# Estimating the size of the potential market for all three flexibility mechanisms under the Kyoto Protocol

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**Abstract**

The Kyoto Protocol is the first international environmental agreement that sets legally binding greenhouse gas emissions targets and timetables for Annex I countries. It incorporates emissions trading and two project-based flexibility mechanisms, namely joint implementation and the clean development mechanism to help Annex I countries to meet their Kyoto targets at a lower overall cost. This paper aims to estimate the size of the potential market for all three flexibility mechanisms under the Kyoto Protocol over the first commitment period 2008-2012, both on the demand side and on the supply side. Taking the year 2010 as representative of the first commitment period and based on the national communications from 35 Annex I countries, the paper first estimates the potential demand in the greenhouse gas offset market. We show that for most of the OECD countries excluding the EU, their Kyoto targets are stringent than they appear at first glance. Then, the paper addresses supplementarity constraints and provides a quantitative assessment of the implications of the EU proposal for concrete ceilings on the use of flexibility mechanisms for the division of abatement actions at home and abroad. Our results suggest that although the aggregate allowed acquisitions for the Annex I countries as a whole in 2010 from all three flexibility mechanisms under the two alternatives are well below 50% of the difference between the projected baseline emissions and the target in 2010, the proposed restrictions to each Annex I country vary, in some case even substantially. Finally, using the 12-region's marginal abatement cost-based model, the paper estimates the contributions of three flexibility mechanisms to meet the total emissions reductions required of Annex I countries under the four trading scenarios, respectively. Our results clearly demonstrate that the fewer the restrictions on trading the gains from trading are greater. The gains are unevenly distributed, however, with Annex I countries that have the highest autarkic marginal abatement costs tending to benefit the most. With respect to non-Annex I countries, their net gains are highest when trading in hot air is not allowed. Because of a great deal of low-cost abatement opportunities available in the energy sectors of China and India and their sheer sizes of population, we found that the two countries account for about three-quarters of the total non-Annex I countries' exported permits to the Annex I regions.

**CONTENTS**

**Abbreviations**

| | |
|---|---|
| AIJ | Activities implemented jointly |
| BAU | Business-as-usual |
| CDM | Clean development mechanism |
| $CO_2$ | Carbon dioxide |
| EIA | Energy Information Administration, US Department of Energy |
| EPPA | Emissions Prediction and Policy Analysis model |
| EU | European Union |
| GHG | Greenhouse gases |
| G-Cubed | Global General Equilibrium Model |
| GREEN | GeneRal Equilibrium ENvironmental model |
| GTEM | Global Trade and Environment Model |
| IEA | International Energy Agency |
| IIASA | International Institute for Applied Systems Analysis, Laxenburg, Austria |
| IPCC | Intergovernmental Panel on Climate Change |
| JI | Joint implementation |
| JUSSCANNZ | Japan, the United States, Switzerland, Canada, Australia, Norway, New Zealand |
| MtC | Million tons of Carbon |
| OECD | Organisation for Economic Co-operation and Development |
| SGM | Second Generation Model |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WorldScan | WORLD model for SCenario ANalysis |

## 1. Introduction

In the face of a potentially serious global climate change problem, 158 countries reached an historical agreement on limiting greenhouse gas emissions in December 1997, Kyoto. While the United Nations Framework Convention on Climate Change (UNFCCC) signed at the Earth Summit in June 1992, committed Annex I countries (i.e., the OECD countries and countries with economies in transition. These countries have committed themselves to greenhouse gas emissions targets) to "aim" to stabilize emissions of carbon dioxide ($CO_2$) and other greenhouse gases at their 1990 levels by 2000, the so-called Kyoto Protocol goes further. It sets legally binding emissions targets for a basket of six greenhouse gases and timetables for these countries. Together, Annex I countries must reduce their emissions of six greenhouse gases by 5.2% below 1990 levels over the commitment period 2008-2012, with the European Union (EU), the United States and Japan required to reduce their emissions of such gases by 8%, 7% and 6% respectively (UNFCCC, 1997a). The Protocol will become effective once it is ratified by at least 55 parties whose $CO_2$ emissions represent at least 55% of the total from Annex I Parties in the year 1990.

Climate change is a global problem requiring a global response. Reflecting the underlying principle in Article 3.3 of the UNFCCC, which states "policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost", the Kyoto Protocol incorporates a variety of provisions for flexibility mechanisms through which the costs of abating emissions can be lowered. Article 6 authorizes the transfer or acquisition of "emission reduction units" (ERUs) from joint implementation (JI) projects among Annex I Parties. Article 12 establishes the so-called "clean development mechanism" (CDM). Through the mechanism, Annex I countries will be able to obtain the certified emission reductions (CERs) from clean development projects jointly implemented with non-Annex I countries (i.e., developing countries), and use them to count towards meeting their commitments under the Kyoto Protocol. In addition to the two project-based mechanisms, the Kyoto Protocol accepts the concept of emissions trading in principle, under which one Annex B (an annex to the Kyoto Protocol that lists the quantified emission limitation or reduction commitment per Party) country or its sub-national entities (e.g., companies, non-governmental organizations) would be allowed to purchase the rights to emit greenhouse gases (GHG) from other Annex B countries or their regulated entities that are able to cut GHG emissions below their assigned amounts or their targets. However, designing the rules and procedures governing these mechanisms has been deferred to subsequent conferences. One year later, after two weeks of intense debate at the fourth Conference of the Parties to the UNFCCC held in November 1998, Buenos Aires, delegates adopted the Buenos Aires Plan of Action, an ambitious two-year work programme intended to make the Kyoto Protocol operative (UNFCCC, 1999a). According to the Plan, decisions on rules governing these flexibility mechanisms are to be made in the year 2000 at the latest.

This paper aims to estimate the size of the potential market for all three flexibility mechanisms under the Kyoto Protocol over the first commitment period 2008-2012, both on the demand side and on the supply side. In so doing, this study takes the year 2010 as representative of the first commitment period, is based on Annex I countries' national communications to the UNFCCC, and covers all six greenhouse gases considered under the Protocol. As discussed earlier, the Protocol as it stands now leaves many questions, including rules governing three flexibility mechanisms, open. Without clear rules on how three flexibility mechanisms will be implemented in practice, any estimate will have to be tentative. With the observations in mind, Section 2 estimates the potential demand in the GHG offset market, based on compilation of the national communications from 35 Annex I countries. Given the great policy relevance to the ongoing negotiations on the overall issues of flexibility mechanisms, Section 3 addresses supplementarity constraints and provides a quantitative assessment of the implications of the EU proposal for concrete ceilings on the use of flexibility mechanisms for the division of abatement actions at home and abroad. Using the 12-region's marginal abatement cost-based model, Section 4 estimates how many of the emissions reductions required of Annex I countries will be met through domestic abatement actions, emissions trading and JI with other Annex I countries, and acquisitions of the certified CDM credits from non-Annex I countries under the four trading scenarios, respectively. To our knowledge, this is the first study to estimate the size of the potential market for Kyoto mechanisms and quantify the implications of the EU proposal on the basis of the individual national communications to the UNFCCC.

