the effects of permit trading and allow for a policy relevant analysis of the permit market including the implications of the behaviour and strategies of the various market players. These elements provide the basis for conducting policy evaluations of, for instance, the Bonn-Marrakesh Agreement (see Chapter 5). However, simple models based on MAC curves also face a numbers of limitations. First of all, they cannot take into account carbon leakage. Second, MAC curves only represent the direct cost effects but not the various linkages and rebound effects through the economy. Therefore, there is no direct link with macroeconomic indicators such as GDP losses or other measures of income of utility losses. Finally, MAC curves are commonly taken as given, but in reality, however, MAC curves may shift over time or may be dependent on the abatement efforts in other countries.

3.2 How can these MAC curves being constructed?

In macro-economic models and energy system models, a carbon tax on fossil fuels is imposed to induce emissions abatement from which the costs can be determined. Such a tax is differentiated according to the CO_2 emissions of the fuels (the carbon content). In response, emissions will decrease as a result of measures such as fuel switching (e.g. from coal to gas), decreases in energy consumption and the introduction of zero-carbon energy options (renewables and nuclear). The carbon tax can be seen as an indication of the marginal reduction costs: the extra costs to reduce an extra unit of carbon. In this Chapter, we will use the methodology of Criqui et al. (1999)[3] and plot different tax levels against the corresponding emissions reduction to construct Marginal Abatement Cost (MAC) curves for the macro-economic model WorldScan and the energy system model TIMER, i.e.:

1. Working with a reference projection (baseline) in which the carbon tax is zero;
2. Calculate by successive simulations, the emissions reduction levels (*q*) associated with tax (*p*) that vary from level to level, from 0 to US$600/tC;
3. Develop the MAC curve as illustrated in Figure 3.1 based on the points (*q,p*).

3.3 Marginal Abatement Cost Curves of WorldScan

The Marginal Abatement Cost Curves we initially use in FAIR 1.1 are derived from WorldScan, a multi-sector, multi-region applied general equilibrium model [4] (CPB, 1999). The model is developed for exploring long-term scenarios and with a focus on long-term growth and trade in the world economy. The model can produce carbon shadow prices for any constraint on carbon emissions, but also vice versa, produce emissions reductions compared to the baseline levels for any shadow price. The latter methodology of running the model under different carbon tax levels is used to develop the MAC curves (see also Section 3.2).

Figure 3.2 shows the MAC curves of the WorldScan model for the WorldScan implementation of the IPCC SRES A1B scenario (A1B scenario)[5], as being used in our default calculations (see Chapter 5). Here we show the MAC curves in terms of relative emission reductions (and not the absolute quantities) compared to the emissions scenario levels (here the A1B scenario), in order to show the variations across regions. This also allows us to compare the individual MAC curves for the various regions. Figure 3.2 clearly shows that the MAC curves differ strongly between the various regions. For example, a carbon tax of US$30/tC [6] results in a 8-11% relative reduction (compared to the baseline A1B emissions scenario) for the OECD Annex I regions (Canada, US, Western Europe, New Zealand, Australia and Japan), 16% for Eastern Europe, 25% for the Former Soviet Union (FSU), 30% for China and 35-40% for India and Africa. This pattern reflects that according to WorldScan the more cost-effective abatement options can be found in the non-Annex I regions (Africa, India and China), the non-OECD90 Annex I regions

[3] See Criqui et al. (1999) for the construction of the MAC curves for the energy model POLES.
[4] The MAC curves of WorldScan model of April 2001 (CPB, 1999).
[5] This scenario reflects high economic growth with rapid introduction of new and more efficient technologies.
[6] The US$ in this study are: US$95.

(FSU and Eastern Europe) compared to the OECD90 regions. The MAC curves for other scenarios show a similar pattern for the various regions, in fact, the MAC curves per region show minor differences for the various scenarios. The MAC curves of the high emissions scenarios (such as A1B scenario) are lower than the MAC curves of the low emissions scenarios (such as the B1 and A2), since is easier to abate the emissions in the high emissions scenarios. Figure 3.5 (section 3.6) illustrates this, for the MAC curves of the A1B and A2 scenario, and clearly shows the minor differences between the scenarios.

The MAC curves of WordScan do not change significantly in time. The reason for this is that WorldScan does not (yet) include carbon-tax induced technological developments (learning) or limitations in time-delays of implementing the options. Effects that can be of influence in time include structural economic changes, but apparently their impact is small.

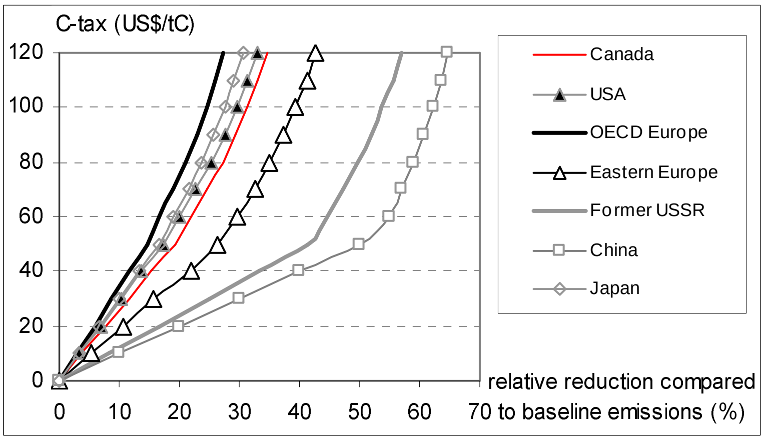

Figure 3.2: The Marginal Abatement Cost (MAC) curves of WorldScan for the A1B scenario (used in the default calculations).

3.4 Marginal Abatement Cost Curves of TIMER

A second set of MAC curves was taken from the energy-system model TIMER (Targets Image Energy Regional model). The TIMER model aims to analyse the long-term dynamics of the energy system, in particular with regard to energy conservation and the transition to non-fossil fuels, and to calculate energy related greenhouse gas emissions (De Vries et al., 2002; Van Vuuren and De Vries, 2001). An important aspect of the model is that technological development has been modelled in terms of log-linear learning curves, according to which the efficiency of processes improves with accumulated output ('learning-by-doing'). These processes are price-induced energy efficiency improvements, fossil fuel production, non-fossil based electricity and biofuels (Van Vuuren and De Vries, 2001). Using learning curves implies that the potential for technological change becomes path-dependent. For instance, cheap solar energy will only be available around 2050 if sufficient experience in the development of solar systems has been built up in the preceding period. Another important aspect is the limitations set on capital turnover. The fact that capital depreciation is limited within the model by its average lifetime introduces inertia between the signal (carbon price or tax) and the responses mentioned. This is crucial for the MAC curves derived from the TIMER model. For instance, in response to a high carbon tax in 2000, only a limited amount of existing coal-based power plants can be replaced in 2010 by less carbon-intensive modes, giving a relatively steep MAC. By 2030, however, a much larger share of these plants will be replaced, shifting the MAC curves to the right, as illustrated in Figure 3.3. It should be noted that both the learning effect and the delays included in the model make the actual MAC curve for each region dependent on earlier abatement action. The implementation of this effect is not yet included in the model. [7]

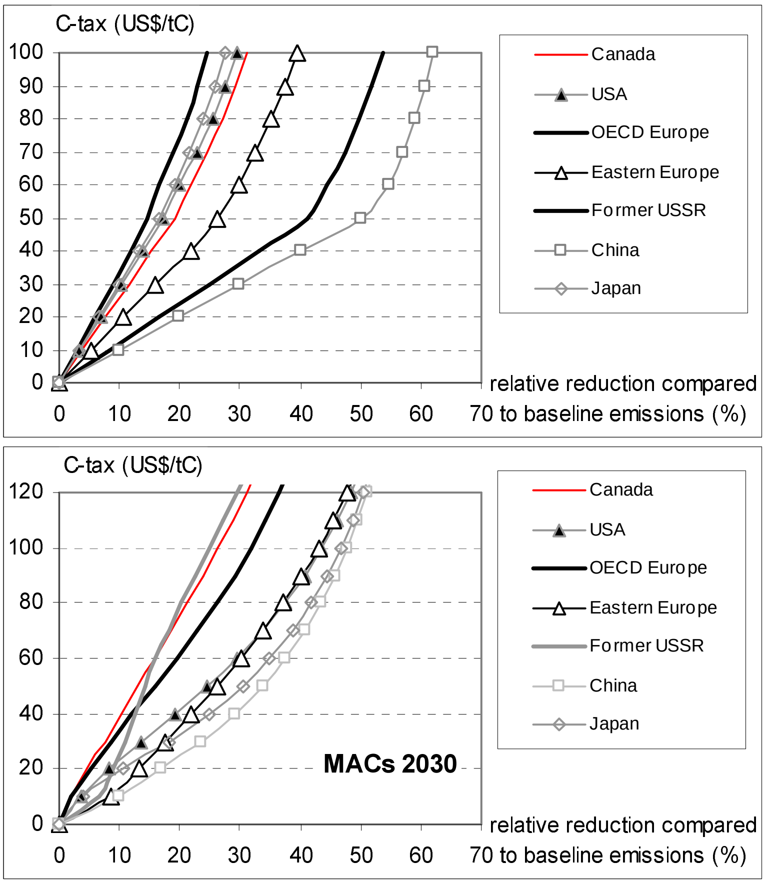

Figure 3.3: The MAC curves of TIMER (2010 and 2030) for the A1B scenario.

Just as for WorldScan, also the TIMER MAC curves do not differ very much for the various scenarios. Figure 3.3 shows the range in the marginal costs for the various regions. For example, for a carbon tax of US$30/tC, the relative reductions vary from 5-12% in 2010 and from 8-25% in 2030. The lower MAC curves are found for Eastern Europe and the developing countries, such as China, whereas the higher MAC are found for the OECD regions (except Japan), but also for the FSU. The 2030 MAC curve of Japan is also relatively low, due to the large price difference between the cheap solar energy and the relative expensive fossil fuels in Japan. This is different in most other energy models, since these models assume a a more dominant role of the relative high energy efficiency. Relative reductions of more than 50% compared to the baseline emissions are found at carbon prices of about US$100-150/tC for 2030. These price levels are similar to those of WorldScan, except for the regions China and FSU with price levels. Section 3.6 will present in more detail a comparison between the MAC curves of WorldScan, TIMER and POLES.

3.5 Marginal Abatement Cost Curves of POLES

POLES (Prospective Outlook on Long term Energy Systems) is a world sectoral energy model that simulates energy demand and supply on a year-to-year basis, up to 2030. The model includes 38 countries or regions and 15 main energy demand equations for each country, 24 power generation technologies, of which twelve new and renewable technologies are explicitly

[7] The MAC curves of TIMER are constructed using the same methodology of Criqui et al. (1999) as described in Section 3.2.

incorporated. The POLES model also projects the energy sector's CO_2 emissions up to 2030 as well as the marginal abatement cost curves for these emissions in each of the 38 countries or regions (Criqui et al., 1999).

The marginal abatement costs in POLES are assessed on the basis of the introduction of a 'shadow carbon tax' in all areas of fossil fuel energy use. This shadow carbon tax leads to adjustments in the final energy demand within the model, through technological changes or implicit behavioural changes, and through replacements in the energy conversion systems for which the technologies are explicitly defined in the model. In this study, we only present the MAC curves for 2010, as presented in literature (Criqui et al., 1999) (see Figure 3.4). The 2010 MAC curves are somewhat lower than the 2010 MAC curves of TIMER for OECD Europe, USA, FSU and China, but higher for Eastern Europe and Japan. For example, for a carbon tax of US$30/tC results in a 4-8% relative reduction for the OECD Annex I regions (Canada, US, Western Europe, New Zealand, Australia and Japan) and Eastern Europe, 10% for the Former Soviet Union (FSU), 15% for China and 5-8% for India and Africa. These reduction percentage are considerable lower compared to the WorldScan values.

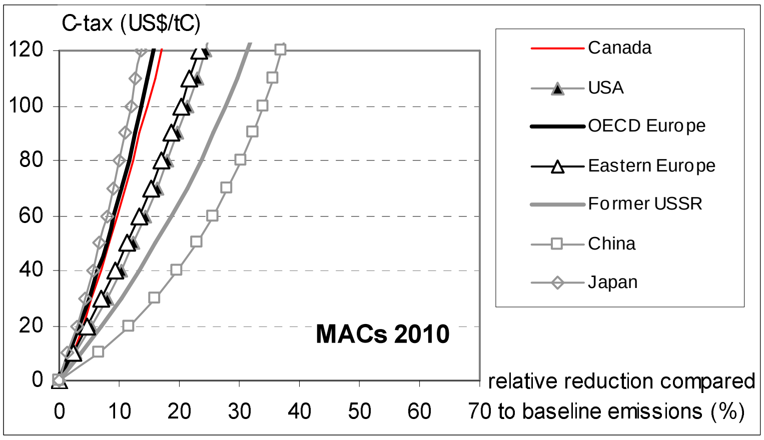

Figure 3.4: The MAC curves of POLES model for 2010 for the A1B scenario.

3.6 Comparing the MAC curves of WorldScan, TIMER and POLES

Figure 3.5 compares the MAC curves of WorldScan, TIMER and POLES. In general, this Figure clearly shows the broad range in the 2010 and 2030 TIMER marginal abatement costs, due to effect of the technological developments and inertia in the TIMER model, as explained in section 3.4. The TIMER MAC curves of other scenarios are almost identical, and therefore, here only the MAC curve of the A1B scenario is presented.

The 2010 MAC curves of POLES are comparable with the 2010 MAC curves of TIMER, although sometimes the position of the MAC curve for individual regions differs. Both MAC curves are rather high due to similar dynamics with respect to the inertia in the energy system.

For WorldScan, the MAC curves are somewhat scenario-independent and more-or-less time-independent. In general the MAC curves of WorldScan lie between the 2010 and 2030 MAC curves of TIMER for the OECD regions and Eastern Europe. For the developing countries and the FSU, the MAC curves of WorldScan are much lower than the 2010 MAC curves of POLES and TIMER. The differences in the MAC curves of WorldScan for various scenarios are much smaller than the differences with the other MAC curves of the POLES and TIMER model. In general the MAC curves of WorldScan are lowest for the A1B scenario (compared to the A2 and

B1 MAC curves). For these high emissions scenarios it is easier to abate the emissions than in the emissions scenarios with lower baseline developments.

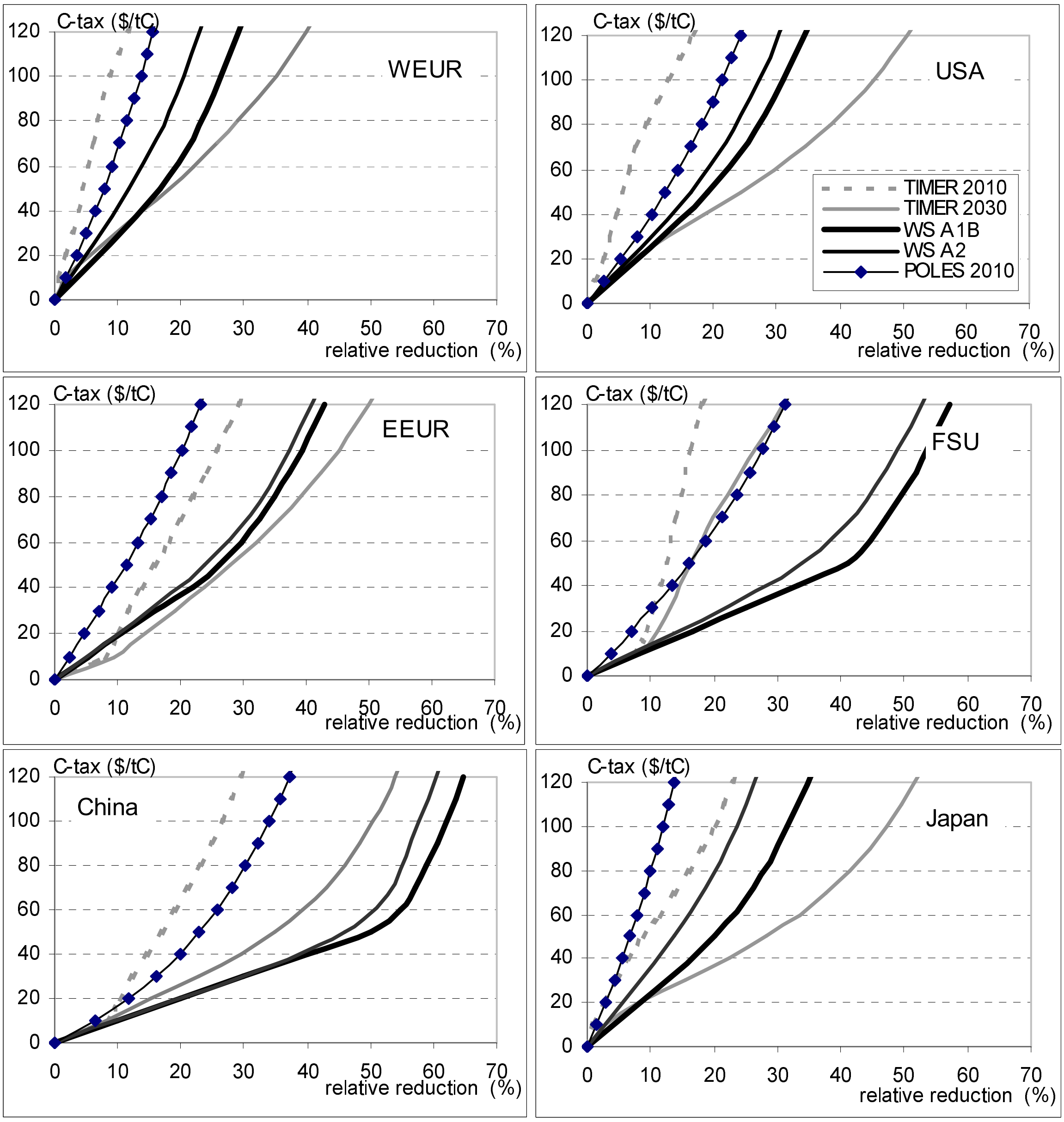

Figure 3.5: The Marginal Abatement Cost Curves of TIMER model (2010 and 2030, for A1B scenario), the POLES model (2010) and the WorldScan model (denoted by WS) (time-independent, for the A1B and A2 baseline).

If we analyse the results in more detail, we find for the OECD regions that the 2010 MAC curves of TIMER and POLES are both rather high compared to the MAC curves of WorldScan. In fact, the 2010 MAC curves of TIMER are in general even higher than those of POLES (except for Japan). The possible reason for this difference is that TIMER is conservative in the carbon-tax induced energy efficiency improvements. This effect will be especially important in the regions with low energy efficiency such as the FSU and China.

For Eastern Europe, a similar pattern exists with respect to the MAC curves of TIMER (2010 and 2030), POLES (2010) and WorldScan. However, now the TIMER MAC curves are somewhat lower than those of POLES.

For the FSU, the MAC curves of WorldScan are much lower than those of POLES and TIMER. Since we used the MAC curves of the WorldScan for our default calculations in our earlier analysis of Den Elzen and De Moor (2001a; 2001b; 2002a; 2002b), we will analyse to whether this has an effect on our calculations about Joint Implementation (JI) and emissions trading in our case study of the Bonn-Marrakesh Agreement (Chapter 4).

For a major developing country such as China, again the MAC curves of WorldScan are lower than the 2010 MAC curves of POLES and TIMER, but also lower than the 2030 MAC curve of TIMER.

4 Methodology: emissions trading and abatement costs

The marginal Abatement Cost Curves can be used to calculate marginal and total abatement costs, but more importantly, they can indicate the gains of emissions trading for various Parties. This chapter presents the methodology for the calculation of these abatement costs and emissions trading for the various regions, i.e. the world market price of the permits, the level of exchanges and net gains gained by the purchasers and sellers on the market using MAC curves. We start with the basis of emissions trading studies: a perfectly competitive trading market, and apply the methodology of aggregated MAC curves (Section 4.1) (Ellerman and Decaux, 1998). This forms the departure for determining emissions trading and abatement costs under different market circumstances, including constraints on imports and exports of emissions permits, exercising market power (non-competitive behaviour), transaction costs associated with the use of emissions trading and less than fully efficient supply.

4.1 Using MAC curves: perfectly competitive trading market

The methodology of calculating emissions trading and abatement costs in a perfectly competitive trading market without emissions trading constraints, no transaction costs or inefficiencies in supply is illustrated for two regions, R_1 and R_2, subject to emissions reductions q_1 and q_2. The marginal abatement costs for reductions q_1 and q_2 are MAC_{R1} (q_1) (= p_1) and MAC_{R2} (q_2) (= p_2). The total abatement costs without emissions trading correspond to the area below the MAC curve, between zero and the emission reduction target, and is equal to the area $0.Q_1.A$ and $0.Q_2.B$, for region R_1 and R_2 (see Figure 4.1).

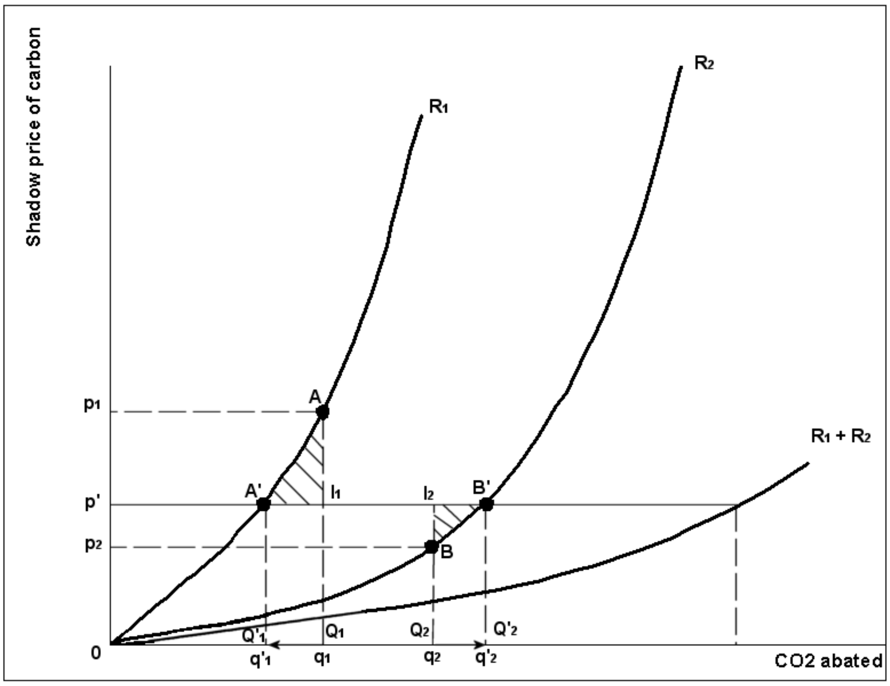

Figure 4.1: Emissions trading for two regions using marginal Abatement Cost Curves in a perfectly competitive trading market (Source: Ellerman and Decaux (1998)).

If a market is opened between R_1 and R_2, the reduction objectives and the MAC curves add together. This will lead to the formation of a consolidated joint curve ($R_1 + R_2$ in Figure 4.1) which allows the overall objective (q_1+q_2) to be reached at a marginal cost that lies between that of R_1 and that of R_2. The cost of achieving the overall objective (the area $0.Q_{1+2}.p'$) will therefore be lower than the total cost in case of no trade.

We suppose now that the two regions can exchange emission permits. Region R_1 will have an interest in limiting its domestic reduction effort to the level Q'_1. In order to fulfil its reduction target, R_1 must therefore import permits in a quantity of Q_1 minus Q'_1 at the market price p' (see Figure 4.1). The total costs for this trade case are now reduced by the quantity, which corresponds with the left rectangle in Figure 4.1.

Region R_2 reduces its emissions beyond its target (down to Q'_2), until its marginal cost is equal to the marginal cost on the market. By construction, both the supply of and the demand for permits are balanced if the price is equal to the marginal cost on the market. Each region will gain through the exchange. Region R_1 imports permits at a price p' lower than the marginal cost of the actions that it could take within its borders to move from Q'_1 to Q_1. Region R_2 sells permits that correspond to the quantity between Q_2 and Q'_2 at the market price (p') (Criqui et al., 1999). Table 4.1 displays the cost calculations in the no trading and trading cases.

Table 4.1: Basics of permit trade studies in a perfectly competitive trading market (Ellerman and Decaux (1998))

	No Trade	Trade between R_1 and R_2
Constraints	R_1: q_1 abated R_2: q_2 abated	R_1 and R_2: $q_1 + q_2$ abated
Marginal Cost / Market Price	R_1: p_1 R_2: p_2	R_1 and R_2: p' such that $p'_1(q'_1) = p'_2(q'_2) = p'$ and $q'_1 + q'_2 = q_1 + q_2$
Abatement Cost	R_1: area $A0Q_1$ R_2: area $B0Q_2$	R_1: area $(A'0Q'_1)$ R_2: area $(B'0Q'_2)$
Emission Permits Trading	NA	R_1: buys right to emit $q_1 - q'_1$ R_2: sells right to emit $q'_2 - q_2 = q_1 - q'_1$
Imports (+) / Exports (–) Flows	NA	R_1: pays $p' \cdot (q_1 - q'_1)$ = area $(A'I_1Q_1Q'_1)$ to R_2 R_2: receives $p' \cdot (q'_2 - q_2)$ = area $(B'I_2Q_2Q'_2)$ from R_1
Total Cost	R_1: area $A0Q_1$ R_2: area $B0Q_2$	R_1: area $(A'OQ'_1)$ + area $(A'I_1Q_1Q'_1)$ < area $(A0Q_1)$ R_2: area $(B'OQ'_2)$ – area $(B'I_2Q_2Q'_2)$ < area $(B0Q_2)$
Gains from Trading	NA	R_1: area (AI_1A') (hatched) R_2: area (BI_2B') (hatched)

In the cost model of FAIR these cost calculations have been generalised to an arbitrary number of regions (a subset of seventeen world regions which participate in the global emissions trading regime), using the MAC curves of WorldScan, TIMER or POLES. The calculations are done according to the following subsequent steps:

1. Calculate the total emission reduction burden (sum of the reduction burdens of all participating regions).
2. Construct the total MAC of all participating regions.
3. Calculate the world permit price using the total MAC of all participating regions.
4. Calculate the internal emissions reduction of each region at this world permit price.
5. Calculate the external emissions reduction and total abatement costs for all regions.

Appendix I (case I.1) illustrates this methodology for a case study of three regions: two constrained regions (with emissions targets) and one unconstrained region (no restrictive reduction target) with linear MAC curves.

4.2 Using demand and supply curves: perfectly competitive trading market

The calculation of emissions trading and costs in a perfectly competitive trading market can also be done using the concept of aggregated demand and supply curves, as illustrated in this section. MAC curves are the basis for the determining the demand and supply for emissions permits in a market.

More specifically, a MAC curve represents the willingness of any Party to import permits (i.e. demand), or to abate more than is required to meet the Kyoto commitment (q_R) or undertake abatement when not required to do so (i.e. supply), see Figure 4.2. This willingness of a Party to sell or buy permits depends on the relation of the market permit price to its autarkic marginal price ($MAC_R(q_R)$), i.e. the price for its Kyoto emissions reduction. More specifically, if the market permit price (p') is lower than its autarkic marginal abatement cost ($p' < MAC_R(q_R)$) it will be cheaper for this Party to buy permits, up to the quantity difference between the autarkic emission reduction and the domestic abatement it would undertake at the market price. If the market price is higher than its autarkic marginal abatement cost ($p' >= MAC_R(q_R)$), it would be willing to undertake more abatement and supply a corresponding quantity of permits to the market. In the current situation, the Annex-I FSU with large amounts of hot air [8] that have zero autarkic marginal costs, will supply its hot air in the market.

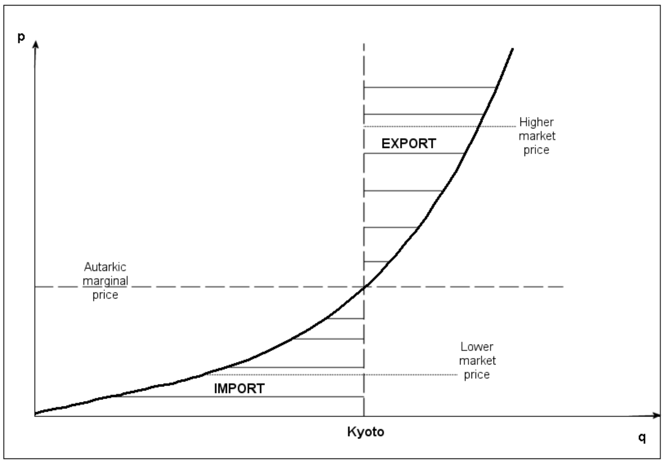

Figure 4.2: Willingness to import/export with regard to emission permit market. Source: Ellerman and Decaux (1998).

In a perfectly market, the emissions trading and abatement costs are calculated using the methodology:

1. Construct the supply curve for all participating regions by shifting the MAC over the horizontal axis to the left at a quantity corresponding to the burden (q_R). Figure 4.3 illustrates this for one region.
2. Construct the demand curve for all participating regions by reversing the negative part of the supply curve (see Figure 4.3).
3. Construct the total demand- and supply curve by simply adding up the quantities (x-axis) potentially supplied and those potentially demanded at each price (y-axis) across the constituent regions on the international market. Figure 4.4 illustrates this for two constrained regions (emission reduction targets) and one unconstrained region.

[8] Hot air is defined as the positive difference between the assigned and actual emissions under business- as-usual conditions. This estimate of hot air is based on current emissions projections.

4. Calculate the world permit price (p') based on the intersection of the total demand curve and the total supply curve on this international market. This point also represents on the x-axis the total quantity traded in that market.
5. Determine the regional demands and supplies at this world permit price.
6. Calculate the internal and external emissions reduction and total abatement costs for all regions using the MAC curves.

This methodology is illustrated for three regions with linear MAC curves in a perfect market in Appendix I (case I.2).

In the cost model of FAIR this methodology is used for the cases of minimum permit prices, restrictions on import and export, transaction costs and inefficient supply as explained in the following subsections.

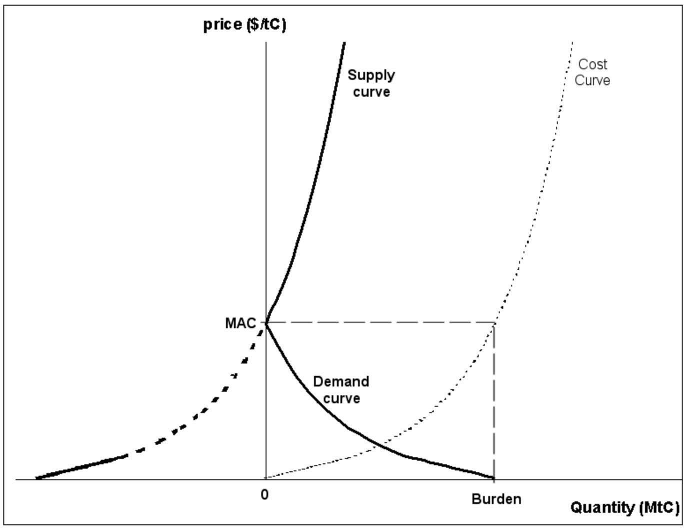

Figure 4.3 Construction of demand and supply curve for region R with emission reduction burden q_R and marginal Abatement Cost Curve MAC_R.

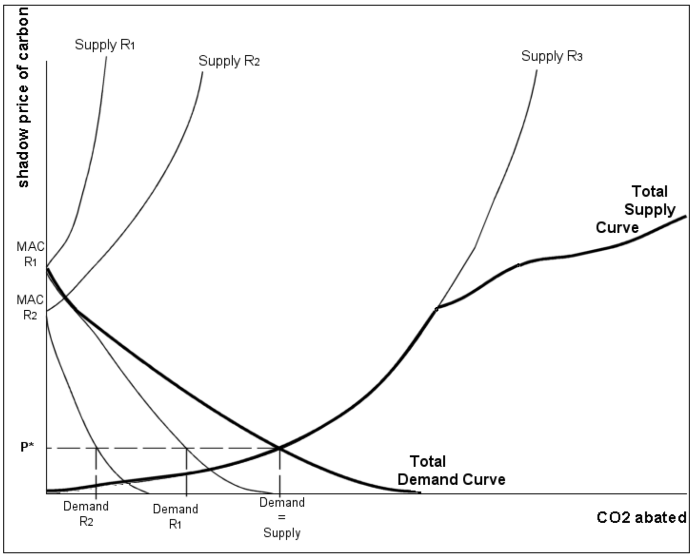

Figure 4.4: Construction of the total demand and supply curve for two constrained regions R_1 and R_2 with emission reduction targets q_1 and q_2 and one unconstrained region R_3.

4.3 Departures from perfect trading

4.3.1 Restrictions on permit imports: voluntary target for domestic reduction

The Bonn-Marrakesh Agreement comprises no quantitative caps on emissions trading (no concrete ceilings on import and export). However, this so-called supplementarity issue has been of major importance in the subsequent international negotiations. The Kyoto Protocol stipulates that Parties may participate in emissions trading, but that such trading should supplement domestic abatement measures. The EU, in particular, has been a strong advocate of imposing concrete ceilings on permit trading in order to encourage domestic actions. Although the Bonn-Marrakesh Agreement includes no quantitative cap on permit imports, this option is included in the model to assess, for example, what the impact on the emissions trading market will be if the EU voluntarily decides to realise 50 per cent of their own commitments domestically. In the cost model of FAIR 1.1 this voluntary target for domestic reduction is represented through a minimum domestic reduction percentage. The demand curves for each of the supplying regions are adapted in a way as illustrated in Figure 4.5, to account for the internal emissions reduction.

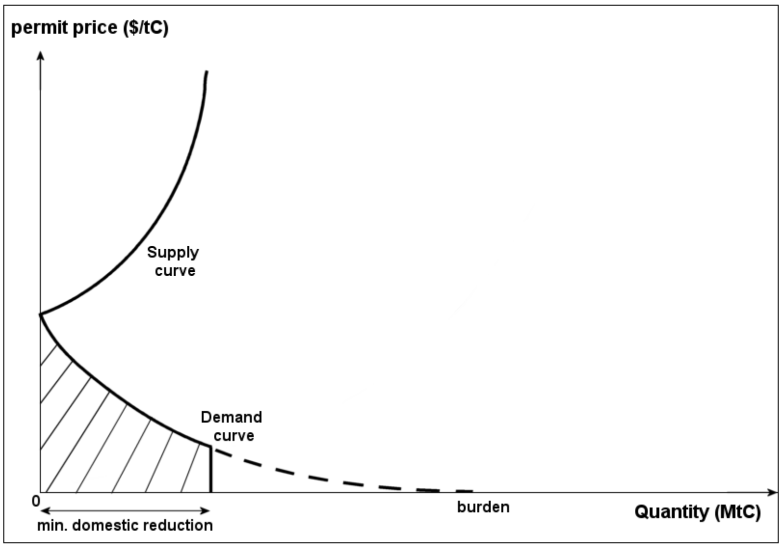

Figure 4.5: Construction of regional demand and supply curve for region R with voluntary target for domestic reduction (i.e. minimum domestic reduction percentage).

4.3.2 Restrictions on permit exports: exercising market power (volume or minimum price)

In a market with just a few major permit suppliers such as China or the FSU, these suppliers could take advantage of their dominant position by exercising market power and engage upon strategies towards maximising the revenues from permit sales. There are two ways, in which these suppliers are capable of exercising market power through 1. volume controls and 2. price controls, as implemented in the cost model.

1. Volume control, i.e. hot air banking

In the first option, volume control, the FSU, could bank a percentage of the (hot air) supply for the second commitment period, which would maximise FSU revenues. This is represented in the model by banking a fraction of hot air (fr_b), which may reflect the possibility of reducing the quantities of hot air (*HA*) allowed to enter the permit trading system. In the calculation the supply curve for the FSU is adapted for the exclusion of hot air, as described in Figure 4.6. This leads to a shift from point (*q,p*) on the supply curve to point ($q-\ fr_b.HA,p$) after accounting hot air banking. For the further calculation of abatement costs the general emissions trading methodology of aggregated demand and supply curves is followed.

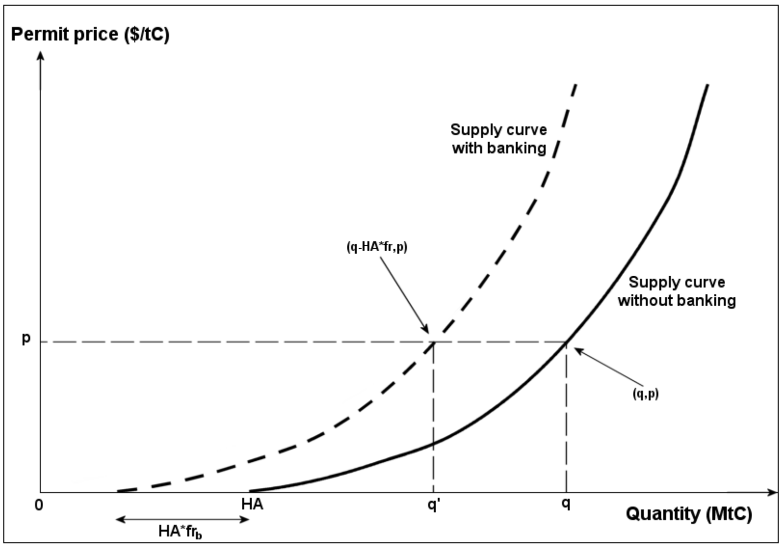

Figure 4.6: Construction of supply curve of the FSU (with Hot Air) with banking of their hot air (hot air banking fraction, denoted by fr_b).

2. Minimum permit price

In the second option, price control, we assume the FSU or China is capable of imposing a minimum permit price. As a consequence, the permit price is raised above the price level in a perfectly competitive market without trade restrictions, and the suppliers can maximise their gains. If the price raises, the importing regions abate more domestic and import less. Therefore, raising the price makes sense for the dominant supplier as long as the increase in the price compensates for the decrease in quantity sold (see Den Elzen and De Moor (2001b)).

The permit price for this case is now no longer the intersection of the total demand curve and the total supply curve, but a given price at a level above the equilibrium price (see Figure 4.4). The calculations as follows:

1. Calculate the world permit price according to step 1 to 4 in section 4.2 (with no restrictions, except for possible transaction costs and inefficiencies in supply).

If the permit price is lower than the minimum permit price, than continue with step 5. If the permit price is higher, than:

2. Determine the regional and total demands at the given minimum world permit price (Figure 4.7 illustrates this in terms of Demand R_1 and Demand R_2).
3. Determine the marginal costs of supplying the total demand (MAC_{TD} in Figure 4.7).
4. Determine the regional supplies at this marginal cost MAC_{TD} in the individual regional supply curves (in Figure 4.7 there is only one supplier (the unconstrained region R_3) at this permit price).
5. Calculate the internal and external emissions reduction and total abatement costs for all regions using the MAC curves.

This methodology is illustrated for three regions with linear MAC curves in a perfect market in Appendix I (case I.4).

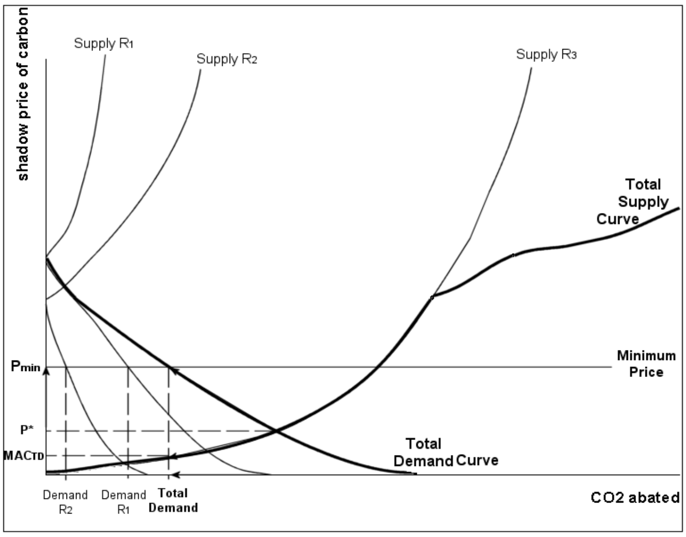

Figure 4.7: Calculating emissions trading for a minimum price case with demand & supply curves for regions R_1 and R_2 with reduction targets q_1 and q_2 and one unconstrained region R_3.

4.3.3 Transaction costs and other inefficiencies in supply

The methodology of aggregated demand and supply curves can be adapted to account for transaction costs associated with the use of Kyoto Mechanisms (KMs), i.e. international emissions trading (IET), Joint Implementation (JI) and Clean Development Mechanism (CDM). The transaction costs are proportional to the direct abatement cost, and set at 20 per cent for the default calculations. The methodology can also account for inefficiencies in supply, represented in the model via a CDM-accessibility factor reflecting the operational availability of viable CDM projects (Criqui et al., 1999), which is set at 10 per cent for the default calculations.