In writing the paper, we have taken a balanced approach combining the calculations with policy analysis in order to put the numbers into perspective and thus facilitate the understanding of what the numbers say.

Wherever necessary we have compared our estimates with those from a variety of economic modelling studies. Although not aimed to provide a completely rigorous explanation for the differences between these estimates, such a comparison will indicate the range of such estimates and identify the sources of the differences, thus providing the broad perspective on the issues examined. Finally, it should be pointed out that, although carbon sequestration by sinks may reduce GHG emissions at much lower costs than reducing GHG emissions from industrial activities and its potential is not negligible,[1] this study does not take sinks into account because of great uncertainties regarding this issue. We expect that the ongoing methodological work of the Intergovernmental Panel on Climate Change (IPCC) helps to reduce uncertainties by providing what sink enhancements can and cannot be assessed meaningfully.

**2. Potential Demand for the GHG Offsets in 2010**

Annex I countries under the United Nations Framework Convention on Climate Change are Australia, Austria, Belgium, Belarus, Bulgaria, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, the Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Kingdom, and the United States. The Kyoto Protocol to the UNFCCC sets differentiated emissions targets for these Annex I countries between 2008 and 2012, except for Belarus and Turkey, either of which has not ratified the UNFCCC. Thus, this study will cover all the above 35 Annex I countries with emissions targets.

Once the Protocol enters into force, the emissions targets will become legally binding. Because emissions are expected to continue to rise under the business-as-usual and because the emissions targets will not become binding until the first commitment period, the real reductions must thus be measured against their projected business-as-usual (BAU) or baseline emissions levels over the commitment period. So, the

[1] In the briefing on the Kyoto Protocol on Climate Change on 15 January 1998, the US State Department' assessment of the accounting of carbon-absorbing sinks could lower the US emissions target to 4% below 1990 levels in comparison with the target of 7% below 1990 levels.

mandated reductions from projected baseline emissions levels represent the potential demand in the GHG offset market. The question then arises: how big the size of the market on the demand side is?

### 2.1 The Size of the Potential GHG Offset Market on the Demand Side

Estimating the size of the GHG offset market involves three steps. The first step is to determine GHG emissions for each Annex I country in the base year. The base year refers to the year 1990 for all the Annex I countries, except for Bulgaria, Hungary, Poland and Romania. The decision 9/CP.2 allows the four countries to use base years other than 1990: Bulgaria and Romania use 1989 as their base year; Hungary uses the average emissions between 1985 and 1987; and Poland uses 1988 (UNFCCC, 1996). Because emissions were higher prior to 1990, these base year adjustments have given these four countries targets that are less stringent than suggested by Annex B. In accordance with the decision 9/CP.2, Annex I parties were required to submit their second national communications not later than 15 April 1998. At the third session of the Conference of the Parties, the Secretariat was requested to prepare a full compilation and synthesis of the second national communications from Annex I parties. With these information available at the web site of the UNFCCC Secretariat, the first step in essence involves gathering data on inventory of greenhouse gas emissions from the second national communications submitted by Annex I countries (or from an update of the second national communication in the case of the Netherlands, or from the first national communications in the cases of Lithuania, Slovenia and Ukraine) and the corresponding Secretariat's second compilation. Because many countries in the Eastern Europe and the former Soviet Union only provide aggregate emissions of $CO_2$, $CH_4$ and $N_2O$ in their inventories, their total GHG emissions in 1990 are estimated, assuming that the ratio of $CO_2$, $CH_4$ and $N_2O$ emissions to total GHG emissions for Ukraine is the same as the ratio for Russia Federation in 1990, and that the ratio for Bulgaria, Estonia, Hungary, Latvia, Lithuania, Romania, Slovakia and Slovenia is the same as for Czech Republic in 1996.

The second step is to determine the Kyoto target for each Annex I country in 2010. Annex B to the Kyoto Protocol specifies the allowed percentage change from its 1990 level for each Annex I country over the first commitment period 2008-2012. The emissions target is stated in terms of an average over the commitment period of five years, not in terms of a specific year. The multi-year compliance is designed to smooth out the effects of short-term events such as fluctuations in economic performance or certain extreme weather conditions, and to provide Annex I countries with additional flexibility in meeting their targets. This study takes the year 2010 as representative of the first commitment period. As set out in column 5 in Table 1, the emissions targets that are expressed as the percentages relative to the base year emissions levels vary among Annex I countries, particularly within the European Union following its internal burden sharing of the Kyoto commitments among its member countries. By multiplying each Annex I country's emissions in the base year by one plus its allowed percentage change from its base year emissions level, we can obtain the Kyoto target in 2010 for each Annex I country. As indicated at the bottom of column 5 in Table 1, the Kyoto commitments add up to a reduction of 5.2% below Annex I countries' base year emissions levels.

The third step in estimating the size of the GHG offset market on the demand side is to estimate baseline GHG emissions for each Annex I country over the commitment period. We have drawn projections for GHG emissions in 2010 from most Annex I countries' national communications to the UNFCCC. For Austria, Belgium, Estonia, France, Greece, Hungary, The Netherlands, Poland, Slovenia, and Ukraine whose estimates of aggregate GHG emissions in 2010 are not provided, refer to Appendix 1 for our rule of thumb estimates.

It should be pointed out that the data provided by Annex I countries' national communications and the emissions baselines derivations in Appendix 1 provide the basis for our preliminary estimates for the magnitude of the GHG emissions reductions required of Annex I countries under the Kyoto Protocol until Annex I countries provide more detailed information on their historical and projected emissions of all six greenhouse gases.

With this in mind, we can see that for most OECD countries, their Kyoto targets are stringent than they appear at first glance. As indicated in Table 1, emissions in most OECD countries were on a rising trajectory during the period 1990-96 and are expected to rise under the business-as-usual trends. Relative to their BAU scenarios, the targets imply a reduction of up to 28% for the United States, 23% for Japan, 19% for Canada, and 18% for Australia. For the OECD excluding the EU as a whole, its total GHG emissions in 2010 under the BAU scenario are expected to rise to 2714 million tons of carbon (MtC) equivalent, 25.6% above its allowed level. Table 2 summarizes the emissions targets expressed as percentages relative to baseline emissions in 2010 from a variety of economic modelling studies. Given the differences in the model structures and the baseline emissions paths, it is not surprising that results differ somewhat. Our projection based on compilation of the national communications for the US and Japan are slightly lower than those from economic modelling studies. This is partly because our projections cover all six greenhouse gases, whereas other economic modelling studies examined here, except for the SGM-based study of Edmonds *et al.* (1998), focus only on $CO_2$ emissions. Because emissions of other greenhouse gases but $CO_2$ can be cut at lower cost, it would be more cost-effective to cut other greenhouse gases than $CO_2$ emissions. Provided that the emissions target will be fulfilled by means of either of six greenhouse gases as allowed under the Protocol, not surprisingly, less $CO_2$ emissions need to be cut than if the required emissions reductions need to be fulfilled via $CO_2$ alone. Nevertheless, despite these differences across studies, the insights that such OECD countries as the US and Japan face the large emissions gaps between their emissions targets and the baseline emissions in 2010 appear robust.

Regarding to the European Union, however, there is a sharp difference between other economic modelling studies and our projection based on compilation of the national communications. On the one hand, other economic studies project that the EU faces a large emissions gap as the US and Japan do. On the other hand, our results indicate that there is no sharp discrepancy between the Kyoto targets and the official projections of baseline GHG emissions in 2010 by all the EU member countries, except for the Netherlands that has a large gap to make up the difference between its reduction target and projected emissions levels in 2010. For the EU as a whole, its total GHG emissions in 2010 under the BAU scenario are expected to rise to 1096 MtC equivalent, 2.6% higher than its allowed level. There are at least three reasons for the low EU baseline projections. The first reason is internal burden sharing of the Kyoto commitments among the member countries. The 15 member countries of the EU are each listed with an 8% reduction from 1990 levels in Annex B to the Protocol. In June 1998, the EU Council reached an agreement under which the commitments are redistributed among its member countries under the bubble provision as specified in Article 4 of the Protocol. This will now serve as the basis of EU ratification and the redefined targets in Table 1 will become the "quantified emission limitation and reduction commitments" for each EU member country under the Protocol. Comparing the differentiated targets with the common 8% reduction commitments, we can see that the redistribution of the commitments has allocated more assigned amounts to the countries, whose emissions are expected to rise fast, than their allowed levels under the Protocol. The second reason is related to what is meant by business-as-usual projections. The baseline projections by economic modelling studies do not include the impacts of energy policies that are currently being either implemented or negotiated in response to climate change. By contrast, the baselines projected by the EU member countries might have already incorporated the intent to limit GHG emissions. By eliminating some projects that would have been carried out anyway and/or subtracting emissions induced by energy subsidies and other market distortions, the EU comes out the baseline projections close to the targets. The third reason is related to the choice of base year. The UNFCCC has used 1990 as the base year. During the period 1990-96, $CO_2$ emissions rose by 8.4% for the United States, by 14.3% for Japan, and by 9.5% for Australia, whereas the EU $CO_2$ emissions rose only by 0.9% (Jefferson, 1997). During the negotiations leading up to Kyoto, there was some discussion of moving forward the base year for all countries to 1995. In the end, efforts to make such a change failed, although a 1995 base year was accepted for the three trace industrial gases whose emissions comprise only a small share of total greenhouse gas emissions based on the 100 year global warming potentials for greenhouse gases. The EU high emissions in 1990 base year, combined with expectation for modest growth over the projection period, would put the EU projected emissions in 2010 close to its target.

The situation in the former Soviet Union and Eastern Europe is quite different. The economic transition led to a large decline in emissions as economies contracted and energy markets were deregulated since the collapse of the Soviet Union. As indicated in Table 1, by 1995 GHG emissions in these countries had declined to 20-46% below their base year levels. Although economies are projected to begin recovering during the period under review, emissions in most countries with economies in transition are expected to remain below their base year levels. For the bloc as a whole, its total GHG emissions in 2010 under the

BAU scenario are expected to be 1389 MtC equivalent, 4.5% below its base year level. This leads to the so-called hot air problem, an issue to be discussed later.

When an Annex I country is allocated assigned amounts under the Kyoto Protocol that are below its anticipated emissions in 2010, it has to make up the difference in order to meet its Kyoto target. The difference represents the country's maximum potential demand for GHG offsets  By adding up the demand from the countries whose emissions targets are below their business-as-usual emissions, the aggregate magnitude of emissions reductions required of Annex I countries, namely, maximum potential demand for GHG offsets, is estimated to be 620.6 MtC equivalent in 2010. How the needed reductions will be met depends on the extent to which the Kyoto mechanisms will be allowed to contribute to meet the Kyoto targets and the ways the hot air problem will be tackled.

**Table 1 Annex I Countries' GHG Emissions in Base Year, Kyoto Targets, Projected Baseline Emissions, Emissions Reductions Required and the Size of Hot Air in 2010**