The calculations are as follows. First, we calculate the supply curve including the inefficiencies in supply, by multiplying the CDM-accessibility factor (*cdm*) with the supply curve on the x-axis. Next, we multiply this supply curve with the transaction costs factor (*tac*) on the y-axis, and construct the new supply curve. This leads to a shift from point (*q,p*) (marginal costs of abating an additional unit of carbon) on the supply curve to point (*cdm.q,p*) after accounting for the CDM-accessibility, towards the final point (*cdm.q,(1+TAC).p*) after accounting for the transaction costs (as illustrated in Figure 4.8).

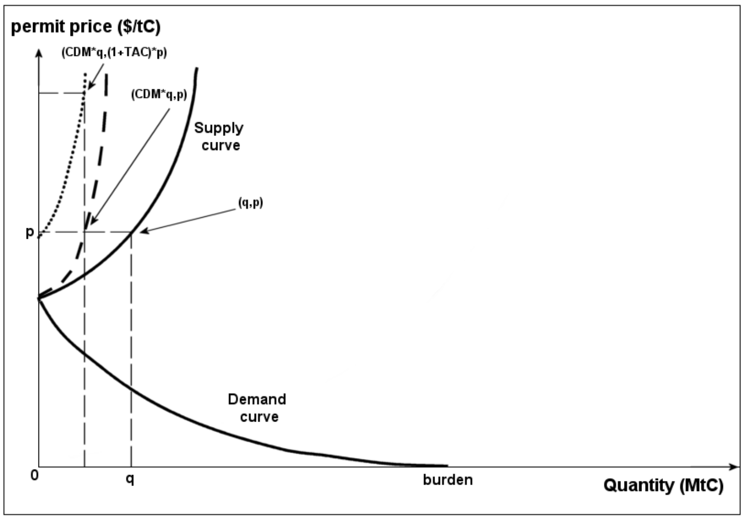

Figure 4.8: Construction of regional demand and supply curve for region R in a trading market with transaction costs for emissions trading (denoted via TAC) and inefficiencies in supply via the CDM accessibility factor (denoted as CDM).

5 Case study: the Kyoto Protocol under the Bonn-Marrakesh Agreement

5.1 Introduction

This chapter evaluates the environmental effectiveness and economic efficiency of the Kyoto Protocol under the Bonn-Marrakesh Agreement in the first commitment period, i.e. 2008-2012. It is not only an illustration of the methodology, but also the background document for our earlier analyses of the Bonn-Marrakesh Agreement, as described in Den Elzen and De Moor (2001a; 2001b; 2002a; 2002b).

The Bonn-Marrakesh Agreement marks the end of a four-year international negotiating period. We evaluate the environmental effectiveness and economic efficiency by decomposing the process leading up to the Bonn-Marrakesh Agreement (UNFCCC, 2001a) into three major steps. The first step reflects the pre-COP-6 version of the Kyoto Protocol (KP) that is with unrestricted IET with US participation but without sinks. After the first session of COP-6 in The Hague, where no consensus was reached, the newly elected US government declared the KP 'fatally flawed' and stepped out of the negotiations on the KP. The second step reflects this US withdrawal. Finally, the Bonn-Marrakesh Agreement, in particular the decisions on sinks, marks the last step in our evaluation. Our evaluation hence distinguishes three cases:
case 1. The pre-COP6 version of the Kyoto Protocol with the participation of the US;
case 2. The Kyoto Protocol without the participation of the US;
case 3. The Bonn-Marrakesh Agreement, i.e. Kyoto Protocol without the participation of the US and including domestic sinks and the sinks under CDM.

We use the following indicators to reflect the environmental effectiveness (Criqui, 2001):

- *Annex I abatement* refers to the total amount of CO_2 emission reductions per year within Annex I countries: i.e. reductions through domestic policies, international emissions trading, Joint Implementation (JI) and Clean Development Mechanism (CDM). The abatement efforts are given in absolute terms, relative to baseline emissions and compared to 1990 levels.[9] Note that our methodology does not include sinks as abatement options. However, they do *remove* CO_2 and hence decrease the atmospheric CO_2 built-up. Therefore, we present abatement efforts both including and excluding removals through sinks, assuming zero-cost sink options.
- *Domestic abatement* indicates how much Annex I countries reduce CO_2 emissions domestically if they strictly follow a least-cost approach; it is expressed in percentage of total reductions. Obviously, the remainder will be realised through the Kyoto Mechanisms.

Economic efficiency is measured as follows:

- *Abatement costs* (in US$95) for Annex I countries to comply with their Kyoto commitments.
- *Net revenues from emissions trading* (in US$95) reflect the net financial gains associated with the Kyoto Mechanisms: i.e. gross revenues minus the costs.
- *International permit price* reflects the expected average clearing price in the international permit market over the commitment period.

[9] Results will be given both with and without the US where appropriate

For the analysis, the abatement costs only reflect CO_2 reductions. The costs of reducing non-CO_2 emissions are *not* included and therefore total abatement costs for reducing CO_2 *equivalent* emissions could be higher. Our reference scenario is the IMAGE 2.2 implementation of the IPCC SRES A1B scenario (IMAGE-team, 2001), which can be characterised as a scenario with increasing globalisation and with rapid introduction of new and more efficient technologies and high economic growth.

Box 5.1 describes the model assumptions for the model analysis as presented in this report.

Box 5.1: Evaluation and model assumptions

- Just like most of the models, FAIR focuses on CO_2 only and, hence, abatement costs only reflect CO_2 reductions. The costs of reducing non-CO_2 emissions are *not* included and therefore total abatement costs for reducing CO_2 *equivalent* emissions will be higher. Although the non-CO_2 emissions account for about 18 per cent of the overall base-year emissions, we estimate total costs of abating all greenhouse gas emissions (including non-CO_2) will only be 5-10 per cent higher since the options to reduce non-CO_2 emissions are assumed to be more cost-effective than energy CO_2 abatement options. FAIR uses Marginal Abatement Cost Curves from the WorldScan model.
- The IMAGE 2.2 implementation of the A1B scenario is our reference scenario (IMAGE-team, 2001). [10] This scenario reflects high economic growth with rapid introduction of new and more efficient technologies. For the sensitivity analysis we also use the other IMAGE 2.2 baseline emissions scenarios.
- Transaction costs associated with the use of the Kyoto Mechanisms are set at 20 per cent.
- The CDM accessibility factor reflects the operational availability of viable CDM projects and is set at 10 per cent of the theoretical maximum.
- The Kyoto targets (CO_2-assigned amounts) are calculated by applying the Kyoto emissions reductions formulated on the 1990 CO_2 emissions estimates.
- FAO estimates are used for carbon credits from Art 3.3 afforestation, reforestation and deforestation, Art 3.4 forest management and Art 3.4 agricultural management. Carbon credits from forest management have been, if necessary, capped, except for Japan, Canada, Greece, Italy, Portugal, Slovenia, Spain, Switzerland, United Kingdom and the US, where we used the reported values in Appendix Z (UNFCCC, 2001b). For more details, we refer to Appendix II.
- Carbon credits from sinks are incorporated by adding these credits to the CO_2-assigned amounts.
- Sink credits are assumed to be more cost-effective than credits from (energy-related) emission reductions; recent research suggests that common sinks projects in non-Annex I countries may cost around US$1/ tCO_2.
- The costs related to the implementation of ARD projects and forest management in Annex I as well as under CDM are assumed to be negligible.

5.2 Case 1: the pre-COP 6 version of the Kyoto Protocol

As a starting point for our analysis there are some specific Articles of the Kyoto Protocol, which lead to country-specific base-years other than 1990 (e.g., Meinshausen and Hare (2001)). [11] These provisions result in differences between base-year and 1990 emissions and impacts on the environmental effectiveness when comparing the level of emissions in 2010 with those in 1990, see also Table 2 in Den Elzen and De Moor (2001a)). More precisely, the Kyoto targets for the

[10] The historical regional CO_2 emissions from fossil fuel combustion and cement production (excluding emissions from bunkers) are based on the CDIAC dataset. For the period 1995-2010 we use the growth trajectories as given by the IMAGE 2.2 A1B scenario.

[11] Article 3.5 allows some economies in transition to use base-years other than 1990, in particular Bulgaria (1988), Hungary (average of 1985-1987); Poland (1988) and Romania (1989). Article 3.7 states that Annex-I Parties for whom land-use change and forestry constituted a net source of greenhouse gas emissions in 1990, are allowed to add their 1990 emissions from deforestation to their base-year emissions. For a country as Australia , this provision raises the Kyoto target to 126% relative to 1990 instead of 108% relative to the base-year. Article 3.8 allows any Annex-I Party to use 1995 as the base-year for some halocarbons, i.e. non-CO_2 gases such as hydrofluorcarbons, perfluorocarbons and sulphur hexafluoride. This is particularly relevant for Japan (UNFCCC, 1997).

whole of Annex-I, including the US, will not be 5.2% below 1990 but only 3.6%. Relative to the base-year emissions, however, emissions in 2010 will still come out 5.2% lower. As some corrections also affect non-CO_2 gases, it no longer suffices to use only CO_2 emissions to express the relative environmental performance. We have therefore taken CO_2 *equivalents* emissions to reflect abatement efforts, relative to both 1990 and base-year levels.

Table 5.1 presents the results of the evaluation. The outcome for case 1 re-illustrates the economic significance of the Kyoto Mechanisms to substantially cut down the costs of the Kyoto Protocol from US$47 to US$19 billion, less than 0.1% of GDP. [12] The large quantity of available hot air of about 225 MtC reduces the effective reductions to 744 MtC (compared to 970 MtC in the situation of the Kyoto Protocol without Kyoto Mechanisms).

Table 5.1: Environmental effectiveness and economic efficiency of the Marrakesh Accords.

	Environmental effectiveness					Economic efficiency	
	Annex-I CO_2 equivalent emissions excl. US compared to		Annex-I CO_2 abatement[#]		Domestic reduction Annex-I	Internat permit price	Annex-I costs
	Base-year (in %)[V]	1990 (in %)	MtC	in %	%	US$/tC	bUS$
1. KP with US (with IET)	-5.2	-3.6	744	-17.0	47	38	19.5
2. KP w/o US (with IET)	-4.3	-2.0	235	-5.3	26	17	3.5
3a. Bonn Agreement*	-1.1 (-4.3)	+1.2 (-2.0)	130	-3.0	17	10	1.7
3b. Marrakesh Accords	-0.6 (-4.3)	+1.7 (-2.0)	115	-2.7	15	9	1.5

* The KP without the US, including sinks from LULUCF.

Reductions of CO_2 emissions only, in absolute terms and compared to baseline emissions.

[V] The numbers between brackets include, besides abatement efforts through emission reductions, efforts to remove CO_2 through sinks to capture the overall effect on atmospheric CO_2 built-up.

Figure 5.1 shows the demand and supply curves of permit trading for the pre-COP 6 version of the Kyoto Protocol including US participation for the trading market. [13] The supply curve starts from a point just below 225 MtC. This quantity can be supplied at no cost and reflects the so-called hot air of the Annex I Former Soviet-Union (FSU). [14] The maximum demand is equal to the sum of total Annex I commitments and intersects the horizontal axis at 970 MtC. This estimate is based on the A1B scenario (see Figure 5.1). The market for emissions trading, JI and CDM is determined by the point where demand meets supply. In Figure 5.1, this is at a price of US$38/tC, with about 510 MtC traded on the international market. The amount of hot air is 225 MtC while emissions trading and CDM run up to 285 MtC. Box 5.2 explains the built-up of the regional demand and supply curves of permit trading. The industrialised Annex I countries realise slightly more than half of their commitments abroad and 47 per cent at home (Table 5.1, case 1).

[12] Table 5.2 shows the results of emissions trading, abatement and costs for the various regions.

[13] Note that the reference cases include transaction costs and inefficiencies in CDM supply.

[14] Annex I FSU region only includes Annex I countries of the Former Soviet Union, that is Russia, Ukraine, Latvia, Lithuania and Estonia.

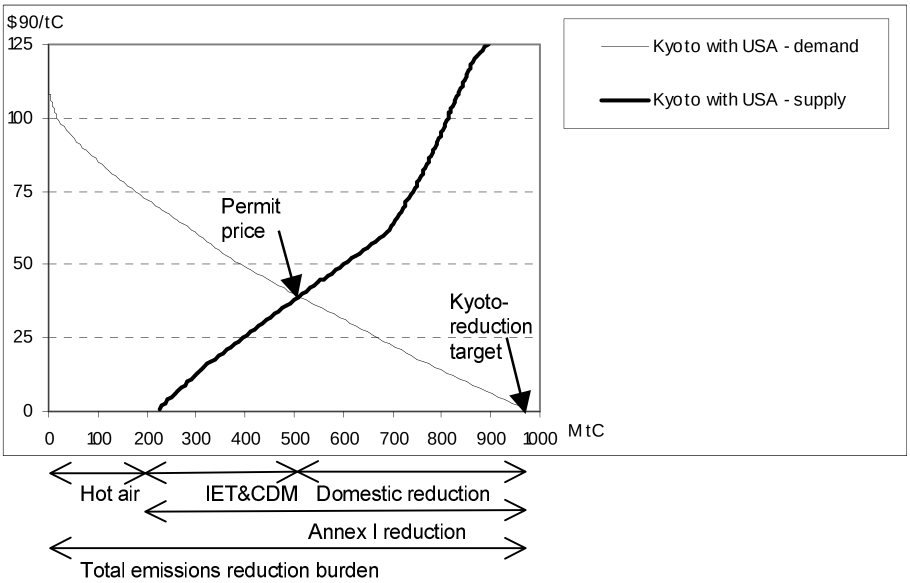

Figure 5.1: Permit demand and supply curves for the pre-COP 6 version of the Kyoto Protocol (including US participation)

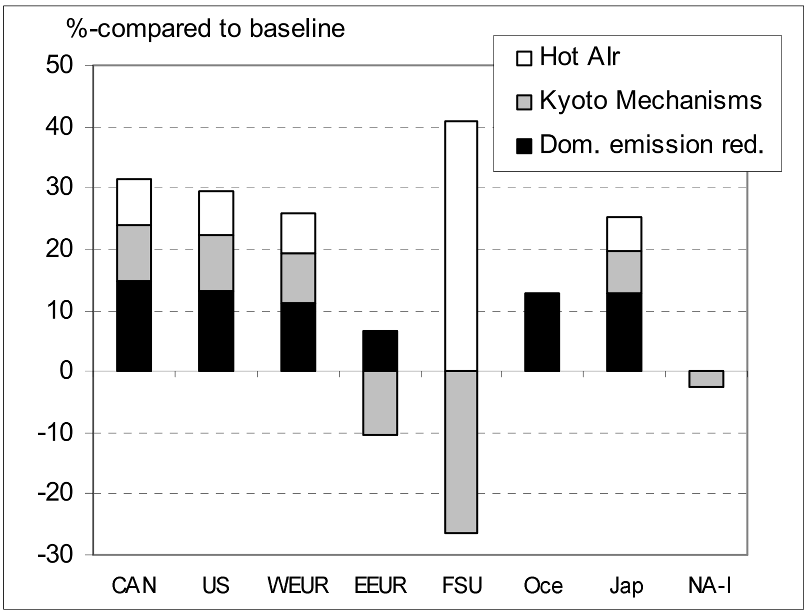

Figure 5.2: Efforts in terms of emissions reductions compared to the baseline emissions A1B for the pre-COP 6 version of the Kyoto Protocol (including US participation).

Figure 5.2 illustrates the efforts of the Annex I regions and the non-Annex I region as a percentage of the baseline emissions. It indicates the distribution of emissions reductions and the flows in the permit market given the participation of the United States. The industrialised Annex I countries realise slightly more than half of their commitments abroad and slightly less than 50 per cent at home. Figure 5.2 clearly shows the Annex I FSU as a dominant supplier of permits.

The financial revenues for the Annex I FSU would be substantial, running up to nearly US$12 billion (see Table 5.2). This is about 1½ per cent of GDP. The United States is the main buyer of emissions permits on the market. The financial benefits for developing countries from CDM projects run up to nearly US$4 billion.

Box 5.2: Demand and supply curves of permit trading for case 1, the pre-COP6 version of the Kyoto Protocol including the US

Figure 5.3a and b shows the demand and supply curves of permit trading. These curves represent the total quantities of permits that would be supplied or demanded at various price levels in a given market for the individual regions. The supply curve starts from a point of just below 225 MtC. This quantity can be supplied at no cost, the so-called hot air of the Former Soviet-Union (FSU). As the price increases, supply increases as more exporting regions are willing to undertake more abatement domestically. The main sellers on the permit market are the FSU and China. The maximum demand is equal to the sum of total Annex I commitments and intersects the horizontal axis at 1100 MtC. This quantity is equal to the demand if the price would be US$0/tC. As the price increases, demand decreases, since more abatement is undertaken domestically. The demand curves also clearly show that the US is the main buyer on the permit market, almost 50% of the total demand. The demand of Western Europe and Japan is respectively 30% and 10% of the total permit demand.

At a price below US$12/tC (lowest autarkic marginal costs for the Kyoto-constrained Annex I regions, i.e. the marginal costs for Eastern Europe, see Table 5.2), all Annex I regions (except the FSU) operate at the demand side. Only the FSU and the non-Annex I regions operate at the supply side. At a price above US$14/tC (i.e. including 20% transaction costs), Eastern Europe becomes an exporter, supply increases faster, and the demand decreases slowly. This could give a kink, both in demand and in supply curves (although this is not seen because of the relative small portion of Eastern Europe's emissions in the overall Annex I emissions). Finally, at a market price above US$100/tC, all regions abate their Kyoto emissions reduction domestically, and the demand of the Annex I region is zero.

The market clears where demand meets supply for the world region, in Figure 5.2 at a price of US$38/tC.

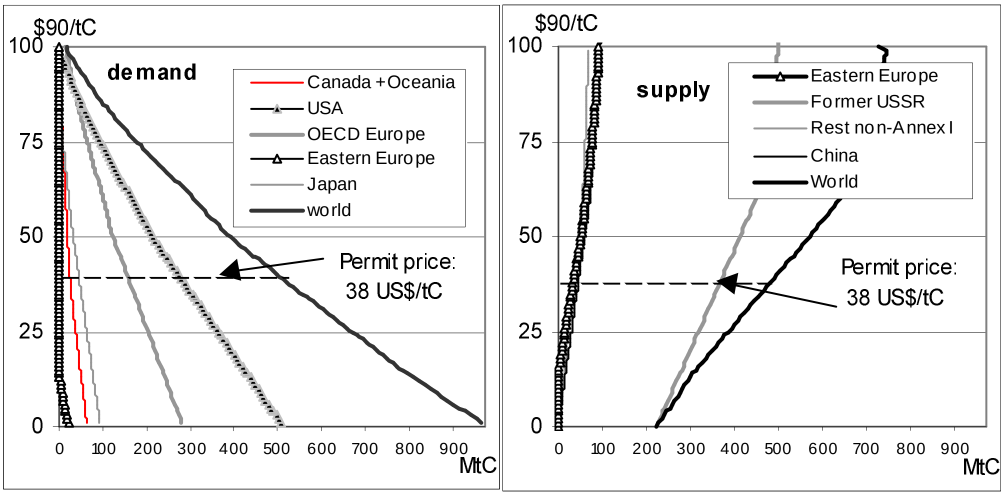

Figure 5.3a-b: Permit demand and supply curves for the individual regions as well as the world for the pre-COP 6 version of the Kyoto Protocol (including US participation)

Table 5.2: Emissions trading, abatement and costs for the pre-COP 6 version of the Kyoto protocol (including US participation) (with IET).

REGIONS	**No trade**			**Environmental Effectiveness**			**Economic Efficiency**	
	Burden	Reduction	MAC	Domestic Abatement	Domestic Abatement	Trade	MAC	Total costs
	MtC	%	US$/tC	%	MtC	MtC	US$/tC	MUS$
Canada	48	-31	101	47	22	25	38	1595
US	509	-29	98	45	229	280	38	17222
OECD Europe	281	-26	109	44	123	158	38	9596
Eastern Europe	21	-7	12	100	21	-34	38	-398
Former USSR	-224	41	0	0	0	-370	38	-11801
Oceania	16	-13	33	100	16	0	38	264
Japan	93	-25	87	51	47	46	38	3019
Annex I	744	-17	70	47	458	107	38	19499
Non-Annex I	0	0	0	0	0	-107	38	-3901
World	744	-9	1	47	458	0	38	15598

5.3 Case 2: the withdrawal of the US

As the US accounts for roughly half of total Annex I reduction commitments, the US withdrawal has a dramatic impact on the environmental Effectiveness of the Kyoto Protocol. Total abatement is reduced substantially to a level of only 5 per cent below baseline levels instead of 17 per cent with US participation. The total Annex I emissions end up to +8% above the 1990-levels instead 5% under the 1990 levels as in the pre-COP6 version of the Kyoto Protocol with the US participation.