| | 1990 | 1996 | Kyoto target in 2010 | | Projected emissions in 2010 | | Emissions reductions required in 2010 (MtC) | Hot air in 2010 (MtC) |
|---|---|---|---|---|---|---|---|---|
| | Emissions (MtC) | Change from 1990 levels (%) | Emissions (MtC) | Change from 1990 levels (%) | Emissions (MtC) | Change from Kyoto target (%) | | |
| **Non-EU&EIT Annex I Countries** | **2298.1** | | **2161.9** | | **2714.3** | **25.6** | | |
| Australia | 113.3 | 7 | 122.4 | 8 | 144.1 | 17.8 | 21.7 | |
| Canada | 163.0 | 12 | 153.2 | -6 | 182.4 | 19.1 | 29.2 | |
| Iceland | 0.8 | -4[a] | 0.9 | 10 | 1.0 | 11.1 | 0.1 | |
| Japan | 337.2 | 11[a] | 317.0 | -6 | 388.2 | 22.5 | 71.2 | |
| New Zealand | 19.8 | 3 | 19.8 | 0 | 22.9 | 15.7 | 3.1 | |
| Norway | 15.0 | 7 | 15.2 | 1 | 17.3 | 13.8 | 2.1 | |
| Switzerland | 14.6 | 0[a] | 13.4 | -8 | 14.5 | 8.2 | 1.1 | |
| United States | 1634.4 | 9 | 1520.0 | -7 | 1943.9 | 27.9 | 423.9 | |
| **European Union** | **1159.5** | | **1068.0** | | **1095.9** | **2.6** | | |
| Austria | 21.6 | 0.5[a] | 18.8 | -13 | 20.3 | 8.5 | 1.6 | |
| Belgium | 37.9 | 10 | 35.1 | -7.5 | 41.6 | 18.5 | 6.5 | |
| Denmark | 19.6 | 10[a] | 15.5 | -21 | 16.6 | 7.1 | 1.1 | |
| Finland | 19.8 | 7 | 19.8 | 0 | 18.5 | -6.6 | | 1.3 |
| France | 151.9 | 1 | 151.9 | 0 | 152.5 | 0.4 | 0.6 | |
| Germany | 329.5 | -10 | 260.3 | -21 | 266.9 | 2.5 | 6.6 | |
| Greece | 28.7 | 9 | 35.9 | 25 | 32.8 | 14.3 | | 3.1 |
| Ireland | 15.5 | 5 | 17.5 | 13 | 18.1 | 3.4 | 0.6 | |
| Italy | 145.2 | 2[a] | 135.8 | -6.5 | 129.6 | -4.6 | | 6.2 |
| Luxembourg | 3.7 | -24[a] | 2.7 | -28 | 1.8 | -33.3 | | 0.9 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Netherlands | 60.8 | 6[a] | 57.2 | -6 | 70.6 | 23.4 | 13.4 | |
| Portugal | 18.6 | 6[b] | 23.6 | 27 | 22.4 | -5.1 | | 1.2 |
| Spain | 82.1 | 8[a] | 94.4 | 15 | 98.6 | 4.4 | 4.2 | |
| Sweden | 18.1 | 4[b] | 18.8 | 4 | 20.4 | 8.5 | 1.6 | |
| United Kingdom | 206.5 | -5 | 180.7 | -12.5 | 185.1 | 2.4 | 4.4 | |
| **Former Soviet Union** | **1113.5** | | **1110.7** | | **1032.2** | **-7.1** | | |
| Estonia | 11.1 | -43 | 10.2 | -8 | 5.5 | -46.1 | | 4.7 |
| Latvia | 9.7 | -46[a] | 8.9 | -8 | 5.5 | -38.2 | | 3.4 |
| Lithuania | 14.0 | n.a.[c] | 12.9 | -8 | 13.8 | 7.0 | 0.9 | |
| Russia | 828.4 | -31[b] | 828.4 | 0 | 793.4 | -4.2 | | 35.0 |
| Ukraine | 250.3 | n.a.[c] | 250.3 | 0 | 212.0 | -15.3 | | 38.3 |
| **Eastern Europe** | **368.4** | | **342.5** | | **358.3** | **4.6** | | |
| Bulgaria | 37.1 | -36[a] | 34.1 | -8 | 37.8 | 10.9 | 3.7 | |
| Czech Republic | 52.4 | -21[a] | 48.2 | -8 | 52.9 | 9.8 | 4.7 | |
| Hungary | 27.8 | -24[a] | 26.1 | -6 | 28.2 | 8.0 | 2.1 | |
| Poland | 153.8 | -22[b] | 144.6 | -6 | 160.3 | 10.9 | 15.7 | |
| Romania | 72.2 | -38[b] | 66.4 | -8 | 55.6 | -16.3 | | 10.8 |
| Slovakia | 19.9 | -21[a] | 18.3 | -8 | 18.2 | -0.5 | | 0.1 |
| Slovenia | 5.2 | n.a.[c] | 4.8 | -8 | 5.3 | 10.4 | 0.5 | |
| **Total** | **4939.5** | | **4683.1** | **-5.2** | **5198.7** | **11.0** | **620.6** | **105.0** |

[a] The figure in 1995; [b] The figure in 1994; [c] n.a. = not available.
*Sources:* See Text; Austria (1998); CEC (1999); Estonia (1998); Greece (1997); UNFCCC (1997a, 1998a, 1999b); VROM (1998); Own calculations.

**Table 2 The Kyoto Targets as Percentage Changes Relative to Baseline Emissions in 2010**

| | United States | Western Europe | Japan | Former Soviet Union | Eastern Europe |
|---|---|---|---|---|---|
| Böhringer | -28 | -14 | -26 | 48 | n.a.[b] |
| EIA | -30 | -16 | -20 | 49 | 18 |
| EPPA | -31 | -29 | -34 | 14 | -30 |
| G-Cubed | -30 | -33 | -21 | n.a.[b] | n.a.[b] |
| GREEN | -36 | -22 | -32 | 4 | 0 |
| GTEM[a] | -28 | -25 | -22 | 1.6 | -24 |
| SGM | -29 | -14 | -33 | 26 | n.a.[b] |
| WorldScan | -28 | -29 | -22 | 1 | -10 |
| **Our projection** | -22 | -2 | -18 | 8 | -4 |

[a] The figure for Western Europe is for Western Europe, Canada and New Zealand as a whole.
[b] n.a. = not available.
*Sources:* Böhringer (1999); Edmonds *et al.* (1998); Ellerman and Decaux (1998); EIA (1999); Gielen and Koopmans (1998); McKibbin *et al.* (1999); OECD (1999); Tulpulé *et al.* (1998); Own calculations.

### 2.2 The Size of Hot Air

In contrast with countries whose emissions targets are well below their business-as-usual emissions, some countries are allocated assigned amounts under the Kyoto Protocol that exceed their anticipated emissions requirements even in the absence of any limitation. When emissions trading were allowed, these countries would be able to trade these excess emissions to other countries, thus creating the hot air that would otherwise have not occurred. Because the transfer of the hot air does not represent any real emissions reductions by the selling countries, allowing to acquire the surplus from the selling countries to meet the buying countries' commitments makes the total emissions higher than what would be in the absence of emissions trading, although not above the aggregate Kyoto targets.

As indicated in Table 1, the hot air problem is particularly acute in Russia and Ukraine whose emissions are expected to remain below their 1990 levels until 2010. But the exact amount of hot air is by its nature uncertain. This depends particularly on expectations for economic recovery and developments in the energy sector in Russia and Ukraine. Because there is no agreement among experts on these factors, estimates of the size of hot air from a wide range of studies, as summarized in Table 3, vary. For example, the official Russian projections are based on optimistic expectations for economic growth and continued use of outdated technology up to the year 2010. This will inevitably result in emissions rising back towards its base year levels. As indicated in Table 2, the total GHG emissions in 2010 are expected to be 4.2% lower than that in 1990, and the size of hot air amounts to 35 MtC equivalent accordingly. On the other hand, other studies seem less optimistic about economic recovering than the official expectations. Thus, they project the larger amount of hot air. The in-depth review team estimates that by 2010 the total $CO_2$ emissions in Russia are expected to be 10% lower than that in 1990, and the size of hot air amounts to 65 MtC accordingly (UNFCCC, 1997b). Among the economic modelling studies examined in Table 3, the estimate based on the Emissions Prediction and Policy Analysis (EPPA) model is at the lowest end. It projects that the size of hot air from the Former Soviet Union amounts to 111 MtC (Ellerman and Decaux, 1998). At the highest end of estimates of the magnitude of hot air is one derived from the Energy Information Administration (1999). It puts the estimate at 374 MtC, with 324 MtC from the Former Soviet Union.