Another consequence of the US withdrawal is that the demand for permits collapses and the permit price drops to US$17/tC (see also Figure 5.4). The permits that the United States would have imported now become available to other countries. Under the assumption of a least-cost approach, the industrialised countries will cut down on their domestic abatement efforts to less than a quarter of total commitments and increase their use of the Kyoto Mechanisms. The fall in permit prices reduces total costs for Annex I countries by over 80 per cent to US$3.5 billion, an insignificant portion of GDP (0.01 per cent). The conclusion that the US withdrawal is of major influence in reducing the environmental Effectiveness of the Kyoto Protocol, the permit price and Annex-I abatement costs is in line with several earlier studies. [15]

[15] See Table 1 in Buchner et al. (2001) for a quantitative overview and synthesis of the implications of the US withdrawal. Compare also Grüb et al.(2001), Eyckmans et al. (2001) and Hagem and Holtsmark (2001).

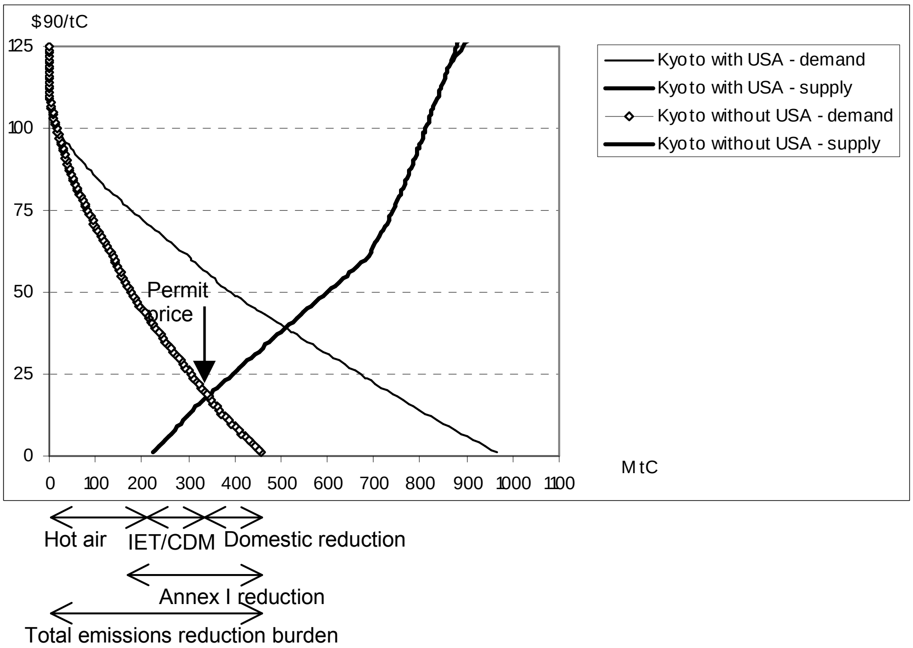

Figure 5.4: Permit demand and supply curves for the Kyoto Protocol without the US (with IET). Note: The supply curves for the Kyoto Protocol with the US and without the US are the same.

On a country-level, we see that most Annex I regions gain economically from Kyoto without US, except for the Annex I FSU (see Table 5.3). However, US withdrawal implies for the Annex-I FSU that it would trade much less at a far lower permit price. Financial revenues are slashed to US$4.5 billion or 0.7 per cent GDP. The same dramatic implications are found for the financial revenues for non-Annex I countries. The volume traded through CDM is more than halved to 50 MtC and this reduces the original US$4 billion in revenues to less than US$1 billion.

Table 5.3: Emissions trading, abatement and costs for the pre-COP 6 version of the Kyoto protocol without the US (with IET).

REGIONS	**No trade**			**Environmental Effectiveness**			**Economic Efficiency**	
	Burden	Reduction	MAC	Domestic Abatement	Domestic Abatement	Trade	MAC	Total costs
	MtC	%	US$/tC	%	MtC	MtC	US$/tC	MUS$
Canada	48	-31	101	21	10	38	17	873
US	-5	0	0	0	0	0	17	0
OECD Europe	281	-26	109	20	56	225	17	5169
Eastern Europe	21	-7	12	100	21	-4	17	115
Former USSR	-224	41	0	0	0	-290	17	-4551
Oceania	16	-13	33	52	8	8	17	230
Japan	93	-25	87	23	22	72	17	1684
Annex I	229	-5	32	26	116	48	17	3521
Non-Annex I	0	0	0	0	0	-48	17	-804
World	229	-3	1	26	116	0	17	2718

5.4 Case 3: the Bonn-Marrakesh Agreement

Case 3a The Bonn Agreement. Compared to the US withdrawal the decisions in the Bonn Agreement and, in particular, on sinks have a relatively minor impact on the environmental

Effectiveness of the KP. [16] The ‘price’ for this agreement is another lower Annex I abatement effort of 105 MtC (see case 3a in Table 5.1). It does, however, further reduce demand for emissions permits and the permit price drops to US$10/tC. [17] Domestic abatement accounts for one-seventh of total reductions. Thus, compared to the US withdrawal, the decisions on sinks is of less importance for the environmental Effectiveness and economic efficiency (for a discussion of the sinks, see Den Elzen and De Moor (2001b)).

Overall, the Bonn Agreement brings total Annex I abatement efforts excluding the US emissions down to 130 MtC, which implies a reduction of 3 per cent below baseline and a 0.1 per cent reduction under the level of 1990. Total costs of the current Bonn Agreement for Annex I countries amount to US$2 billion, which is less than 0.01 per cent of GDP.

Case 3b The Marrakesh Accords. The additional sinks for Russia of 15 MtC as agreed in Marrakesh decreases Annex-I abatement without the US to 115 MtC and increases the supply of hot air by 5% and hence, the permit price will be about US$1/tC lower compared to the Bonn Agreement. The additional Russian sinks credits reduces Annex-I costs slightly to $1.5 billion (see case 3b in Table 5.1). Hot air becomes even more dominant, and it is in the interest of the Annex-I FSU to curtail permit supply and bank the credits for better times.

Without removals through sinks, the Marrakesh Accords bring Annex-I CO_2-equivalent emissions in 2010 without the US more than a ½ percent below base-year level. [18] This is different compared to the 1990 level; Annex-I emissions come out nearly 2% *above* the 1990 level. Including removals through sinks the total decreasing effect on CO_2 built-up would run up from a ½ percent to over 4% under base-year levels.

Figure 5.5 visualises the different steps leading to the Marrakesh Accords. It shows the shift in permit demand and supply curves. As the demand curve is continuously pushed down by the US withdrawal and decisions on sinks, the permit price drops to US$9/tC. The quantity traded on the market amounts to some 325 MtC. Decomposition of the permit market shows that 83% concerns hot air, about 10% JI, while almost 7% CDM.

[16] The requirements on the commitment period reserve, intended to prevent a country from overselling, do not effectively restrict FSU permit sales.

[17] Sink credits are assumed to be more cost-effective than credits from (energy-related) emission reductions. The costs related to the implementation of ARD projects and forest management in Annex-I as well as under CDM are assumed to be negligible.

[18] Note that our methodology does not include sinks as abatement efforts. However, they do remove CO_2 and hence decrease the atmospheric CO_2 built-up. Therefore, we present Annex-I efforts both excluding and including removals through sinks, assuming zero-cost sinks options.

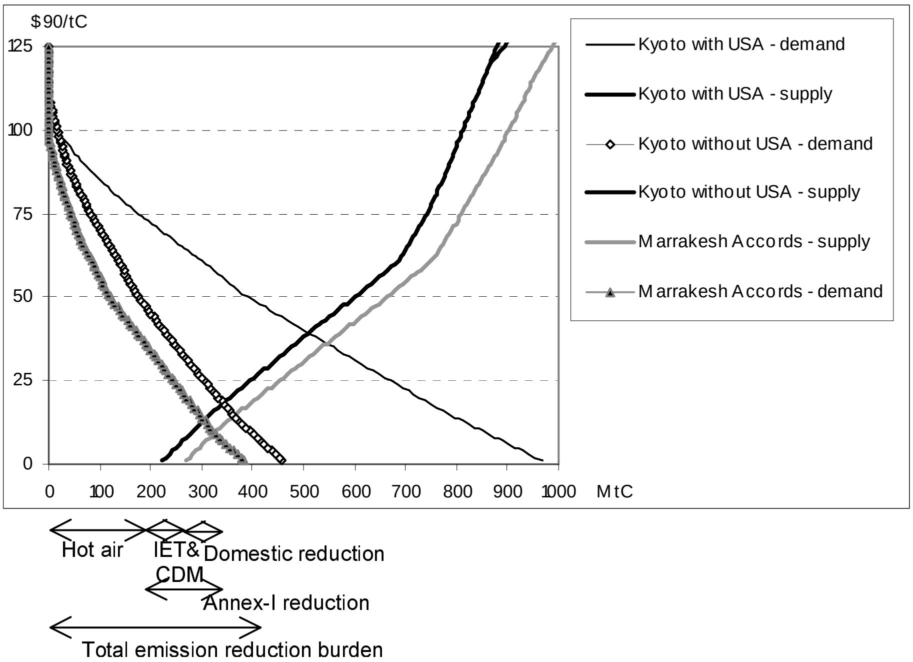

Figure 5.5: Permit demand and supply curves for the major steps towards the Bonn-Marrakesh Agreement. Note: The supply curves for the Kyoto Protocol with the US and without the US are the same.

Figure 5.6 illustrates the distribution of emissions reductions efforts as a percentage of the baseline emissions in the A1b scenario over the various regions. Assuming a full use of the sinks provisons, it shows the further increasing dominance of the Annex I FSU on the supply side and only a few major buyers. In particular Western Europe, Japan and Canada are likely to make substantial use of the Kyoto Mechanisms. Eastern Europe achieves its Kyoto targets by only using the domestic abatements.

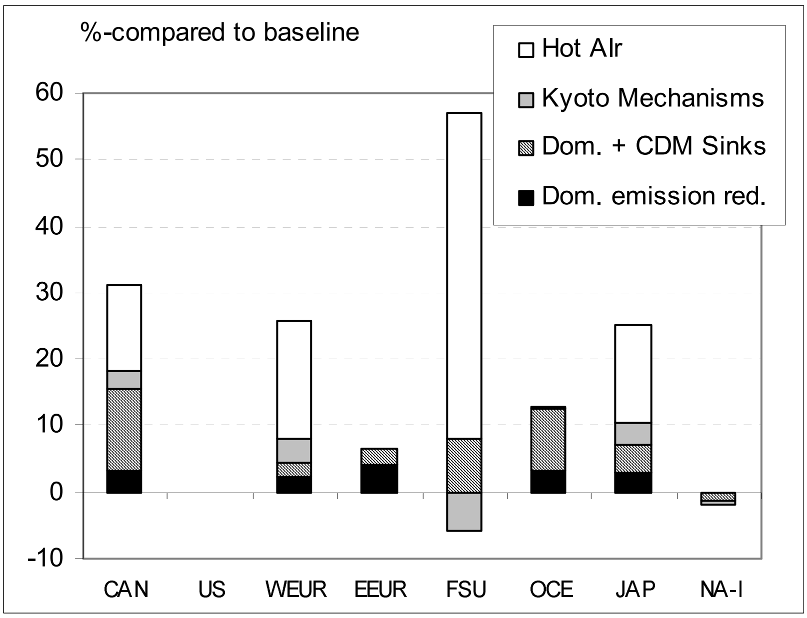

Figure 5.6: Efforts in terms of emissions reductions compared to the baseline emissions A1B for the Bonn-Marrakesh Agreement.

Box 5.3: Permit demand and supply curves for the Bonn-Marrakesh Agreement

Figure 5.7a and 5.7b show the demand and supply curves for the Bonn-Marrakesh Agreement. The sinks decisions have reduced permit demand for the individual regions, which results in lower autarkic marginal costs for the Kyoto-constrained Annex I regions, in particular those with high sinks credits, i.e. Canada, Japan and Oceania. The market clears where demand meets supply, in Figure 5.7 at a price of US$9/tC. At this price level OECD Europe is the main buyer on the market (60% of the total Annex I demand), whereas Japan takes 17% of the total demand, and Canada& Oceania and Eastern Europe both take 10%. The dominant seller on the market is still the FSU (95%), whereas China and the rest of the non-Annex I regions equally share the remainder.

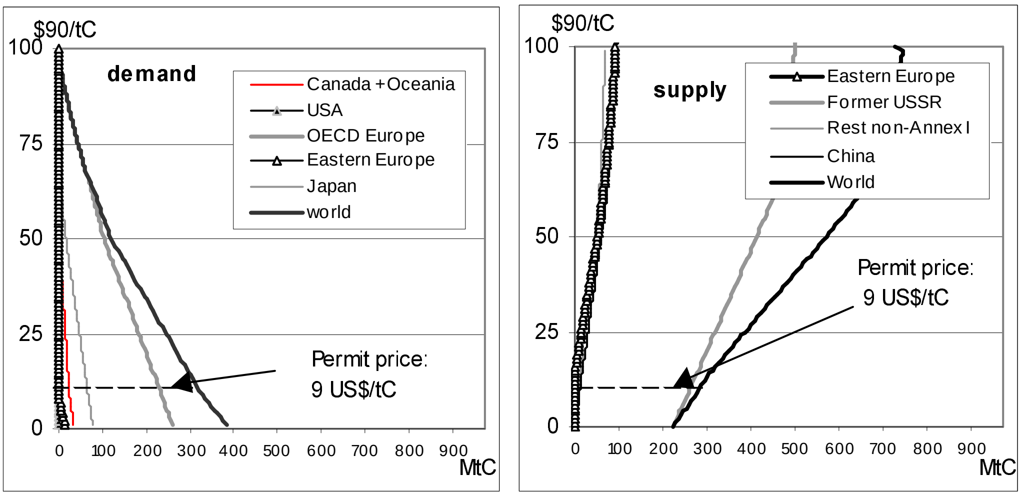

Figure 5.7a-b: Permit demand and supply curves for the individual regions as well as the world for the Bonn-Marrakesh Agreement

Table 5.4 shows the implication of the Bonn Agreement for the various regions. The revenues from permit sales for the FSU have dropped to over US$2 billion. Following the decrease in demand, the revenues from CDM projects are less than US$½ billion.

Table 5.4: Emissions trading, abatement and costs for the Marrakesh Agreement (with IET).

REGIONS	**No trade** Burden	Reduction	MAC	**Environmental Effectiveness** Domestic Abatement	Domestic Abatement	Trade	**Economic Efficiency** MAC	Total costs
	MtC	%	US$/tC	%	MtC	MtC	US$/tC	MUS$
Canada	29	-19	50	17	5	24	9.0	285
US	0	0	0	0	0	0	9.0	0
OECD Europe	260	-24	96	10	27	234	9.0	2614
Eastern Europe	13	-4	8	100	13	0	9.0	91
Former USSR	-269	49	0	0	0	-301	9.0	-2329
Oceania	4	-3	9	93	4	0	9.0	36
Japan	77	-21	66	14	10	67	9.0	758
Annex I	115	-3	26	15	60	24	9.0	1454
Non-Annex I	0	0	0	0	0	-24*	9.0	-475
World	115	-1	1	15	60	0	9.0	979

* Excluding the 33 MtC from CDM.

5.5 Assessing the decisions on sinks

At the first session of COP 6 in The Hague, the negotiations on sinks proved to be an insuperable barrier to reach international consensus. Therefore, many regard the decision on sinks in Bonn as a major achievement. What has been decided and what are the implications?

The Kyoto Protocol allows the following activities related to land use, land use change and forestry (LULUCF) to be counted as (domestic) sinks:
1. Article 3.3 afforestation, reforestation and deforestation (ARD);
2. Article 3.4 forest management;
3. Article 3.4 agricultural management (cropland management, grazing land management), revegetation and conservation activities.

The Bonn Agreement further allows:
4. afforestation and reforestation projects to be eligible under CDM in non-Annex I countries, capped at a level 1 per cent of base-year emissions.

The Bonn Agreement limits the application of the sink potential in the respect that only direct human induced activities can be selected. Countries have to demonstrate that these activities have occurred since 1990 and are human induced. [19]

Based on the decisions made in Bonn, we have calculated the sinks as follows:
- FAO estimations are used for the carbon credits from Art 3.3 afforestation, reforestation and deforestation (ARD), Art 3.4 forest management and Art 3.4 agricultural land management.
- The Art 3.4 maximum carbon credits accounts for the Art 3.3 ARD credits (+) or debits (-), Art 3.4 forest management is capped (compensation of debit under Art 3.3, 85% discounting rate for indirect human actions and the forest management cap (Appendix Z)), as well as the Art 3.4 agricultural management (net-net).
- The final carbon credits levels of Art 3.4 forest management accounts for national circumstances, i.e. maximum values as described in Appendix Z are used for the countries: Japan, Canada, Greece, Italy, Portugal, Slovenia, Spain, Switzerland, United Kingdom &US.
- sinks under CDM are set on 1% of the base year emissions of the Annex I countries involved.

The main decision in Marrakesh involved the additional 15 MtC of Russian sinks from forest management, i.e:
- The extra sinks credits from forest management for Russia; in Bonn the cap amounted to nearly 18 MtC but in Marrakesh this was raised to 33 MtC.

Table 5.5 shows regional estimates on the above-mentioned sinks-related activities in the Bonn-Marrakesh Agreement based on FAO data (TBFRA, 2000).

[19] Indirect human induced carbon removals through CO_2 and N fertilization are excluded from the accounting framework.

Table 5.5: Estimated achievable carbon credits from LULUCF-activities under Article 3.3, 3.4 and CDM for the Bonn-Marrakesh Agreement

	Domestic sinks credits					CDM-sinks			
Annex I countries	Base-year emis-sions*	1. carbon credits from ARD Art 3.3	2. carbon credits from forest management (App. Z) Art 3.4	3. carbon credits from agricultural management (no cap) Art 3.4	To-tal	4. sinks CDM projects for non-Annex I Art 12	Total carbon credits	%-base year	Corrected assigned amounts
	MtC/yr	MtC/yr	MtC/yr	MtC/yr	MtC/yr	MtC/yr	MtC/yr	%	Base-year = 100
Canada	166	0.00	12.00	5.00	17.00	1.66	18.7	11.2%	105.2
US	1655	0.00	28.00	10.20	38.20	16.55	54.8	3.3%	96.3
Western Europe	1184	2.07	6.06	0.32	8.45	11.85	20.3	1.7%	93.7
Eastern Europe	375	0.00	3.75	0.00	3.75	3.74	7.5	2.0%	95.0
FSU	1112	0.00	34.83	0.00	34.83	11.12	46.0	3.9%	103.9
Oceania	154.	7.64	0.20	2.18	10.02	1.54	11.6	7.5%	114.5
Japan	335	0.00	13.00	0.00	13.00	3.35	16.4	4.9%	98.9
Annex I w. US	4982	9.7	97.9	17.7	125.3	49.8	175.0	3.2%	98.1
Annex I w/o US	3326	9.7	69.8	7.5	87.0	33.3	120.3	3.1%	98.9

* Base-year emissions are based on the Pronk proposal at COP 6 in The Hague (Pronk, 2001)
Source: FAO data (TBFRA, 2000)

The calculations are described in Appendix III, which also offers some detailed information on country and regional level of the domestic sinks and sinks under CDM.

Without the US, the carbon credits from sinks-related activities total about 120 MtC per year, three-quarters are domestic sinks (mainly from forest management) while the remaining quarter stems from CDM projects. This is just over 3 per cent of base-year emissions and slightly above the minimum potential, as reported in Van Minnen et al. (2001). Translating the sinks decisions into ‘corrected’ assigned amounts shows that Annex I emissions without the US will come out just below the 1990 level.

When confronting the regional numbers with FAO data, Table 5.5 shows that Canada, Australia, New Zealand and Japan have been generously treated in their domestic sinks potential (see also Table II.1 for more details). The total credits for these countries amount to 5 per cent or more of base-year emissions. Japan and Canada in particular have been granted many more credits for forest management than on the basis of FAO data, i.e. almost 11 and 5 MtC more credits (see also Table 5.6). The latest FAO data of forest management reports 92 MtC carbon credits from forest management for Canada instead of the 49 MtC (possibly based on an earlier version of TBFRA (2000) report) as used by Pronk (2001). This would indicate that Canada is not being granted with more credits (see Table 5.6).