**Table 3 Estimates of the Amount of Hot Air in 2010 (MtC equivalent)**

| | National communications | EPPA[a] | GREEN[a] | IEA[a] | SGM | IIASA[a] | EIA[a] |
|---|---|---|---|---|---|---|---|
| Former Soviet Union | 81 | 111 | 130 | n.a.[b] | 247 | 275 | 324 |
| Eastern Europe | 11 | 0 | 0 | n.a.[b] | 42 | 69 | 50 |
| Total | 92 | 111 | 130 | 156 | 289 | 344 | 374 |

[a] Only for $CO_2$ emissions; [b] n.a. = not available.
*Sources:* Edmonds *et al.* (1998); Ellerman and Decaux (1998); EIA (1999); IEA (1998); OECD (1999); UNFCCC (1997a, 1998a, 1999b); Victor *et al.* (1998); Own calculations.

From Table 3, it can be seen that even if hot air is assumed to be used to the full extent, none of the above estimates indicates that the size of hot air is sufficiently large that all of the advanced Annex I countries can comply with their Kyoto targets merely through acquisitions of hot air. Thus, the remaining demand has to be met through domestic actions and three flexibility mechanisms.

## 3. Supplementarity Constraints: A Quantitative Analysis of the EU Proposed Concrete Ceilings

The demand for GHG offsets depends also on the extent to which the Kyoto mechanisms will be allowed to contribute to meet the Kyoto targets. Under the Kyoto Protocol, each of the Articles defining the three flexibility mechanisms carries wording that the use of the mechanism must be supplemental to domestic actions. Article 6 state that emission reduction units from joint implementation projects shall be "supplemental to domestic actions" for the purpose of meeting quantified emission limitation or reduction commitments. Article 12 states that Annex I Parties may use the certified emission reductions from CDM projects to contribute to compliance with "part of their quantified emission limitation and reduction commitments", while Article 17 states that emissions trading shall be "supplemental to domestic actions" for the purpose of meeting quantified emission limitation or reduction commitments. Interpretations of these supplementarity provisions are still open to question. At one extreme, the supplementarity clause could be interpreted as simply meaning that domestic actions should provide the main means of meeting Annex I countries' commitments, so that any action abroad would be additional to domestic actions. At the other extreme, it could be interpreted as meaning that any action abroad will be supplemental to whatever domestic actions are taken (Grubb *et al.*, 1999; Lanchbery, 1998; OECD, 1999). Then the implication is that one Annex I country could use the flexibility mechanisms to meet its Kyoto commitments as much as it wished.

Whether the supplementarity clauses will be translated into a concrete ceiling remains to be seen. If this were a case, supplementarity should be an overall ceiling collectively imposed to all three flexibility mechanisms (Haites, 1998a; European Union, 1999). Put another way, the issue of supplementarity should be addressed together for all three flexible mechanisms. There are at least two reasons for this view.

Over-restrictions on one mechanism, such as emissions trading, could lead to a shift to another mechanism, such as the CDM. Unless the Kyoto Protocol is further amended to impose a specific ceiling for each mechanism, it seems to be lack of legal basis to reject the legitimate claim that the three mechanisms are substitutes in terms of complying with national emissions commitments. In addition, given that it is more costly to establish and monitor heterogeneous CDM projects than homogenous permits, such a shift away from trading to the CDM would provide few incentive for developing countries to take on emissions commitments, a prerequisite for engaging in emissions trading. Without the emissions targets for developing countries, while the CDM can provide an incentive for firms to invest in energy efficient technologies in developing countries, it would likely occur on a smaller scale than what would be anticipated under an emissions target with effective international trading (US Administration, 1998).

How should a concrete ceiling on the use of the three flexible mechanisms be defined? So far there have many proposals. The most representative is the EU proposal. Documented as the Community Strategy on Climate Change (European Union, 1999), the EU proposal calls for the limits on both buying countries and selling countries. For a buying country, the maximum purchase for GHG emission reduction units via all three flexible mechanisms can not exceed the higher of the following two alternatives:

- 5% of {(its base year emissions multiplied by 5 + its assigned amount)/2} or
- 50% of the difference between its annual actual emissions in any year between 1994 and 2002, multiplied by 5, and its assigned amount.

The difference between the two alternatives is that the first is based mainly on the Kyoto Protocol's quantified emission limitation or reduction commitments, whereas the second takes the actual emission reduction effort of buying countries as its basis (*Joint Implementation Quarterly*, June 1999). One reason behind the two alternatives is that industrialized countries whose emissions are already very high on a per capita basis should take the lead in reducing their own emissions so that developing countries are encouraged to follow suit and take on emissions commits at a later date. Another reason has been to urge Annex I countries to stimulate technical innovation domestically by raising marginal abatement costs of buying countries, although it is unclear to what extent a stimulus of increased technical innovation in buying countries would remain. Motivated by alleviating the concern about hot air, the EU proposal also sets the rule for a selling country. Similar to the first alternative for a buying country, the EU proposal specifies that the maximum allowed sale for GHG emission reduction units via all three flexible mechanisms can not exceed the amount calculated by: 5% of {(its base year emissions multiplied by 5 + its assigned amount)/2}.

How severe are the EU proposed concrete ceilings? In what follows, we attempt to quantify the implications of the restrictions on both buying and selling countries.

Table 4 gives each Annex I country's GHG emissions in base year, the Kyoto target and the baseline GHG emissions in 2010, and the difference between the baseline emissions and the target. Section 2 provides the details of the derivation of these data. Applying the first alternative to each Annex I country, we have calculated the maximum allowed acquisitions in 2010 for those Annex I countries whose emissions targets in 2010 are below their projected business-as-usual emissions. As indicated in Table 4, the aggregate magnitude of acquisitions in 2010 from all three flexibility mechanisms amounts to 170.4 MtC. Expressed as a percentage of the difference between the projected baseline emissions and the targets, this number, on average, is calculated to be 27.5% under the first alternative. For the so-called JUSSCANNZ countries (Japan, the United States, Switzerland, Canada, Australia, Norway, New Zealand), an umbrella group that meets daily during the international climate change negotiations to exchange information and discuss substance/strategy on issues where there is common ground, the aggregate magnitude of acquisitions in 2010 from all three flexibility mechanisms amounts to 111.5 MtC. Expressed as a percentage of the difference between the projected baseline emissions and the targets, this number, on average, is 20.2% under the first alternative. For the EU as a whole, the corresponding figure in 2010 is 110.4%.