Interestingly, a similar observation can be made for the US, which has been given an amount of 28 MtC worth of credits from forest management, twice as much compared with FAO data. Here again the latest FAO data for forest management are much higher, i.e. 166 MtC instead of 101 MtC, suggesting a less favourable treatment.

On the other hand, the cap on carbon credits from forest management for Russia (in Appendix Z) is still under the potential (about 46 MtC) based on FAO data, and even more using the latest FAO data.[20] For Western Europe, credits from sinks are in line with FAO data and account for less than 2 per cent of base-year emissions. In conclusion, the total amount of sink credits allowed are just above the minimum potential and slightly less than what could have been expected from FAO data.

Table 5.6: Estimated achievable carbon credits from forest management according to the FAO data of Pronk (2001) and TBFRA (2000), as well as the Appendix Z cap values.

	carbon credits from forest management		
Annex I countries	After 85% discount Pronk (2001)*	After 85% discount TBFRA (2000)**	Appendix Z
	MtC/yr	MtC/yr	MtC/yr
Canada	6.7	13.3	12.00
US	14.1	23.9	28.00
Western Europe	8.2	10.2	6.06
Eastern Europe	3.7	3.7	3.75
FSU	65.7	68.8	33.0
Oceania	6.6	7.1	0.20
Japan	1.9	1.9	13.00
Annex I	106.9	128.9	98.0

* FAO data (TBFRA, 2000), as reported in Table 2 of Pronk (2001)
** FAO data as reported Annex 3.B3 (TBFRA, 2000) (see Footnote 18)

5.6 Exercising market power: hot air banking

Our analysis clearly demonstrates that the US withdrawal from the KP substantially reduces permit demand by Annex-I countries. As a consequence, hot air becomes extremely dominant. This happens in all scenarios; in fact, hot air may even exceed 100% of the Annex-I demand in case of low emissions baselines.[21] This excess supply over Annex-I demand drives prices down to zero and such a situation would seriously undermine the development of an international permit market. Such a situation of zero price and a dysfunctional market is unlikely to occur, since this is also clearly not in the interest of the sellers themselves, the Annex-I FSU and non-Annex-I countries. A rational reaction for the dominant seller on the market, i.e. Annex-I FSU, would be to exercise market power by limiting the supply of hot air and bank it for better times.

Other studies by Manne and Richels (2001) and Böhringer (2001) have also examined the impacts of strategic behaviour on the supply side. They find that the changes in permit prices and abatement costs are indeed much smaller if banking and monopolistic behaviour in the permit market are taken into account. Buchner et al. (2001) further examine the consequences of the US withdrawal, taken technological innovation and diffusion explicitly into account. They argue that the US decision by reducing permit demand and hence the permit price, lowers the incentives to undertake energy-saving R&D. This results in higher Annex-I emissions and in the longer run, a rising demand for permits or a reduction of supply in order to meet the Kyoto targets. Although the US withdrawal pushes the permit price downwards, this mechanism causes the reduction to be smaller than predicted in other studies.

[20] When using the data submitted by Parties on 1 August 2000 (Table 1, Pronk Proposal) for forest management after discount, the observation of generous treatment also holds for Canada and Japan but not for the US which reports 42 MtC. The 28 MtC in Appendix Z reflect the average of FAO data and data provided by Parties. For the Russian Federation, the value in Appendix Z corresponds with the data provided by Parties (Table 1, Pronk Proposal) after discount. See Table II.1 for more details.

[21] Our 2010 reference emissions of FSU varies from 25 to 33% below 1990 levels, an almost identical range as the IEA projections. It also corresponds well with the estimate of 30% below 1990 levels of the Russian National Energy Strategy (Korppoo and Vrolijk, 2001).

Our analysis shows that Annex-I FSU financial revenues from permit trading will be maximised by banking 40% of the hot air (see Figure 5.8). As supply is curtailed, the permit price will rise from US$9/tC onwards (see triangled line); OECD countries will turn more to domestic efforts for abatement and decrease permit imports. The impact on financial revenues for the Annex-I FSU will increase as well. This process continues up to the point where the price increase is outweighed by the decrease in the traded volume, and revenues will fall. In the lower baseline scenario B1, the optimum for banking runs up to 70% of hot air.

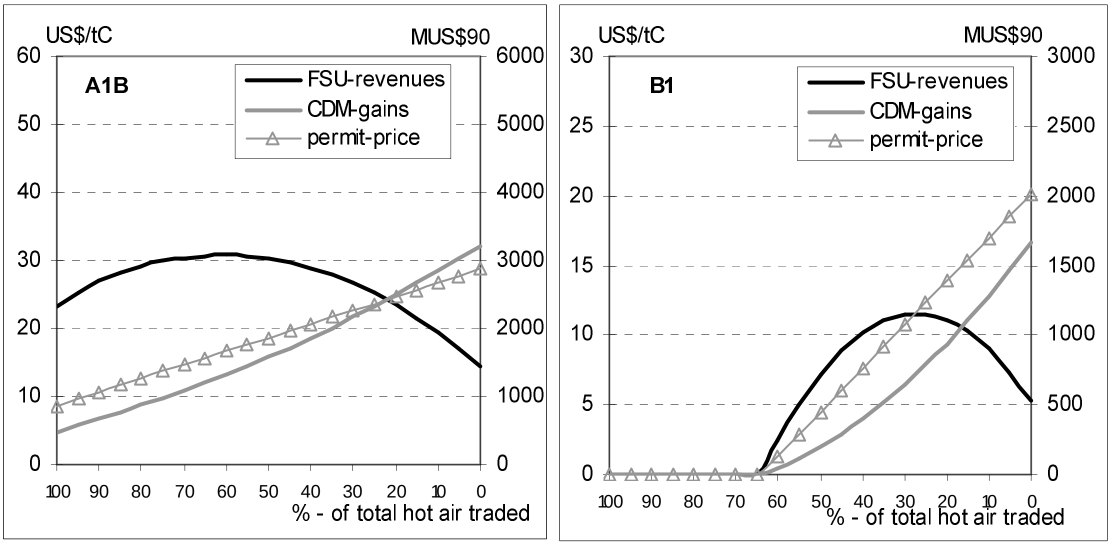

Figure 5.8: The revenues of the Annex-I FSU region and non-Annex-I countries, and the international permit price in the A1B scenario (left) and B1 scenario (right) for different percentages of hot air traded under the Marrakesh Accords (Den Elzen and De Moor, 2002b).

However, the decisions in Marrakesh on transferability and bankability of credits imply that banking is not unrestricted. In particular, credits from sink projects are non-bankable and should be sold before the end of the first commitment period. For the Annex-I FSU region this is about 35 MtC or about 15% of the total hot air. On the other hand, the transfer of credits between Annex-I Parties is free: thus, the non-bankable unit can be exchanged with other Parties for bankable units. Even if there were insufficient options to do so, this would not affect the overall strategy of the Annex-I FSU region to curtail and bank permit supply.

A strategy of curtailing and banking permit supply is not only in the interest of the dominant seller FSU. The non-Annex-I regions benefit indirectly by the higher permit price (see Figure 5.9). Furthermore, banking large amounts of hot air is also of absolute importance to improve the environmental Effectiveness of the Protocol and enhance the development of a viable emission trading market. Our analysis on the robustness of our results shows that banking all hot air will increase Annex-I abatement efforts to over 8% below baseline emissions in the reference scenario. In the case in which Annex-I FSU banks an optimum amount of hot air, i.e. 40%, this will be about 5%. The only 'losers' of banking are the Annex-I Parties. Their costs almost triple in comparison with the current Marrakesh Accords, to about US$4 billion. However this is still far below the cost level of the pre-COP-6 version of he Kyoto Protocol.

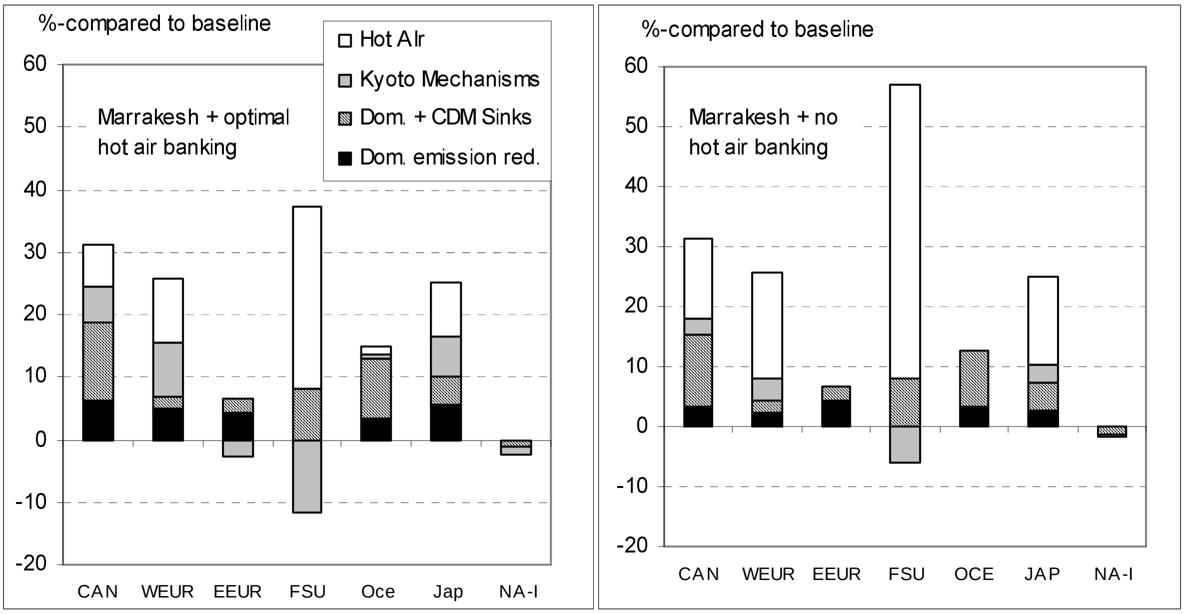

Figure 5.9: Efforts in terms of emissions reductions compared to the baseline emissions A1B for the Bonn-Marrakesh Agreement under optimal hot air banking (left) and no hot air banking (reference case) (right).

Figure 5.9 shows the emissions reduction efforts compared to the baseline emissions A1B for the Bonn-Marrakesh Agreement under optimal hot air banking and no hot air banking. It clearly shows that still the trade of hot air is important to achieve the Kyoto targets. For the optimal hot air banking case Eastern Europe is now also operating on the supply side. For this optimal banking case the OECD regions, Canada, Western Europe and Japan now achieve more emissions reductions domestically.

5.7 Robustness of results

This section investigates to what extent the results for the environmental effectiveness and economic efficiency depend on key assumptions and model parameters. We examine the impact of different baseline scenarios, hot air banking, sinks, marginal abatement curves and different assumptions concerning the CDM accessibility factor and transaction costs. We also analyse the impact of the potential US re-entry.[22]

Figure 5.10 presents the abatement efforts to achieve the Kyoto targets for the Marrakesh Accords. It shows that the baseline scenarios, banking of hot air and US re-entry can have a strong impact on the environmental effectiveness. We have calculated emission reductions for a range of scenarios through abatement efforts only, and including CO_2 removals through sinks. We have used the B1 scenario to indicate the low end of this spectrum and the A1F scenario for the high end.[23] The reference A1B scenario is represented in Figure 5.10 by the dot on the arrows. This figure also shows the impact of hot air banking and the participation of Kazakhstan.

[22] For more details, see Den Elzen and De Moor (2001a; 2001b)

[23] The CO_2 emissions of the IMAGE 2.2 baseline emissions are in line with the historical data of IEA (2001) for the period 1970-2000 (e.g., Den Elzen and De Moor (2001a)). After 2000, the scenarios diverge, the emissions without US increase from -1% (B1) to 10% (A1F) above 1990 levels (IMAGE-team, 2001).

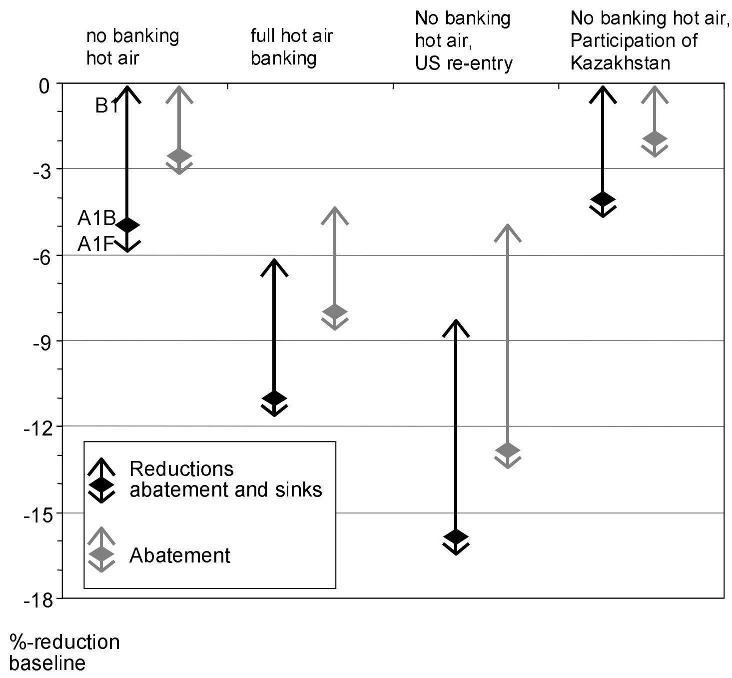

Figure 5.10: Annex-I abatement without the US compared to the baseline emissions (including and excluding removals through sinks) for the Marrakesh Accords for no banking of hot air, full banking of hot air, US re-entry and the participation of Kazakhstan.

Figure 5.10 shows the abatement efforts to achieve the Kyoto targets range from 0 to 3% under the baseline developments. Our reference A1B scenario, at nearly 3%, is found at the higher end of the spectrum. If sinks are seen as efforts additional to emission reductions, the overall decrease on the atmospheric CO_2 built-up would vary from 0 to nearly 6%. For the A2 and B1 scenarios, however, baseline emissions come out even below the Kyoto targets and net Annex-I abatement is reduced to (near) zero. Figure 5.10 reconfirms the significance of hot air banking, which would substantially improve the environmental effectiveness. Banking all hot air will increase abatement efforts to over 8% below baseline emissions in the reference scenario, or close to 11% if sinks are seen as efforts additional to emission reductions. With full banking, even in the lowest B1 scenario, there will be an abatement effort of at least 4%. A re-entry of US would significantly improve the environmental effectiveness. The abatement effort would increase to 13% below baseline levels, and to 16% including the sink efforts. Even for the B1 scenario, the abatement reaches 5% below baseline emissions. Finally, the participation of Kazakhstan reduces the (range of) environmental effectiveness by bringing even more hot air to the market, hence underlining the absolute importance of banking.

A similar analysis has been conducted to put the results for economic efficiency in perspective, focusing in particular on the permit price. We have calculated the outcomes for several scenarios and key factors that determine the permit price by choosing assumptions that reflect the low and the high end of the spectrum (see Box 5.4). Figure 5.11 shows the impacts on the permit price with our reference case pinpointed at US$8.5/tC. The shaded areas in each bar reflect the most likely outcome.

Box 5.4: A sensitivity analysis on the results for the permit price.

The following key factors and associated assumptions were chosen for the analysis:

- *Baseline emissions:* LOW reflects the B1 scenario and HIGH the A1F scenario (IMAGE-team, 2001); our reference is the A1B scenario.
- *Hot air banking:* the LOW case reflects no banking of hot air while in the HIGH case, all hot air is banked; the reference case is one in which hot air banking is optimal for the Annex-I FSU (see Figure 5.7 in Section 5.6).
- *Marginal Abatement Cost (MAC) curves:* the MAC curves of WorldScan are used in the reference case while the MAC curves of the POLES model represent the HIGH case.
- *Participation Annex-I:* at the LOW end, we examined the participation of Kazakhstan while the HIGH end reflects US re-entry.
- *Sinks:* a LOW case has been constructed by assuming CDM sink credits capped to 0.5 per cent of base year emissions (instead of 1 per cent), carbon credits from forest management based on data submitted by the Parties (which are lower than the reported values in Appendix Z, see Pronk, 2001) and low estimates for carbon credits from agricultural and grassland management using the ALTERRA ACSD model (Nabuurs et al., 2000). The HIGH case reflects sinks credits based on high ACSD estimates for agricultural and grassland management and maximum carbon credits from forest management as reported in Appendix Z. In total, the LOW case implies 70 MtC while the HIGH case 195 MtC of carbon credits from sinks-related activities. The Marrakesh Accords represent the reference case of 120 MtC.
- *CDM accessibility factor:* this reflects the operational availability of viable CDM projects and is set at 10 per cent of the theoretical maximum in the reference case. In the LOW case, we assume no accessibility, while in the HIGH case the factor is set at 30 per cent.
- *Transaction costs*: the transaction costs associated with the use of the Kyoto Mechanisms is set at 20 per cent in the reference case, at 10 per cent in the LOW case and at 30 per cent in the HIGH case.

It can be concluded that the main factors determining the permit price are the baseline scenarios, the banking of hot air supply and the re-entry of the US. Baseline scenarios other than A1B forecast a lower permit demand, far under supply. The oversupply is threatening to push the permit price towards zero, hence undermining the emissions trading market and the viability of the KMs.

Banking hot air supply has the largest and strongest impact on the permit price; it will significantly raise the permit price, up to a maximum of nearly US$30/tC. However, considering the interests of the dominant sellers and the optimum for banking, the most likely outcome is a permit price between US$15/tC and US$20/tC.

US re-entry has in quantitative terms a similar effect, potentially raising the price to US$30/tC, and thereby strengthening the international emissions permit market. It would also result in more domestic abatement, and increase the Annex-I abatement costs (e.g. Den Elzen and De Moor, (2001b)). Although the current US administration seems determined in its preference for alternatives to the Kyoto Protocol, the Marrakesh Accords leaves the door open for US re-entry. Many decisions largely meet previous US demands on key issues and may even be characterised as US-friendly. The sinks agreement, for example, implies more credits for the US than what could have been expected from FAO data. Furthermore, the absence of a quantitative and mandatory cap on permit trading corresponds with US interests. Obviously, however, the potential for re-entry is largely determined by the domestic political environment.

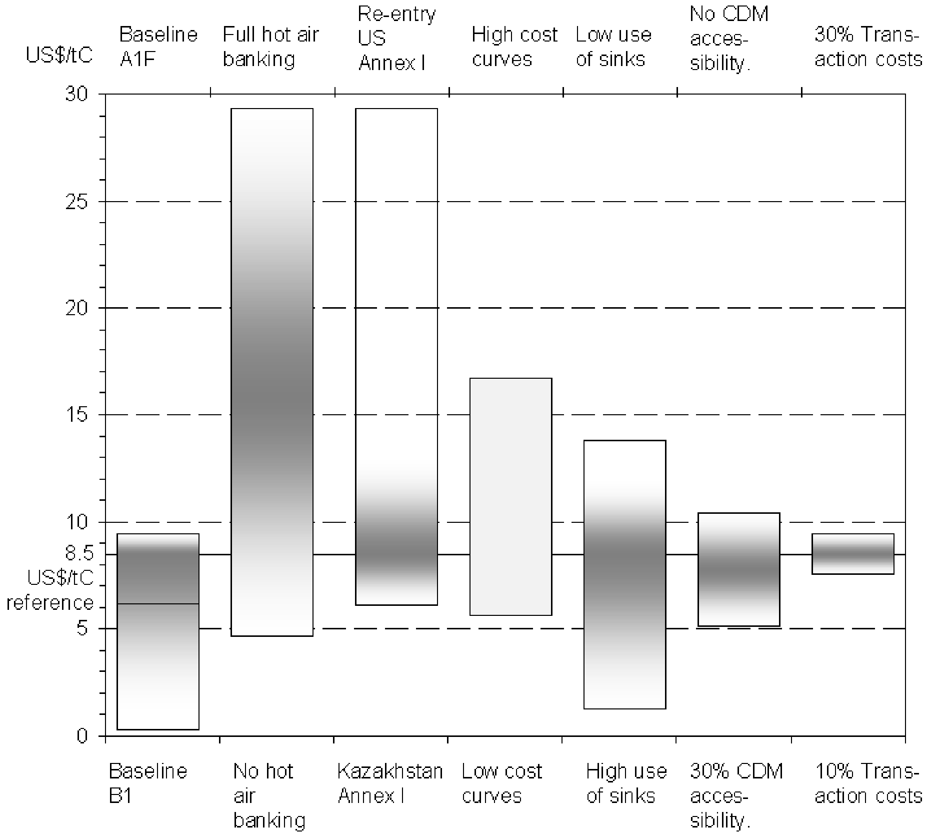

Figure 5.11: Key factors with their impact on the permit price compared to a level of US$8.5/tC (reference case) (Den Elzen and De Moor, 2002b).

Using the higher marginal abatement curves from the POLES model (Criqui et al., 1999), the permit price will double to about US$16/tC. The impact of the use of sinks [24] on the permit price is small compared to hot air banking and US re-entry. Assuming a low use of sinks, the permit price may rise to about US$14/tC. However, where use of the sinks potential is high, permit demand is further reduced and the price may approach zero. The other factors concerning CDM accessibility and transaction cost have a very limited impact.

[24] A low use of sink is based on CDM credits capped to 0.5% of base-year emissions, carbon credits from forest management based on data submitted by the Parties and low estimates for carbon credits from agricultural and grassland management using the ACSD model. For the high use of sink the high ACSD estimates and the maximum Appendix Z values are used. The total credits now vary from 70 to 195 MtC.

6 Conclusions

Using the Marginal Abatement Cost (MAC) curves we have developed a powerful instrument, the cost model of FAIR 1.1. It allows us to determine marginal and total abatement costs and to examine the gains of emissions trading. The calculations in the cost model make use of the properties of the permit supply and demand curves in order to compute the equilibrium permit price, abatement costs and emissions trading for the various regions, under different regulation schemes in an emission trading market. These schemes could include constraints on imports and exports of emissions permits, non-competitive behaviour, transaction costs associated with the use of emissions trading and less than fully efficient CDM supply. To illustrate the methodology, we have evaluated the environmental effectiveness and economic efficiency of the Bonn-Marrakesh Agreement in the first commitment period, as described in Den Elzen and De Moor (2001a; 2001b; 2002a; 2002b).

The results of the case study of the Bonn-Marrakesh Agreement are:

- The Annex-I abatement efforts relative to baseline emissions vary between 0 and 3%, depending on the scenario. If sinks are seen as efforts additional to emission reductions to capture the overall decreasing effect on CO_2 built-up, this range would increase to 6%.
- The US withdrawal has been by far the greatest impact in reducing the environmental effectiveness of the KP.
- Without a major buyer like the US, permit demand is significantly reduced and as a consequence, permit prices may drop to around US$9/tC. Hot air becomes increasingly dominant and may threaten the viability of the KMs.
- *Banking large amounts of hot air is of major importance to improve the environmental effectiveness and enhance the development of a viable emissions trading market. A strategy of curtailing and banking permit supply is also in the interest of the dominant seller, the Annex-I FSU region. Banking all hot air will increase Annex-I abatement efforts to over 8% below baseline emissions in the reference scenario, and about 4% for the low baseline B1 scenario.*
- Hot air banking may raise the permit price up to a maximum of nearly US$30/tC. The outcome in the ‘middle’ is a permit price between US$15/tC and US$20/tC.

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Appendix I Simple cases illustrating the methodology

This Appendix illustrates the methodology of calculating the permit price, emissions trading and abatement as explained in Chapter 4 based the simple case studies: no trade, full-trade, minimum domestic reduction and minimum permit price. These case studies were also used for testing the functioning of the cost model.

All studies are performed for three regions with linear MAC curves. Each region has baseline emissions as shown in Table I.1. The MAC curves are simple linear functions, i.e.: $MAC = ax$, where x is the amount of abatement (MtC), MAC is the marginal costs in (US$/tC) and a is a coefficient that differs per region (US$/(tC.MtC)) (see Figure I.1; Table I.1). The two regions A and B are constrained with total emissions reduction burdens (difference between baseline emissions and emissions targets) of 8 and 20 MtC, while region C is unconstrained.

Table I.1: MAC curves and basic and target emission for the three regions.

Region	a	Baseline (MtC)	Target (MtC)	Burden (MtC)
A	4	100	92	8
B	2	250	230	20
C	1.33	150	150	0
Total		500	472	28

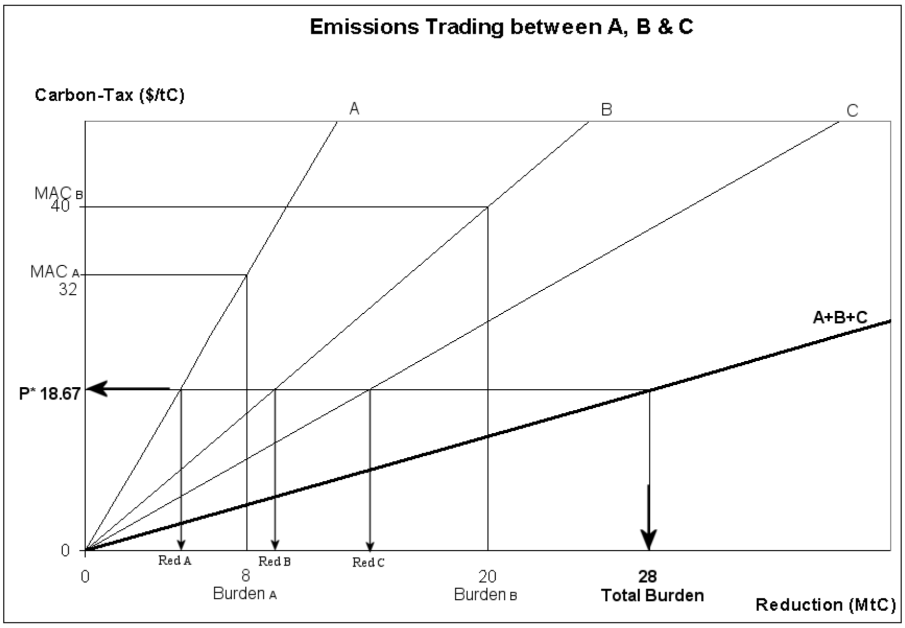

Figure I.1: Emissions trading between 3 regions with linear MAC curves (case full trade: using MAC curves).

I.0 Case No Trade: using MAC curves

Table I.2 illustrates the marginal and total abatement costs for the case no trade, showing high marginal costs for regions A and B of US$32/tC and US$40/tC, respectively.

Table I.2: Marginal and total abatement costs for case no trade.

Region	Marginal Costs (US$/tC)	Total costs without trading (MUS$)
A	32	128
B	40	400
C	0	0
Total		528

I.1 Case full trade: using MAC curves

The case ‘full trade’ illustrates the gains of emission trading in a perfectly competitive market (no restrictions). This simple case follows the methodology of marginal abatement curves as described in section 4.1.

Table I.3: Domestic emissions reduction, trade and emissions after trade for case full trade.

Region	Permit price (US$/tC)	Domestic reduction. (MtC)	External reduction (trade) (MtC)	Total Emissions after trade (MtC)
A	18.67	4.67	3.33	95.33
B	18.67	9.33	10.67	240.67
C	18.67	14.00	-14.00	136
Total		28	0	472

The methodology consists of the following steps (see also Figure I.1 and Table I.3):
1. Calculate the total emission reduction burden, i.e. 28 MtC.
2. Construct the total MAC curve of all participating regions (curve $A+B+C$ in Figure I.1).
3. Calculate the world permit price at the total MAC curve where the total emission reduction burden is reached (p' = US$18.67/tC).
4. Calculate the domestic emission reductions of each region at this permit price
5. Calculate the external reductions (trade) (see Table I.3), the total abatement costs and gains of emissions trading (see Figure I.2).

The costs of the domestic reductions for region A is illustrated as the surface under the MAC curve of region A from zero to the actual domestic reduction (4.67) (left triangle in Figure I.2). The costs of permits bought by region A are equal to the amount of permits bought (3.33) times the permit price (18.67). Table I.4 summarises the abatement costs and gains of emissions of the three regions.

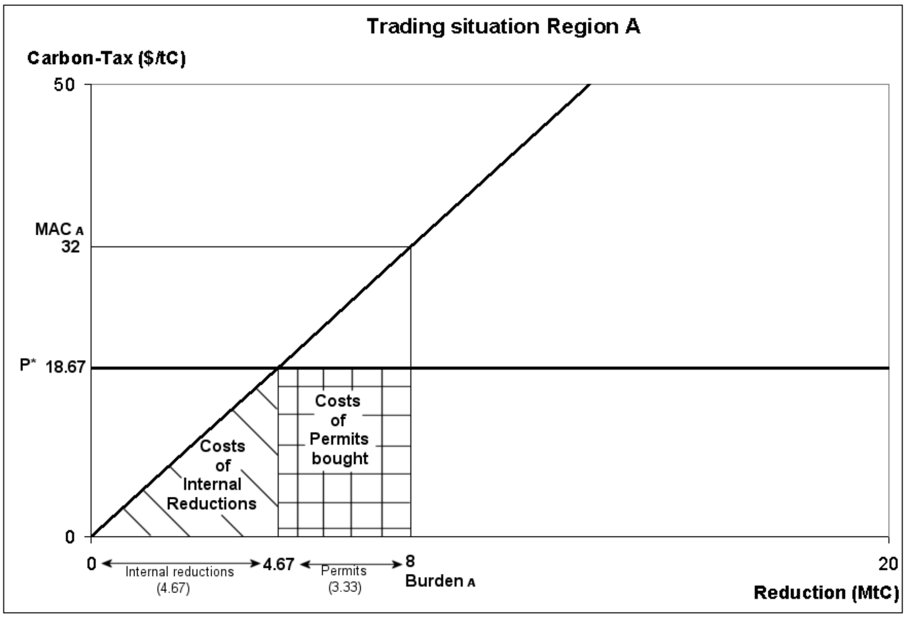

Figure I.2: Costs for region A in case of full emissions trade. The upper triangle indicates the gains of emissions trading.

Table I.4: Costs of emissions trading for the three regions.

Region	Costs of buying permits (MUS$)	Costs of domestic reductions (MUS$)	Total costs with trading (MUS$)	Gains of trading (MUS$)
A	62	43	105	+23
B	199	87	286	+114
C	-261	131	-130	+130
Total	0	261	261	+267

I.2 Case full trade: using demand and supply curves

The emissions trading and abatement costs calculations in the case full trade can also be based on the methodology of aggregated demand and supply curves, as described in section 4.2.

Demand and supply curves can be calculated for each region, using the MAC curve and the reduction burden of a region. Figure I.3 shows the demand and supply curve of region I. At market permit prices higher than the autarkic marginal permit price, i.e. the marginal costs for its emissions reduction target for no trade (MAC_A: US$32/tC) (see Table I.2), region A will be a supplier of emission permits. At lower permit prices, region A will buy permits, according to its demand curve.

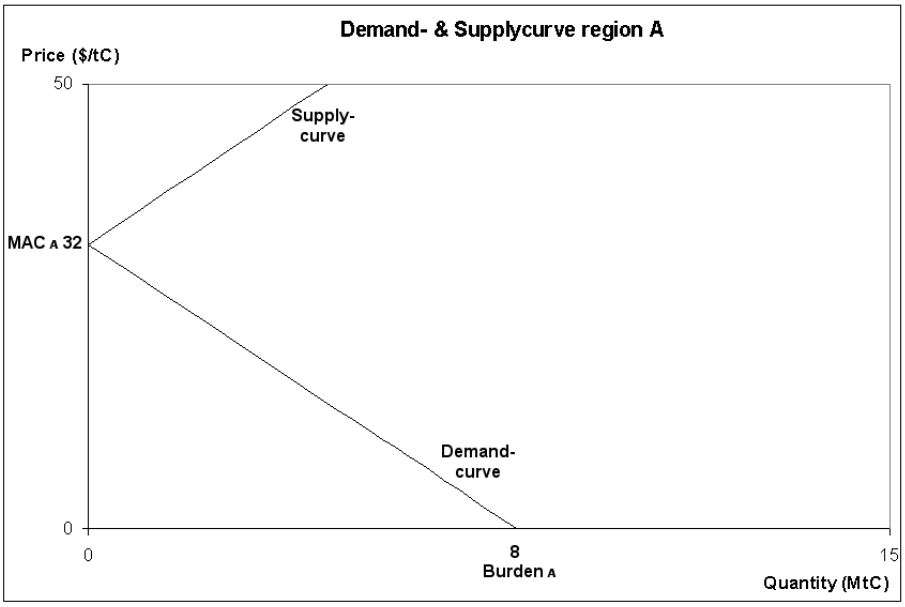

Figure I.3: Demand and supply curve for region I.

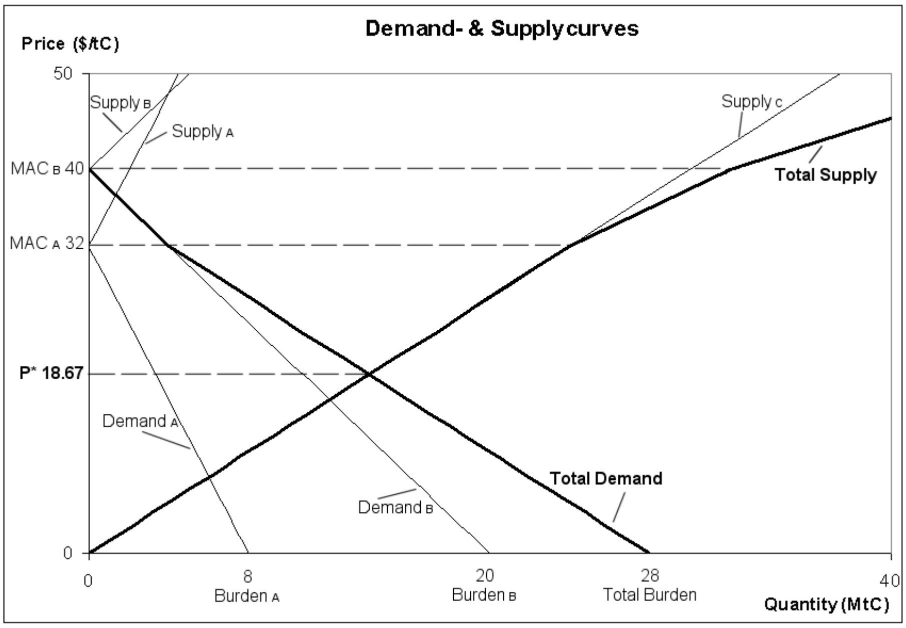

Figure I.4: Total demand curve and total supply curve for full trade, leading to permit price p'

Adding the regional demand curves together gives the total demand curve. The same can be done for constructing the total supply curve (see Figure I.4). In a situation of full trade, the permit price (*p'*) is at the level where the total demand equals the total supply, which is at US$18.67/tC (the same level as found in section I.1).

I.3 Case minimum domestic reduction

In the case of minimum percentage domestic reduction a restriction is made on the import of permits in the form of a minimum domestic reduction of 50%. As mentioned in section 4.3.1 the methodology for the calculation of emissions trading and abatement costs is normally based on the aggregated demand & supply curves. For a trading market with no transaction costs and inefficiencies in supply, as assumed here, you could also use the methodology of MAC curves, as illustrated for this case. Table I.5 demonstrates that the permit price decreases, due to lower demand for emissions permits from region B.

Table I.5: Domestic emissions reduction, external reduction (trade) and emissions after trade for case minimum 50% domestic reductions.

Region	Permit price	Domestic reduction. (MtC)	External reduction (MtC)	Total Emissions after trade (MtC)
A	18.0	4.5	3.5	95.5
B	18.0	10	10	240
C	18.0	13.5	-13.5	136.5
Total		28	0	472

The calculation is done by adjusting the MAC curves of the two constrained regions A and B with the given restriction of a minimum domestic reduction of at least 50%. This leads to domestic reductions of at least 4 MtC (50% of 8 MtC) and 10 MtC (50% of 20 MtC) for region A and B, respectively. Figure I.5 shows the restricted MAC curves for the constrained regions A and B.

The further calculations are similar as under the case full trade (see section I.1): calculate the total MAC curve (Figure I.5) and the permit price (US$18/tC), and then calculate the domestic and external emissions reductions. The total abatement costs and gains of emissions trading can also be calculated easily, although not illustrated here. This case leads to a minor decrease in the gains from emissions trading compared to the gains for the case full trade.

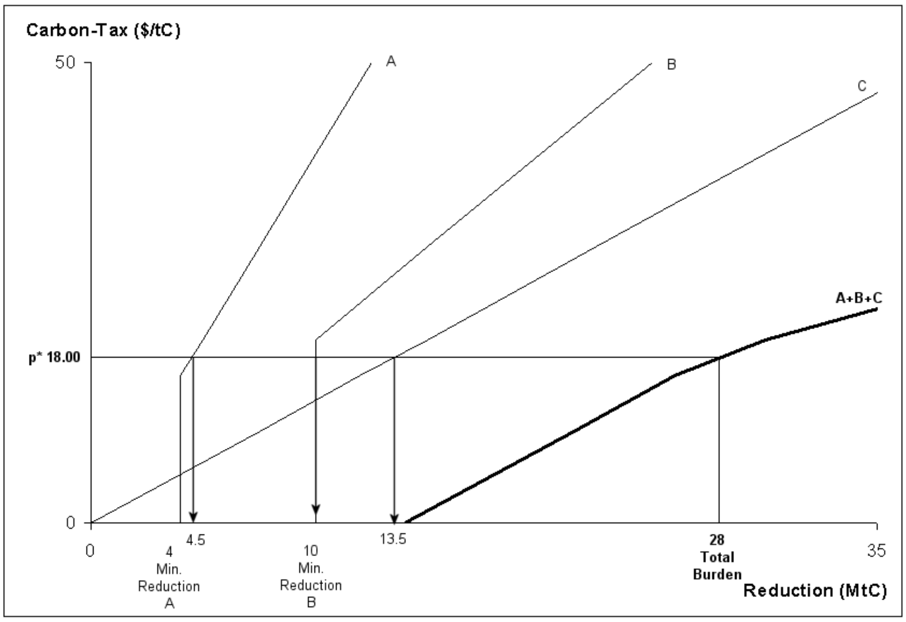

Figure I.5: Restricted MAC curves in case of a minimum % domestic reductions for regions A and B.

I.4 Case minimum permit price

The calculation of emissions trading in the case of a minimum permit price is also done using the methodlogy of demand and supply curves, as described in section 4.3.2. Here we suppose a minimum permit price of US$25/tC. Since this minimum price is higher than the permit price at full trade (US$18.67/tC), this minimum permit forms a restriction in the trading market, leading less imports of permits and more domestic action (see Table I.6). The calculation consists of the following steps (see also Figure I.6):

1. Calculate the regional demand and supply curves (section I.2).
2. Aggregate the regional curves to total demand and supply curves (see section I.2).
3. Calculate the regional demands and the total demand at this given minimum permit price of US$25/tC (total demand: 9.25 MtC).
4. Calculate the marginal costs of supplying this total demand. Next, determine the individual supplies of all supplying regions to meet this total demand. In this case only region C is supplying permits, so this step is straightforward. If there are more supplying regions however, this step describes the allocation of the permits that should be supplied among the supplying regions to meet the total demand.

Table I.6 shows the resulting domestic and external emissions reduction. Again the total abatement costs and the gains of emissions trading can easily be calculated (not illustrated here). The results clearly indicate that the gains of emissions trading are now more limited.

Table I.6: Domestic emissions reduction, trade and emissions after trade for case a minimum permit price of US$25/tC.

Region	Permit price (US$/tC)	Domestic reduction. (MtC)	External reduction (trade) (MtC)	Total Emissions after trade (MtC)
A	25.0	6.25	1.75	93.75
B	25.0	12.5	7.5	237.5
C	25.0	9.25	-9.25	140.75
Total		28	0	472

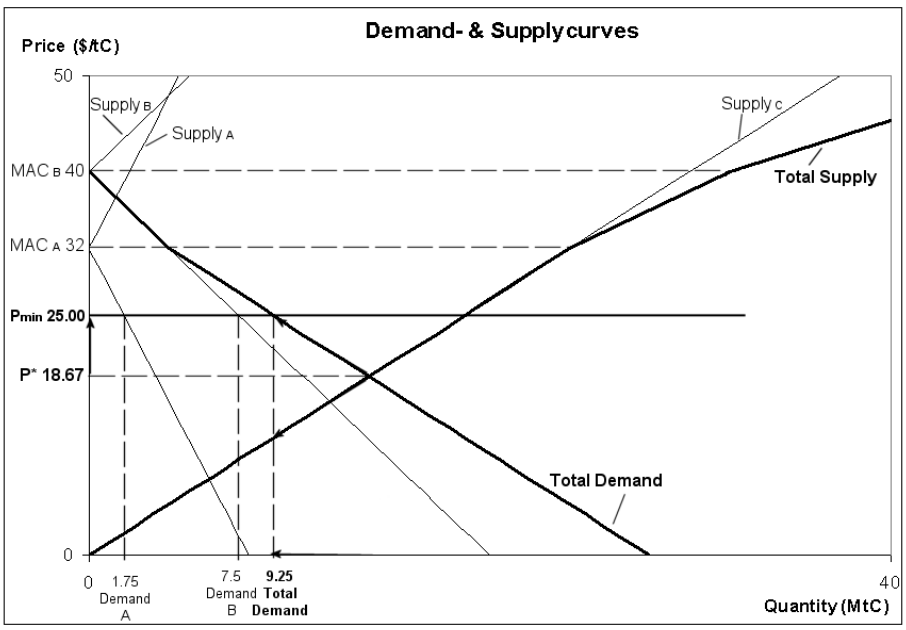

Figure I.6: Emission trading in the case of a minimum permit price of US$25/tC.