In order to quantify the implications of the second alternative, we need to find the highest annual GHG emissions in any year between 1994 and 2002. To this end, we first examine the emissions data over the period between the base year and 2005, which are documented at the second national communications submitted by Annex I countries (or from the first national communications, in the case of Lithuania and Slovenia) and the corresponding Secretariat's second compilation. We found that the highest GHG emissions appeared in 1994 for Lithuania, in 1995 for Austria, in 1996 for Belgium, Denmark, France, Germany, Greece, Sweden, and United Kingdom. For those Annex I countries whose emissions are on a rising trajectory, we follow the procedure discussed in Section 2 when estimating GHG emissions in 2010, and estimate their emissions in 2002 in most cases by interpolating their projected emissions in 2000 and 2005. Applying the second alternative to each Annex I country, we have then calculated the maximum allowed acquisitions in 2010 for those Annex I countries whose emissions targets are below their business-as-usual emissions. As indicated in Table 4, the aggregate magnitude of acquisitions in 2010 from all three flexibility mechanisms amounts to 230.6 MtC. Expressed as a percentage of the difference between the projected baseline emissions and the targets, this number, on average, is calculated to be 37.2% under the second alternative. For the JUSSCANNZ countries as a whole, the corresponding figures are 189.3 MtC and 34.3% respectively, whereas for the EU as a whole the aggregate magnitude of acquisitions in 2010 is 99.3% of the difference between the projected baseline emissions and the targets.

Comparing the maximum allowed acquisitions in 2010 under the two alternatives, and assuming that countries would wish to use the higher allowed acquisitions in 2010, we can obtain the higher allowed acquisitions in 2010 for each Annex I country's whose emissions targets in 2010 are below its business-as-usual emissions. The higher allowed acquisitions in 2010 from all three flexibility mechanisms add up to the aggregate magnitude of 261.9 MtC. On average, the number is equivalent to 42.2% of the difference between the projected baseline emissions and the targets in 2010. For the JUSSCANNZ countries as a whole, the corresponding figures are 191.6 MtC and 34.7% respectively, whereas for the EU as a whole the aggregate magnitude of acquisitions in 2010 is 138.6% of the difference between the projected baseline emissions and the targets.

The bottom line of the EU proposal for concrete ceilings is that at least 50% of GHG emissions reductions must be achieved via domestic actions. If this were applied to the Annex I countries as a whole, the EU demand will be met because the aggregate allowed acquisitions in 2010 from all three flexibility mechanisms under the above alternatives are well below 50% of the difference between the projected baseline emissions and the target in 2010. However, the EU proposed restrictions to each country vary, in some case even substantially. Although for major GHG emitters, such as the US and Japan, the second alternative allows for a higher quantity of acquisitions than the first alternative, it is still very restrictive, particularly for the US. Under either of the two alternatives, the US is not allowed to acquire more than one third of the difference between its projected baseline emissions and the target in 2010. This is the intended outcomes of the EU proposal. The outcomes themselves explain why the JUSSCANNZ countries, particularly the US, disagree with the EU proposal.

**Table 4 Allowed Acquisitions and Transfers of GHG Emission Reduction Units under the two EU Ceiling Alternatives**

| | GHG emissions in base year (MtC) | Highest annual GHG emissions between 1994 and 2002 | Kyoto target in 2010 (MtC) | Baseline GHG emissions minus the target in 2010 (MtC) | Allowed acquisitions in 2010 under Alternative 1 | | Allowed acquisitions in 2010 under Alternative 2 | | Maximum acquisitions in 2010 | | Allowed transfers in 2010 under Alternative 1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Volume (MtC) | As % baseline emissions minus the target | Volume (MtC) | As % baseline emissions minus the target | Volume (MtC) | As % baseline emissions minus the target | Volume (MtC) | As % baseline emissions minus the target |
| **Non-EU&EIT Annex I Countries** | | | | | | | | | | | | |
| Australia | 113.3 | 129.9 | 122.4 | 21.7 | 5.9 | 27.2% | 3.8 | 17.3% | 5.9 | 27.2% | | |
| Canada | 163.0 | 182.9 | 153.2 | 29.2 | 7.6 | 27.1% | 14.9 | 50.9% | 14.9 | 50.9% | | |
| Iceland | 0.8 | 0.9 | 0.9 | 0.1 | 0.0 | 42.5% | 0.0 | 0.0% | 0.0 | 42.5% | | |
| Japan | 337.2 | 380.2 | 317.0 | 71.2 | 16.4 | 23.0% | 31.6 | 44.4% | 31.6 | 44.4% | | |
| New Zealand | 19.8 | 21.6 | 19.8 | 3.1 | 1.0 | 31.9% | 0.9 | 29.0% | 1.0 | 31.9% | | |
| Norway | 15.0 | 16.7 | 15.2 | 2.1 | 0.8 | 36.0% | 0.8 | 35.7% | 0.8 | 36.0% | | |
| Switzerland | 14.6 | 14.7 | 13.4 | 1.1 | 0.7 | 63.6% | 0.6 | 59.1% | 0.7 | 63.6% | | |
| United States | 1634.4 | 1793.6 | 1520.0 | 423.9 | 78.9 | 18.6% | 136.8 | 32.3% | 136.8 | 32.3% | | |
| **European Union** | | | | | | | | | | | | |
| Austria | 21.6 | 21.6 | 18.8 | 1.6 | 1.0 | 63.1% | 1.4 | 87.5% | 1.4 | 87.5% | | |
| Belgium | 37.9 | 41.6 | 35.1 | 6.5 | 1.8 | 28.1% | 3.3 | 50.0% | 3.3 | 50.0% | | |
| Denmark | 19.6 | 25.4 | 15.5 | 1.1 | 0.9 | 79.8% | 5.0 | 450.0% | 5.0 | 450.0% | | |
| Finland | 19.8 | | 19.8 | -1.3 | | | | | | | 1.0 | 76.2% |
| France | 151.9 | 153.2 | 151.9 | 0.6 | 7.6 | 1265.8% | 0.6 | 108.3% | 7.6 | 1265.8% | | |
| Germany | 329.5 | 297.3 | 260.3 | 6.6 | 14.7 | 223.4% | 18.5 | 280.3% | 18.5 | 280.3% | | |
| Greece | 28.7 | 30.9 | 35.9 | -3.1 | | | | | | | 1.6 | 52.1% |
| Ireland | 15.5 | 16.9 | 17.5 | 0.6 | 0.8 | 137.5% | -0.3 | | 0.8 | 137.5% | | |
| Italy | 145.2 | | 135.8 | -6.2 | | | | | | | 7.0 | 113.3% |
| Luxembourg | 3.7 | | 2.7 | -0.9 | | | | | | | 0.2 | 17.8% |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Netherlands | 60.8 | 66.7 | 57.2 | 13.4 | 3.0 | 22.0% | 4.8 | 35.4% | 4.8 | 35.4% | | |
| Portugal | 18.6 | | 23.6 | -1.2 | | | | | | | 1.1 | 87.9% |
| Spain | 82.1 | 93.0 | 94.4 | 4.2 | 4.4 | 105.1% | -0.7 | | 4.4 | 105.1% | | |
| Sweden | 18.1 | 19.8 | 18.8 | 1.6 | 0.9 | 57.7% | 0.5 | 31.3% | 0.9 | 57.7% | | |
| United Kingdom | 206.5 | 195.3 | 180.7 | 4.4 | 9.7 | 220.0% | 7.3 | 165.9% | 9.7 | 220.0% | | |
| **Former Soviet Union** | | | | | | | | | | | | |
| Estonia | 11.1 | | 10.2 | -4.7 | | | | | | | 0.5 | 11.3% |
| Latvia | 9.7 | | 8.9 | -3.4 | | | | | | | 0.5 | 13.7% |
| Lithuania | 14.0 | 12.2 | 12.9 | 0.9 | 0.7 | 74.7% | -0.4 | | 0.7 | 74.7% | | |
| Russia | 828.4 | | 828.4 | -35.0 | | | | | | | 41.4 | 118.3% |
| Ukraine | 250.3 | | 250.3 | -38.3 | | | | | | | 12.5 | 32.7% |
| **Eastern Europe** | | | | | | | | | | | | |
| Bulgaria | 37.1 | 32.2 | 34.1 | 3.7 | 1.8 | 48.1% | -0.9 | | 1.8 | 48.1% | | |
| Czech Republic | 52.4 | 45.9 | 48.2 | 4.7 | 2.5 | 53.5% | -1.2 | | 2.5 | 53.5% | | |
| Hungary | 27.8 | 24.2 | 26.1 | 2.1 | 1.3 | 64.2% | -1.0 | | 1.3 | 64.2% | | |
| Poland | 153.8 | 140.6 | 144.6 | 15.7 | 7.5 | 47.5% | -2.0 | | 7.5 | 47.5% | | |
| Romania | 72.2 | | 66.4 | -10.8 | | | | | | | 3.5 | 32.1% |
| Slovakia | 19.9 | | 18.3 | -0.1 | | | | | | | 1.0 | 955.0% |
| Slovenia | 5.2 | 4.5 | 4.8 | 0.5 | 0.3 | 50.0% | -0.2 | | 0.3 | 50.0% | | |
| Total | **4939.5** | | **4683.1** | | **170.4** | **27.5%** | **230.6** | **37.2%** | **261.9** | **42.2%** | **70.2** | **66.9%** |

*Sources:* See Text; Austria (1998); CEC (1999); Estonia (1998); Greece (1997); UNFCCC (1997a, 1998a, 1999b); VROM (1998); Own calculations.

On the other hand, the EU proposal allows, in percentage terms, some countries, particularly its member countries, to undertake a significant amount of acquisitions. There are at least three reasons for the high figures well above 100%, for example, for the United Kingdom (220%), Germany (280%), Denmark (450%), and France (1266%). The first reason is related to certain extreme weather conditions in some countries, which in turn result in sharp variations in GHG emissions. For example, due to low hydroelectricity available from Norway and Sweden in 1996, Denmark used much more coal, the most carbon-polluting fuel, than what would otherwise have been the case. This led to the large increase in $CO_2$ emissions in that year. As a result, the difference between its emissions in 1996 and its target in 2010 appears high relative to the gap between its projected baseline emissions and the target in 2010. The second reason is related to projected baseline emissions in 2010. As discussed in Section 2, the official projections of baseline GHG emissions in 2010 by most EU member countries are very close to their targets. Put another way, there are very small discrepancies between their baseline emissions and their targets. As a result, the allowed acquisitions are high relative to the gap between their projected baseline emissions and their targets in 2010. This explains why, in percentage terms, many EU member countries have a significant amount of acquisitions under either of the two alternatives. The third reason is due to largely unrelated political events or policies of a one-off nature. Because of economies contracting and a shift from coal to natural gas in the former East Germany following unification and the utility privatization and reform of coal subsidies encouraging a shift from coal to natural gas in the United Kingdom, for Germany and the United Kingdom their projected baseline GHG emissions in 2010 are below emissions in 1990 and their highest annual GHG emissions in any year between 1994 and 2002 appeared in 1996. As a result, the differences between their emissions in 1996 and their targets in 2010 appear high relative to the gaps between their projected baseline emissions and the targets in 2010. This will lead to very high percentages for the two countries under the second alternative.

Following the same procedure as one in calculating the maximum allowed acquisitions, we have calculated the maximum allowed transfers in 2010 for those Annex I countries whose emissions targets in 2010 are above their projected business-as-usual emissions. As indicated in Table 4, the aggregate magnitude of transfers in 2010 amounts to 70.2 MtC. Expressed as a percentage of the total magnitude of hot air, which amounts to 105.0 MtC as indicated in Table 1, this number, on average, is calculated to be 66.9%. Because of a large decline in GHG emissions in Russia since the collapse of the Soviet Union, and, as discussed in Section 2, because the official Russian projections of baseline emissions in 2010 are very close to its base year levels, certain percentages of the sum of its base year emissions and the target appear high relative to its size of hot air. This will lead to very high percentage for Russia under the first alternative. For Slovakia, its projected baseline emissions in 2010 are almost the same as its target. It is thus not surprising that its allowed transfers are extremely high relative to the minor size of hot air. In addition, because some EU member countries project their baseline GHG emissions in 2010 below their targets, they appear sellers, although, as discussed in Section 2, for reasons very different from those for Russia and Ukraine. Depending to a large extent on the differences between their projected baseline emissions and the targets in 2010, some EU member countries appear, in percentage terms, to have a significant amount of transfers.

Now let us summarize the implications of the EU proposal for the division of abatement actions at home and abroad. In Section 2, the aggregate magnitude of demand for GHG offsets in 2010 has been estimated to be 620.6 MtC. In this Section, we have estimated that the maximum allowed acquisitions in 2010 from all three flexibility mechanisms amount to 261.9 MtC under the EU proposal for concrete ceilings. If the EU proposal were adopted, the remaining amount of 358.7 MtC must be met in 2010 via domestic abatement actions. In addition, because hot air is available at zero abatement cost, hot air is assumed to be used to the full extent. Given that the amount of hot air allowed for sale in 2010 is estimated to be 70.2 MtC, then the maximum net demand for acquisitions in 2010 from all three flexibility mechanisms amounts to 191.7 MtC (261.9 MtC minus 70.2 MtC) under the EU proposal for concrete ceilings.

## 4. Contributions of the Kyoto Flexibility Mechanisms to Meet the Total Emissions Reductions Required of Annex I Countries in 2010 under the Four Trading Scenarios

In order to meet the Kyoto targets, Annex I countries must reduce GHG emissions by 620.6 MtC in 2010. Part of the needed reductions will take place domestically. The rest will come from emissions trading and JI with other Annex I countries, and acquisitions of the certified CDM credits from non-Annex I countries.