Appendix II: Detailed sinks estimates

Table II.1 Estimates of emissions by sources and removals by sinks under Article 3.3 and 3.4 based on FAO data, accounting for the LULUCF caps as agreed in Bonn and Marrakesh

	Base-year	Art 3.3 credit (+) or debit (-)	Art 3.4[25] Forest mana ge-ment	Art 3.3 debit com-pen-sated	Forest mana-gement after discount	Appendi x Z	Art 3.4 Forest mana-gement 26	Art 3.4 Agricult ural manage ment (net-net)	Art 3.3 credits	Total Art 3.3 + 3.4	CDM 1% Base-year	Total credits	%-base-year
	1	2	3	4	5=0.15*((3)-(4))	6	7=min (6,5)	8	9	10=7 +8+9	11	12=11 +10	15
	MtC/yr	MtC/yr	MtC/yr	MtC/yr	MtC/yr	MtC/yr	MtC/yr	MtC/yr	MtC/yr	MtC/yr	MtC/yr		%
Australia	134.54	0.00	40.49	0.00	6.07	0.00	0.00	2.18		2.18	1.35	3.53	2.4%
Austria	21.04	-0.20	5.14	0.20	0.74	0.63	0.63			0.63	0.21	0.84	4.3%
Belgium	37.24		0.22		0.03	0.03	0.03			0.03	0.37	0.40	1.2%
Bulgaria	42.84		2.44		0.37	0.37	0.37			0.37	0.43	0.79	2.0%
Canada	166.17	-4.30	49	4.30	6.71	12.00	12.00	5.00		17.00	1.66	18.66	11.9%
Czech Republ.	51.74		2.13		0.32	0.32	0.32			0.32	0.52	0.84	1.8%
Denmark	19.08	0.09	0.31	0.00	0.05	0.05	0.05		0.09	0.14	0.19	0.33	1.9%
Estonia	11.10		0.64		0.10	0.10	0.10			0.10	0.11	0.21	2.0%
Finland	20.51	-0.36	5.65	0.36	0.79	0.16	0.16			0.16	0.21	0.37	1.9%
France	148.96	-0.62	8.95	0.62	1.25	0.88	0.88			0.88	1.49	2.37	1.7%
Germany	330.28	-0.21	14.07	0.21	2.08	1.24	1.24			1.24	3.30	4.54	1.5%
Greece	29.28		0.23		0.03	0.09	0.09			0.09	0.29	0.38	1.4%
Hungary	27.72		1.92		0.29	0.29	0.29			0.29	0.28	0.57	2.2%
Iceland	0.70	0.02	0	0.00	0.00	0.00	0.00	0.04	0.02	0.06	0.01	0.07	8.7%
Ireland	14.59	0.91	0.32	0.00	0.05	0.05	0.05		0.91	0.96	0.15	1.10	8.2%
Italy	141.64	0.47	0.71	0.00	0.11	0.18	0.18		0.47	0.65	1.42	2.07	1.6%
Japan	334.78	-1.02	13.58	1.02	1.88	13.00	13.00			13.00	3.35	16.35	5.2%
Latvia	9.73		2.52		0.38	0.34	0.34			0.34	0.10	0.44	4.9%
Liechtenstein	0.07				0.00	0.01	0.00			0.00	0.00	0.00	1.1%
Lithuania	14.06		1.88		0.28	0.28	0.28			0.28	0.14	0.42	3.3%
Luxembourg	3.67		0.01		0.00	0.01	0.01			0.01	0.04	0.05	1.4%
Monaco	0.03				0.00	0.00	0.00			0.00	0.00	0.00	1.1%
Netherlands	59.77	0.00	0.4	0.00	0.06	0.01	0.01	0.02	0.00	0.03	0.60	0.63	1.1%
New Zealand	19.90	7.64	3.67	0.00	0.55	0.20	0.20		7.64	7.84	0.20	8.04	40.4%
Norway	14.22	0.02	3.53	0.00	0.53	0.40	0.40		0.02	0.42	0.14	0.56	3.9%
Poland	153.89		5.45		0.82	0.82	0.82			0.82	1.54	2.36	1.6%
Portugal	17.12		0.51		0.08	0.22	0.22			0.22	0.17	0.39	2.5%
Romania	72.24		7.35		1.10	1.10	1.10			1.10	0.72	1.82	2.7%
Russian Federation	826.56		425.5		63.83	33.0	33.0			33.0	8.27	41.3	5.0%
Slovakia	20.79		3.36		0.50	0.50	0.50			0.50	0.21	0.71	3.7%
Slovenia	5.24		1.78		0.27	0.36	0.36			0.36	0.05	0.41	8.6%
Spain	84.13		3		0.45	0.67	0.67			0.67	0.84	1.51	2.0%
Sweden	19.25	-0.09	10.89	0.09	1.62	0.58	0.58			0.58	0.19	0.77	4.4%
Switzerland	14.46	-0.02	0.66	0.02	0.10	0.50	0.50	0.01		0.51	0.14	0.65	4.9%
Ukraine	250.70		7.41	0.00	1.11	1.11	1.11			1.11	2.51	3.62	1.4%
UK	208.84	0.56	1.67	0.00	0.25	0.37	0.37	0.25	0.56	1.18	2.09	3.27	1.7%
US	1655.38	-7.20	101.2	7.20	14.10	28.00	28.00	10.20		38.20	16.55	54.75	3.6%
TOTAL with US	4982.25	-4.31	726.6	14.02	106.89	97.9	97.9	17.70	9.71	125.3	49.82	175.0	3.7%
Non-EU	3826.9	-4.86	674.5	12.5	99.3	77.3	77.3	17.4	7.7	102.4	38.3	140.7	3.8%
EU	1155.39	0.55	52.08	1.48	7.59	5.17	5.16	0.27	2.03	7.46	11.55	19.02	1.8%
TOTAL wo US	3326.9	2.89	625.4	6.8	92.8	69.9	69.9	7.50	9.71	87.0	33.27	120.0	3.8%
FAIR Annex I regions													
Canada	166.17	-4.30	49.00	4.30	6.71	12.00	12.00	5.00	0.00	17.00	1.66	18.66	11.2%
US	1655.38	-7.20	101.2	7.20	14.10	28.00	28.00	10.20	0.00	38.20	16.55	54.75	3.3%
West.Europe	1184.88	0.57	56.27	1.50	8.22	6.08	6.06	0.32	2.07	8.45	11.85	20.30	1.7%
East. Europe	374.46	0.00	24.43	0.00	3.66	3.76	3.75	0.00	0.00	3.75	3.74	7.50	2.0%
FSU	1112.14	0.00	438.9	0.00	65.70	34.8	34.8	0.00	0.00	34.8	11.12	46.0	3.9%
Oceania	154.44	7.64	44.16	0.00	6.62	0.20	0.20	2.18	7.64	10.02	1.54	11.56	7.5%
Japan	334.78	-1.02	13.58	1.02	1.88	13.00	13.00	0.00	0.00	13.00	3.35	16.35	4.9%
Annex I	4982.25	-4.31	726.6	14.02	97.9	97.9	17.70	9.71	125.3	49.82	175.0	3.7%	97.9

25 Here we use the FAO data (TBFRA, 2000), as reported in Table 2 of Pronk (2001). Although Pronk is referring to Annex 3.B3 page 169, the numbers in Table 2 do not correspond with the reported FAO-data in Annex 3.B3. In particular, for Canada, Italy, Russia and US, these are higher. Since we already use the Appendix Z values for these regions, the final carbon credits from forest management do not change by using the updated FAO data.

26 For Japan, Canada, Greece, Italy, Portugal, Slovenia, Spain, Switzerland, United Kingdom and the US, the values as given in Appendix Z are used.

Appendix III: Detailed model results

Table B.1: Emissions trading, abatement and costs for the pre-COP 6 version of the Kyoto protocol including US participation (reference case)

REGIONS	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
	Reference	Target	Reduc-tion	Burden	MAC	Costs	Emissions	Dom./ Total	MAC	Dom Act	Trade	Dom costs	Trade costs*	Total costs*	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	105	-31	48	101	2092	131	47	38.2	22	25	431	1165	1595	-0.19	497	24	3.15	3.91
US	1739	1230	-29	509	98	22719	1510	45	38.2	229	280	4387	12835	17222	-0.15	5498	24	4.06	4.98
OECD Europe	1088	808	-26	281	109	13331	966	44	38.2	123	158	2349	7248	9596	-0.08	3734	28	1.99	2.38
Eastern Europe	318	297	-7	21	12	129	263	100	38.2	21	-34	885	-1283	-398	0.06	527	407	2.39	2.12
Former USSR	549	773	41	-224	0	0	404	0	38.2	0	-370	2318	-14119	-11801	1.47	11801	100	2.55	1.33
Oceania	124	108	-13	16	33	264	108	100	38.2	16	0	264	0	264	-0.04	0	0	3.44	3.44
Japan	372	278	-25	93	87	3675	325	51	38.2	47	46	901	2119	3019	-0.05	656	18	2.09	2.44
Annex I	4343	3599	-17	744	70	42212	3706	47	38.2	458	107	11534	7965	19499	-0.06	22713	54	2.70	2.78
Non-Annex I	4141	4141	0	0	0	0	4034	0	38.2	0	-107	170	-4070	-3901	0.03	3901	100	0.75	0.73
World	8483	7740	-9	744	1	42212	7740	47	38.2	458	0	11704	3894	15598	-0.03	26614	63	1.12	1.12

Table B.2: Emissions trading, abatement and costs for the pre-COP 6 version of the Kyoto protocol without US participation (reference case)

REGIONS	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
	Reference	Target	Reduc-tion	Burden	MAC	Costs	Emissions	Dom./ Total	MAC	Dom Act	Trade	Dom costs	Trade costs*	Total costs*	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	105	-31	48	101	2092	143	21	17.3	10	38	89	784	873	-0.10	1219	58	3.15	4.28
US	1739	1744	0	-5	0	0	1739	0	17.3	0	0	0	0	0	0.00	0	0	5.76	5.74
OECD Europe	1088	808	-26	281	109	13331	1033	20	17.3	56	225	485	4684	5169	-0.04	8161	61	1.99	2.55
Eastern Europe	318	297	-7	21	12	129	293	100	17.3	21	-4	182	-67	115	-0.02	14	11	2.39	2.36
Former USSR	549	773	41	-224	0	0	483	0	17.3	0	-290	479	-5030	-4551	0.57	4551	100	2.55	1.60
Oceania	124	108	-13	16	33	264	115	52	17.3	8	8	72	158	230	-0.04	35	13	3.44	3.69
Japan	372	278	-25	93	87	3675	350	23	17.3	22	72	188	1496	1684	-0.03	1991	54	2.09	2.63
Annex I	4343	4113	-5	229	32	19492	4156	26	17.3	116	48	1496	2026	3521	-0.01	15971	82	3.08	3.12
Non-Annex I	4141	4141	0	0	0	0	4092	0	17.3	0	-48	35	-839	-804	0.01	804	100	0.75	0.74
World	8483	8254	-3	229	1	19492	8249	26	17.3	116	0	1530	1187	2718	-0.01	16775	86	1.20	1.20

Table B.3: Emissions trading, abatement and costs for the Bonn Agreement (reference case)

REGIONS	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
	Reference	Target	Reduc-tion	Burden	MAC	Costs	Emissions	Dom./Total	MAC	Dom Act	Trade	Dom costs	Trade costs*	Total costs*	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	124	-19	29	50	727	147	19	9.7	6	24	27	294	322	-0.04	406	56	3.71	4.42
US	1739	1739	0	0	0	0	1739	0	9.7	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	828	-24	260	96	11252	1058	12	9.7	31	230	149	2818	2967	-0.02	8285	74	2.04	2.61
Eastern Europe	318	304	-4	13	8	53	305	99	9.7	13	0	52	45	97	-0.01	-44	-83	2.45	2.45
Former USSR	549	804	46	-255	0	0	513	0	9.7	0	-291	150	-2704	-2554	0.32	2554	100	2.65	1.69
Oceania	124	119	-3	4	9	19	119	100	9.7	4	0	19	18	37	-0.01	-18	-93	3.81	3.81
Japan	372	295	-21	77	66	2432	360	15	9.7	12	65	58	800	858	-0.01	1574	65	2.21	2.70
Annex I	4343	4213	-3	130	26	14484	4240	17	9.7	66	27	456	1271	1727	-0.01	12757	88	3.16	3.18
Non-Annex I	4141	4141	0	0	0	0	4113	0	9.7	0	-27	11	-587	-576	0.00	253	100	0.75	0.74
World	8483	8354	-2	130	1	14484	8354	17	9.7	66	0	467	684	1151	0.00	13010	90	1.21	1.21

Table B.4: Emissions trading, abatement and costs for the Marrakesh Accords (reference case)

REGIONS	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
	Reference	Target	Reduc-tion	Burden	MAC	Costs	Emissions	Dom./Total	MAC	Dom Act	Trade	Dom costs	Trade costs*	Total costs*	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	124	-19	29	50	727	148	17	8.5	5	24	21	264	285	-0.03	442	61	3.71	4.44
US	1739	1739	0	0	0	0	1739	0	8.5	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	828	-24	260	96	11252	1061	10	8.5	27	234	114	2500	2614	-0.02	8638	77	2.04	2.62
Eastern Europe	318	304	-4	13	8	53	304	100	8.5	13	0	53	38	91	-0.01	-38	-72	2.45	2.45
Former USSR	549	818	49	-269	0	0	517	0	8.5	0	-301	114	-2443	-2329	0.29	2329	100	2.70	1.71
Oceania	124	119	-3	4	9	19	120	93	8.5	4	0	17	19	36	-0.01	-16	-83	3.81	3.82
Japan	372	295	-21	77	66	2432	361	14	8.5	10	67	44	714	758	-0.01	1674	69	2.21	2.72
Annex I	4343	4227	-3	115	26	14484	4251	15	8.5	60	24	363	1091	1454	0.00	13029	90	3.17	3.19
Non-Annex I	4141	4141	0	0	0	0	4117	0	8.5	0	-24	8	-483	-475	0.00	193	100	0.75	0.74
World	8483	8368	-1	115	1	14484	8368	15	8.5	60	0	371	608	979	0.00	13222	91	1.21	1.21

Appendix IV: Detailed results for the sensitivity analysis (robustness of results)

Impact of Baseline scenario:

Table C.1 Baseline A1F: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the A1F scenario (reference) (MAC-WorldScan, CDM-10%, TAC: 20%).

	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
REGIONS	Ref-erence MtC	Target MtC	Reduc-tion %	Burden MtC	MAC US$/tC	Costs MUS$	Emis-sions MtC	Dom./Total %	MAC US$/tC	Dom Act MtC	Trade MtC	Dom costs MUS$	Trade costs MUS$	Total costs MUS$	%-GDP %	Gains trade MUS$	% %	Target tC/cap	Emission tC/cap
Canada	156	124	-20	32	55	846	150	19	10.0	6	26	30	331	361	-0.04	485	57	3.71	4.49
USA	1748	1748	0	0	0	0	1748	0	10.0	0	0	0	0	0	0.00	0	0	5.77	5.77
OECD Europe	1094	828	-24	266	99	11704	1062	12	10.0	32	234	160	2961	3121	-0.03	8583	73	2.04	2.62
Eastern Europe	319	304	-5	14	9	61	304	100	10.0	14	0	61	45	107	-0.02	-45	-74	2.45	2.45
Former USSR	558	818	47	-261	0	0	519	0	10.0	0	-299	162	-2873	-2711	0.34	2711	100	2.70	1.71
Oceania	126	119	-5	6	13	40	121	77	10.0	5	1	24	35	59	-0.01	-19	-48	3.81	3.86
Japan	374	295	-21	79	68	2544	361	16	10.0	12	67	62	843	905	-0.01	1639	64	2.21	2.72
Annex 1	4373	4236	-3	136	27	15194	4265	17	10.0	69	28	500	1342	1842	-0.01	13353	88	3.18	3.20
non-Annex1	4163	4163	0	0	0	0	4135	0	10.0	0	-28	12	-617	-605	0.00	271	100	0.75	0.74
World	8536	8400	-2	136	4	15194	8400	17	10.0	69	0	511	725	1237	0.00	13624	90	1.22	1.22

Table C.2 Baseline B1: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the B1 scenario (MAC-WorldScan, CDM-10%, TAC: 20%).

	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
REGIONS	Ref-erence MtC	Target MtC	Reduc-tion %	Burden MtC	MAC US$/tC	Costs MUS$	Emis-sions MtC	Dom./Total %	MAC US$/tC	Dom Act MtC	Trade MtC	Dom costs MUS$	Trade costs MUS$	Total costs MUS$	%-GDP %	Gains trade MUS$	% %	Target tC/cap	Emission tC/cap
Canada	141	124	-12	17	32	282	141	0	0.0	0	17	0	0	0	0.00	282	100	3.71	4.24
USA	1618	1618	0	0	0	0	1618	0	0.0	0	0	0	0	0	0.00	0	0	5.34	5.34
OECD Europe	1009	828	-18	181	66	5615	1009	0	0.0	0	181	0	0	0	0.00	5615	100	2.04	2.49
Eastern Europe	258	304	18	-46	0	0	258	0	0.0	0	-30	0	0	0	0.00	0	0	2.45	2.08
Former USSR	489	818	67	-329	0	0	489	0	0.0	0	-211	0	0	0	0.00	0	0	2.70	1.61
Oceania	118	119	1	-1	0	0	118	0	0.0	0	-1	0	0	0	0.00	0	0	3.81	3.77
Japan	338	295	-13	43	39	836	338	0	0.0	0	43	0	0	0	0.00	836	100	2.21	2.54
Annex 1	3972	4107	3	-135	17	6733	3972	0	0.0	0	0	0	0	0	0.00	6733	100	3.08	2.98
non-Annex1	3670	3670	0	0	0	0	3670	0	0.0	0	0	0	0	0	0.00	0	0	0.66	0.66
World	7642	7778	2	-135	2	6733	7642	0	0.0	0	0	0	0	0	0.00	6733	100	1.13	1.11

Impact of Hot Air banking

Table C.3 Full Hot Air Banking: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the A1 scenario (MAC-WorldScan, CDM-10%, TAC: 20%).

REGIONS	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
	Ref-erence	Target	Reduc-tion	Burden	MAC	Costs	Emis-sions	Dom./ Total	MAC	Dom Act	Trade	Dom costs	Trade costs	Total costs	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	124	-19	29	50	727	136	58	28.7	17	12	241	484	726	-0.09	2	0	3.71	4.08
USA	1739	1739	0	0	0	0	1739	0	28.7	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	828	-24	260	96	11252	997	35	28.7	92	169	1314	6216	7530	-0.06	3722	33	2.04	2.46
Eastern Europe	318	304	-4	13	8	53	279	100	28.7	13	26	457	867	1325	-0.20	-1271	-2392	2.45	2.24
Former USSR	549	549	0	0	0	0	440	0	28.7	0	-110	1311	-2759	-1448	0.18	1448	100	1.81	1.45
Oceania	124	119	-3	4	9	19	112	100	28.7	4	7	144	265	408	-0.06	-389	-2000	3.81	3.58
Japan	372	295	-21	77	66	2432	336	46	28.7	36	42	510	1545	2056	-0.03	376	15	2.21	2.53
Annex 1	4343	3958	-9	384	28	14484	4038	42	28.7	162	146	3978	6618	10596	-0.03	3888	27	2.97	3.03
non-Annex1	4141	4141	0	0	0	0	4061	0	28.7	0	-80	96	-3249	-3153	0.02	2199	100	0.75	0.73
World	8483	8099	-5	384	1	14484	8099	42	28.7	162	66	4073	3369	7443	-0.02	6087	42	1.18	1.18

Table C.4 Optimal Hot Air Banking (60%): Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the A1 scenario (MAC-WorldScan, CDM-10%, TAC: 20%).

REGIONS	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
	Ref-erence	Target	Reduc-tion	Burden	MAC	Costs	Emis-sions	Dom./ Total	MAC	Dom Act	Trade	Dom costs	Trade costs	Total costs	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	124	-19	29	50	727	143	33	16.7	10	19	82	422	504	-0.06	224	31	3.71	4.29
USA	1739	1739	0	0	0	0	1739	0	16.7	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	828	-24	260	96	11252	1035	20	16.7	53	207	447	4375	4823	-0.04	6429	57	2.04	2.55
Eastern Europe	318	304	-4	13	8	53	295	100	16.7	13	9	149	225	374	-0.06	-321	-603	2.45	2.38
Former USSR	549	711	29	-161	0	0	486	0	16.7	0	-225	442	-3523	-3081	0.38	3081	100	2.35	1.60
Oceania	124	119	-3	4	9	19	117	100	16.7	4	3	50	74	125	-0.02	-105	-542	3.81	3.73
Japan	372	295	-21	77	66	2432	351	27	16.7	21	56	173	1195	1368	-0.02	1064	44	2.21	2.64
Annex 1	4343	4120	-5	223	26	14484	4166	26	16.7	101	70	1344	2769	4113	-0.01	10371	72	3.09	3.12
non-Annex1	4141	4141	0	0	0	0	4094	0	16.7	0	-46	32	-1328	-1295	0.01	742	100	0.75	0.74
World	8483	8260	-3	223	1	14484	8260	26	16.7	101	23	1376	1441	2817	-0.01	11113	77	1.20	1.20

Table C.5 Low/No Hot Air Banking (50%): Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the B1 scenario (MAC-WorldScan, CDM-10%, TAC: 20%).

REGIONS	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
	Ref-erence	Target	Reduc-tion	Burden	MAC	Costs	Emis-sions	Dom./ Total	MAC	Dom Act	Trade	Dom costs	Trade costs	Total costs	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	141	124	-12	17	32	282	139	14	4.5	2	15	5	90	95	-0.01	187	66	3.71	4.16
USA	1618	1618	0	0	0	0	1618	0	4.5	0	0	0	0	0	0.00	0	0	5.34	5.34
OECD Europe	1009	828	-18	181	66	5615	996	7	4.5	13	168	29	963	992	-0.01	4622	82	2.04	2.45
Eastern Europe	258	281	9	-23	0	0	253	0	4.5	0	-28	9	-106	-97	0.02	97	100	2.27	2.04
Former USSR	489	654	34	-165	0	0	474	0	4.5	0	-180	28	-743	-715	0.10	715	100	2.16	1.56
Oceania	118	119	1	-1	0	0	116	0	4.5	0	-2	3	-2	1	0.00	-1	0	3.79	3.71
Japan	338	295	-13	43	39	836	333	11	4.5	5	38	11	224	235	0.00	602	72	2.21	2.50
Annex 1	3972	3918	-1	53	18	6733	3930	8	4.5	20	11	86	425	511	0.00	6222	92	2.94	2.95
non-Annex1	3670	3670	0	0	0	0	3659	0	4.5	0	-11	2	-198	-196	0.00	47	100	0.66	0.66
World	7642	7589	-1	53	2	6733	7589	8	4.5	20	0	88	227	316	0.00	6269	93	1.10	1.10

Impact of the participation:

Table C.6 US-re-entry: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the A1 scenario (reference) (MAC-WorldScan, CDM-10%, TAC: 20%).

	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
REGIONS	Ref-erence	Target	Reduc-tion	Burden	MAC	Costs	Emis-sions	Dom./ Total	MAC	Dom Act	Trade	Dom costs	Trade costs	Total costs	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	124	-19	29	50	727	136	59	29.4	17	12	254	482	735	-0.09	-8	-1	3.71	4.07
USA	1739	1285	-26	454	83	17756	1563	39	29.4	176	279	2583	10418	13001	-0.11	4755	27	4.24	5.16
OECD Europe	1088	828	-24	260	96	11252	994	36	29.4	94	166	1381	6293	7674	-0.06	3578	32	2.04	2.45
Eastern Europe	318	304	-4	13	8	53	278	100	29.4	13	-27	481	-655	-174	0.03	227	427	2.45	2.24
Former USSR	549	818	49	-269	0	0	437	0	29.4	0	-381	1378	-10820	-9442	1.17	9442	100	2.70	1.44
Oceania	124	119	-3	4	9	19	112	100	29.4	4	-8	151	-171	-21	0.00	40	206	3.81	3.57
Japan	372	295	-21	77	66	2432	335	47	29.4	36	41	536	1553	2089	-0.03	343	14	2.21	2.52
Annex 1	4343	3773	-13	570	57	32240	3855	41	29.4	341	82	6764	7099	13863	-0.04	18377	57	2.83	2.89
non-Annex1	4141	4141	0	0	0	0	4059	0	29.4	0	-82	101	-3878	-3778	0.03	2313	100	0.75	0.73
World	8483	7914	-7	570	1	32240	7914	41	29.4	341	0	6865	3221	10085	-0.02	20690	64	1.15	1.15

Table C.7 Inclusion of Kazakhstan: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the A1 scenario (reference) (MAC-WorldScan, CDM-10%, TAC: 20%).

	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
REGIONS	Ref-erence	Target	Reduc-tion	Burden	MAC	Costs	Emis-sions	Dom./ Total	MAC	Dom Act	Trade	Dom costs	Trade costs	Total costs	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	124	-19	29	50	727	150	11	5.7	3	26	9	189	198	-0.02	529	73	3.71	4.49
USA	1739	1739	0	0	0	0	1739	0	5.7	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	828	-24	260	96	11252	1070	7	5.7	18	242	51	1739	1791	-0.01	9461	84	2.04	2.64
Eastern Europe	318	304	-4	13	8	53	308	72	5.7	10	4	27	51	79	-0.01	-26	-48	2.45	2.48
Former USSR	634	937	48	-303	0	0	609	0	5.7	0	-328	59	-1796	-1736	0.22	1736	100	3.09	2.01
Oceania	124	119	-3	4	9	19	121	63	5.7	3	2	8	21	29	0.00	-10	-50	3.81	3.86
Japan	372	295	-21	77	66	2432	365	9	5.7	7	70	20	503	523	-0.01	1909	79	2.21	2.74
Annex 1	4427	4346	-2	81	25	14484	4362	11	5.7	41	16	175	708	883	0.00	13601	94	3.26	3.27
non-Annex1	4056	4056	0	0	0	0	4041	0	5.7	0	-16	4	-278	-274	0.00	85	100	0.73	0.73
World	8483	8402	-1	81	1	14484	8402	11	5.7	41	0	179	430	609	0.00	13685	94	1.22	1.22

Impact of the marginal abatement curve:

Table C.8 MAC curve of TIMER: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the MAC-TIMER (reference) (Scenario: A1B, CDM-10%, TAC: 20%).

	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
REGIONS	Ref-erence	Target	Reduc-tion	Burden	MAC	Costs	Emis-sions	Dom./ Total	MAC	Dom Act	Trade	Dom costs	Trade costs	Total costs	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	124	-19	29	197	3147	151	6	16.0	2	27	16	558	574	-0.07	2572	82	3.71	4.53
USA	1739	1739	0	0	0	0	1739	0	16.0	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	828	-24	260	245	32439	1078	4	16.0	11	250	108	5030	5138	-0.04	27302	84	2.04	2.66
Eastern Europe	318	304	-4	13	5	35	292	100	16.0	13	-13	133	-134	-1	0.00	36	103	2.45	2.35
Former USSR	549	818	49	-269	0	0	517	0	16.0	0	-301	176	-4611	-4435	0.55	4435	100	2.70	1.71
Oceania	124	119	-3	4	19	41	120	84	16.0	4	1	29	43	72	-0.01	-31	-75	3.81	3.84
Japan	372	295	-21	77	164	6519	366	8	16.0	6	71	62	1430	1492	-0.02	5027	77	2.21	2.75
Annex 1	4343	4227	-3	115	66	42180	4262	9	16.0	35	35	524	2316	2840	-0.01	39340	93	3.17	3.20
non-Annex1	4141	4141	0	0	0	0	4106	0	16.0	0	-35	18	-1091	-1073	0.01	540	100	0.75	0.74
World	8483	8368	-1	115	3	42180	8368	9	16.0	35	0	542	1225	1767	0.00	39881	95	1.21	1.21

Table C.9 MAC curve of POLES: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the MAC-Poles (Scenario: A1B, CDM-10%, TAC: 20%).

	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
REGIONS	Ref-erence	Target	Reduc-tion	Burden	MAC	Costs	Emis-sions	Dom./Total	MAC	Dom Act	Trade	Dom costs	Trade costs	Total costs	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	124	-19	29	140	1829	148	18	17.0	5	24	41	526	567	-0.07	1262	69	3.71	4.43
USA	1739	1739	0	0	0	0	1739	0	17.0	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	828	-24	260	96	11252	1035	20	16.7	53	207	447	4375	4823	-0.04	6429	57	2.04	2.55
Eastern Europe	318	304	-4	13	8	53	295	100	16.7	13	9	149	225	374	-0.06	-321	-603	2.45	2.38
Former USSR	549	711	29	-161	0	0	486	0	16.7	0	-225	442	-3523	-3081	0.38	3081	100	2.35	1.60
Oceania	124	119	-3	4	9	19	117	100	16.7	4	3	50	74	125	-0.02	-105	-542	3.81	3.73
Japan	372	295	-21	77	66	2432	351	27	16.7	21	56	173	1195	1368	-0.02	1064	44	2.21	2.64
Annex 1	4343	4120	-5	223	26	14484	4166	26	16.7	101	70	1344	2769	4113	-0.01	10371	72	3.09	3.12
non-Annex1	4141	4141	0	0	0	0	4094	0	16.7	0	-46	32	-1328	-1295	0.01	742	100	0.75	0.74
World	8483	8260	-3	223	1	14484	8260	26	16.7	101	23	1376	1441	2817	-0.01	11113	77	1.20	1.20

Impact of the sinks:

Table C.10 Low use of sinks: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the MAC-Poles (Scenario: A1B, CDM-10%, TAC: 20%).

	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
REGIONS	Ref-erence	Target	Reduc-tion	Burden	MAC	Costs	Emis-sions	Dom./Total	MAC	Dom Act	Trade	Dom costs	Trade costs	Total costs	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	109	-29	44	87	1712	145	18	13.6	8	36	54	598	652	-0.08	1060	62	3.27	4.35
USA	1739	1739	0	0	0	0	1739	0	13.6	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	818	-25	271	102	12269	1045	16	13.6	43	227	295	3798	4093	-0.03	8176	67	2.02	2.58
Eastern Europe	318	299	-6	19	11	107	298	100	13.6	19	0	113	37	150	-0.02	-43	-40	2.41	2.40
Former USSR	549	797	45	-247	0	0	498	0	13.6	0	-299	292	-3962	-3670	0.46	3670	100	2.63	1.64
Oceania	124	117	-5	6	13	43	117	99	13.6	6	0	42	14	56	-0.01	-13	-30	3.75	3.75
Japan	372	281	-24	90	83	3423	355	19	13.6	17	74	114	1227	1342	-0.02	2081	61	2.11	2.67
Annex 1	4343	4160	-4	183	29	17554	4198	22	13.6	93	39	910	1712	2622	-0.01	14932	85	3.12	3.15
non-Annex1	4141	4141	0	0	0	0	4103	0	13.6	0	-38	21	-739	-718	0.01	492	100	0.75	0.74
World	8483	8300	-2	183	1	17554	8300	22	13.6	93	1	932	973	1905	0.00	15424	88	1.20	1.20

Table C.11 High use of sinks: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the MAC-Poles (Scenario: A1B, CDM-10%, TAC: 20%).

	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
REGIONS	Ref-erence	Target	Reduc-tion	Burden	MAC	Costs	Emis-sions	Dom./Total	MAC	Dom Act	Trade	Dom costs	Trade costs	Total costs	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	129	-16	24	41	503	152	4	1.8	1	23	1	53	54	-0.01	449	89	3.86	4.56
USA	1739	1739	0	0	0	0	1739	0	1.8	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	846	-22	242	86	9572	1083	2	1.8	6	236	5	532	537	0.00	9035	94	2.09	2.67
Eastern Europe	318	331	4	-14	0	0	315	0	1.8	0	-16	2	-21	-19	0.00	19	100	2.67	2.54
Former USSR	549	850	55	-301	0	0	543	0	1.8	0	-308	5	-525	-520	0.06	520	100	2.81	1.79
Oceania	124	128	3	-4	0	0	123	0	1.8	0	-5	1	-5	-5	0.00	5	100	4.08	3.93
Japan	372	296	-20	76	65	2363	370	3	1.8	2	74	2	166	167	0.00	2196	93	2.22	2.78
Annex 1	4343	4319	-1	24	23	12438	4324	3	1.8	9	5	15	199	215	0.00	12224	98	3.24	3.24
non-Annex1	4141	4141	0	0	0	0	4136	0	1.8	0	-5	0	-68	-68	0.00	9	100	0.75	0.74
World	8483	8460	0	24	1	12438	8460	3	1.8	9	0	16	131	147	0.00	12232	98	1.23	1.23

Impact of the CDM accessibility:

Table C.12 No CDM accessibility: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the MAC-Poles (Scenario: A1B, CDM-0%, TAC: 20%).

REGIONS	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
	Ref-erence MtC	Target MtC	Reduc-tion %	Burden MtC	MAC US$/tC	Costs MUS$	Emis-sions MtC	Dom./ Total %	MAC US$/tC	Dom Act MtC	Trade MtC	Dom costs MUS$	Trade costs MUS$	Total costs MUS$	%-GDP %	Gains trade MUS$	% %	Target tC/cap	Emission tC/cap
Canada	153	124	-19	29	50	727	147	22	11.0	6	23	35	323	358	-0.04	370	51	3.71	4.40
USA	1739	1739	0	0	0	0	1739	0	11.0	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	828	-24	260	96	11252	1054	13	11.0	35	226	191	3126	3317	-0.03	7935	71	2.04	2.60
Eastern Europe	318	304	-4	13	8	53	303	100	11.0	13	1	63	62	124	-0.02	-71	-134	2.45	2.44
Former USSR	549	818	49	-269	0	0	508	0	11.0	0	-311	191	-3261	-3070	0.38	3070	100	2.70	1.68
Oceania	124	119	-3	4	9	19	119	100	11.0	4	0	23	24	47	-0.01	-27	-140	3.81	3.80
Japan	372	295	-21	77	66	2432	358	18	11.0	13	64	74	882	956	-0.02	1476	61	2.21	2.69
Annex 1	4343	4227	-3	115	26	14484	4227	19	11.0	72	3	576	1155	1731	-0.01	12752	88	3.17	3.17
non-Annex1	4141	4141	0	0	0	0	4141	0	11.0	0	0	0	-365	-365	0.00	0	0	0.75	0.75
World	8483	8368	-1	115	1	14484	8368	19	11.0	72	3	576	790	1366	0.00	12752	88	1.21	1.21

Table C.13 30% CDM accessibility: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the MAC-Poles (Scenario: A1B, CDM-30%, TAC: 20%).

REGIONS	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
	Ref-erence MtC	Target MtC	Reduc-tion %	Burden MtC	MAC US$/tC	Costs MUS$	Emis-sions MtC	Dom./ Total %	MAC US$/tC	Dom Act MtC	Trade MtC	Dom costs MUS$	Trade costs MUS$	Total costs MUS$	%-GDP %	Gains trade MUS$	% %	Target tC/cap	Emission tC/cap
Canada	153	124	-19	29	50	727	150	12	6.0	3	26	10	197	207	-0.02	520	71	3.71	4.48
USA	1739	1739	0	0	0	0	1739	0	6.0	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	828	-24	260	96	11252	1069	7	6.0	19	241	57	1820	1876	-0.02	9376	83	2.04	2.64
Eastern Europe	318	304	-4	13	8	53	308	75	6.0	10	3	30	51	81	-0.01	-28	-52	2.45	2.48
Former USSR	549	818	49	-269	0	0	527	0	6.0	0	-292	57	-1666	-1609	0.20	1609	100	2.70	1.74
Oceania	124	119	-3	4	9	19	121	66	6.0	3	1	8	22	30	0.00	-11	-54	3.81	3.86
Japan	372	295	-21	77	66	2432	364	10	6.0	7	70	22	525	547	-0.01	1885	77	2.21	2.74
Annex 1	4343	4227	-3	115	26	14484	4277	11	6.0	43	50	184	948	1132	0.00	13352	92	3.17	3.21
non-Annex1	4141	4141	0	0	0	0	4091	0	6.0	0	-50	37	-499	-461	0.00	262	100	0.75	0.74
World	8483	8368	-1	115	1	14484	8368	11	6.0	43	0	222	449	671	0.00	13614	94	1.21	1.21

Impact of the Transaction costs:

Table C.14 30% Transaction costs: Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the MAC-Poles (Scenario: A1B, CDM-10%, TAC: 30%).

REGIONS	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
	Ref-erence MtC	Target MtC	Reduc-tion %	Burden MtC	MAC US$/tC	Costs MUS$	Emis-sions MtC	Dom./ Total %	MAC US$/tC	Dom Act MtC	Trade MtC	Dom costs MUS$	Trade costs MUS$	Total costs MUS$	%-GDP %	Gains trade MUS$	% %	Target tC/cap	Emission tC/cap
Canada	153	124	-19	29	50	727	148	18	8.9	5	24	23	297	319	-0.04	408	56	3.71	4.43
USA	1739	1739	0	0	0	0	1739	0	8.9	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	828	-24	260	96	11252	1060	11	8.9	28	232	124	2814	2938	-0.02	8314	74	2.04	2.61
Eastern Europe	318	304	-4	13	8	53	304	100	8.9	13	0	53	43	96	-0.01	-43	-81	2.45	2.45
Former USSR	549	818	49	-269	0	0	518	0	8.9	0	-300	106	-2531	-2425	0.30	2425	100	2.70	1.71
Oceania	124	119	-3	4	9	19	119	97	8.9	4	0	18	19	37	-0.01	-18	-93	3.81	3.82
Japan	372	295	-21	77	66	2432	361	14	8.9	11	66	48	802	850	-0.01	1582	65	2.21	2.71
Annex 1	4343	4227	-3	115	26	14484	4250	16	8.9	62	23	373	1444	1816	-0.01	12667	87	3.17	3.19
non-Annex1	4141	4141	0	0	0	0	4118	0	8.9	0	-23	8	-497	-489	0.00	194	100	0.75	0.74
World	8483	8368	-1	115	1	14484	8368	16	8.9	62	0	380	947	1327	0.00	12862	89	1.21	1.21

Table C.15 10% Transaction costs : Emissions trading and abatement costs for the Bonn-Marrakesh Agreement for the MAC-Poles (Scenario: A1B, CDM-10%, TAC: 10%).

REGIONS	NO TRADE						TRADE									GAINS TRADE		PER CAPITA	
	Ref-erence	Target	Reduc-tion	Burden	MAC	Costs	Emis-sions	Dom./ Total	MAC	Dom Act	Trade	Dom costs	Trade costs	Total costs	%-GDP	Gains trade	%	Target	Emission
	MtC	MtC	%	MtC	US$/tC	MUS$	MtC	%	US$/tC	MtC	MtC	MUS$	MUS$	MUS$	%	MUS$	%	tC/cap	tC/cap
Canada	153	124	-19	29	50	727	150	12	6.0	3	26	10	197	207	-0.02	520	71	3.71	4.48
USA	1739	1739	0	0	0	0	1739	0	6.0	0	0	0	0	0	0.00	0	0	5.74	5.74
OECD Europe	1088	828	-24	260	96	11252	1069	7	6.0	19	241	57	1820	1876	-0.02	9376	83	2.04	2.64
Eastern Europe	318	304	-4	13	8	53	308	75	6.0	10	3	30	51	81	-0.01	-28	-52	2.45	2.48
Former USSR	549	818	49	-269	0	0	527	0	6.0	0	-292	57	-1666	-1609	0.20	1609	100	2.70	1.74
Oceania	124	119	-3	4	9	19	121	66	6.0	3	1	8	22	30	0.00	-11	-54	3.81	3.86
Japan	372	295	-21	77	66	2432	364	10	6.0	7	70	22	525	547	-0.01	1885	77	2.21	2.74
Annex 1	4343	4227	-3	115	26	14484	4277	11	6.0	43	50	184	948	1132	0.00	13352	92	3.17	3.21
non-Annex1	4141	4141	0	0	0	0	4091	0	6.0	0	-50	37	-499	-461	0.00	262	100	0.75	0.74
World	8483	8368	-1	115	1	14484	8368	11	6.0	43	0	222	449	671	0.00	13614	94	1.21	1.21

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