The relative differential between the marginal cost of domestic abatement and the international price of emissions permits would apportion the total emissions reductions into domestic reductions and the demand for GHG offsets. To this end, we need to determine the marginal abatement costs for all the countries. Because it is a daunting task to estimate the marginal abatement cost for each individual country, we do so at a regional level. We divide the world into twelve regions. The acronyms for the twelve regions are given in Table 5. The first six regions are Annex I regions, whereas the other six are non-Annex I regions. In defining these regions, we have attempted to employ the minimal level of disaggregation necessary for the purpose of this study.

**Table 5  Definitions of Countries and Regions**

| Annex I countries and regions | Non-Annex I countries and regions |
|---|---|
| 1. US: United States | 7. EEX: Energy Exporting Countries |
| 2. JP: Japan | 8. CN: China |
| 3. EU: European Union | 9. IN: India |
| 4. OOE: Other OECD Countries | 10. DAE: Dynamic Asian Economies |
| 5. EE: Eastern Europe | 11. BR: Brazil |
| 6. FSU: Former Soviet Union | 12. ROW: Rest of the World |

Moreover, how the total emissions reductions required of Annex I countries will be met depends on the extent to which the Kyoto mechanisms will be allowed to contribute to meet the Kyoto targets. This is the area that remains to be decided by the climate change negotiators. For the purpose of illustration, we examine four scenarios here.

- No limits scenario: No caps are imposed on the use of all three flexibility mechanisms;
- 50% reduction from BAU emissions scenario: The maximum allowed acquisitions from all three flexibility mechanisms are limited to 50% of the difference between projected baseline emissions and the Kyoto targets in 2010;
- The EU ceilings scenario: Just as the name implies, the scenario follows the EU proposal for concrete ceilings on the use of all three flexibility mechanisms, as discussed in Section 3;
- No hot air scenario: Trading in hot air is not allowed, indicating that any effectuated trading in GHG emissions must represent ‘real’ emissions reductions.

### 4.1 The Divisions of Abatement Actions at Home and Abroad

For countries whose emissions targets specified under the Kyoto Protocol are expected to exceed their anticipated emissions requirements even in the absence of any limitation, we have estimated that these countries in 2010 will have surplus assigned amounts of 105.0 MtC available for sale. Because hot air is available at zero abatement cost, hot air is assumed to be used to the maximum extent allowed, except for under no hot air scenario. This means that, of the aggregate demand of 620.6 MtC in 2010, hot air contributes to 105.0 MtC both under no limits scenario and under 50% reduction from BAU emissions scenario, and 70.2 MtC under the EU ceilings scenario. Then, the remaining demand will be met via domestic abatement actions and three flexibility mechanisms.

According to the 12-region's marginal abatement cost-based model for determining the division of abatement actions at home and abroad, which is discussed in detail in Appendix 2, even if no limits are imposed on the use of all three flexibility mechanisms, not all the emissions reductions required of an Annex I country will take place abroad. This is because even if no account is taken of ancillary benefits of reducing GHG emissions, it is still in the interest of any buying country to reduce its own emissions as long as the marginal costs of doing so are lower than the prevailing prices of permits. Based on the marginal costs of domestic abatement for the twelve regions, it is estimated that a reduction of 171.7 MtC, or 27.7% of the total needed emissions reductions in 2010 will be met through domestic actions of Annex I countries under no limits scenario (see Table 6). This is broadly in line with the finding of the IPCC (1996) that reducing emissions by 20% from 1990 levels in developed countries within the next two or three decades can be achieved domestically through no-regrets options. When trading in hot air is not allowed, the international price of permits increases in comparison with no limits scenario (see Table 7). As a result, the demand for permits abroad decreases, and more and more domestic abatement is undertaken. This is confirmed in Table 6, which indicates that a reduction of 203.5 MtC, or 32.8% of the total needed emissions reductions in 2010 will be met through domestic actions of Annex I countries under no hot air scenario. Under 50% reduction from BAU emissions scenario, domestic actions contribute, by definition, to 50% of the aggregate demand in 2010. It is worthwhile to point out that the amount of abatement through domestic actions in 2010 under the EU ceiling scenario has been estimated to be 387.8 MtC, larger than 358.7 MtC as estimated as the difference between the aggregate demand and maximum allowed acquisitions in Section 3. This is mainly because the EU is allowed to purchase more than needed. Put another way, it is less costly for the EU to abate part of the allowed acquisitions domestically than to purchase them abroad.

**Table 6 Estimates of the Contributions of Three Flexibility Mechanisms under the Four Trading Scenarios in 2010**

| Scenarios | Domestic actions | Hot air | Emissions trading and JI | CDM | Total supply |
|---|---|---|---|---|---|
| No limits | 171.7 | 105.0 | 51.8 | 292.1 | 620.6 |
| 50% of reduction from BAU emissions | 310.3 | 105.0 | 36.1 | 169.2 | 620.6 |
| EU ceilings | 387.8 | 70.2 | 30.8 | 131.8 | 620.6 |
| No hot air | 203.5 | 0 | 59.6 | 357.5 | 620.6 |

*Source:* Own calculations.

Table 6 summarizes estimates of the contributions of three flexibility mechanisms under the four scenarios. It can be seen that the supply of certified CDM credits in 2010 ranges from 131.8 MtC under the EU ceilings scenario to 292.1 MtC under no limits scenario and to 357.5 MtC under no hot air scenario, respectively. In comparison with no limits scenario, the 50% of reduction from BAU emissions restriction and the EU ceilings restriction would reduce the size of the CDM market by 42.1% and 54.9%, respectively. Of the total emissions reductions required of Annex I countries in 2010, the supply of certified CDM credits accounts for 21.2% under the EU ceilings scenario, 47.1% under no limits scenario, and 57.6% under no hot air scenario, respectively.

**Table 7 Autarkic Marginal Abatement Costs in the No Trading Case, and Domestic Prices and the International Price of Permits under the Four Trading Scenario (at 1998 US$ per Ton of Carbon)**

| Scenarios | United States | Japan | European Union | Other OECD | International price |
|---|---|---|---|---|---|
| No emissions trading | 160.1 | 311.8 | 9.1 | 33.4 | - |
| No limits | 9.6 | 9.6 | 9.6 | 9.6 | 9.6 |
| 50% of reduction from BAU emissions | 45.5 | 124.7 | 6.0 | 6.0 | 4.7 |
| EU ceilings | 79.0 | 144.3 | 3.5 | 9.7 | 3.5 |
| No hot air | 12.6 | 12.6 | 12.6 | 12.6 | 12.6 |

*Source:* Own calculations.

When there are no limits imposed on the use of flexibility mechanisms, the marginal cost of domestic abatement for each region equalize, and there is no distinction between the international price and domestic prices. Based on the model detailed in Appendix 2, the international price is calculated to be US$ 9.6 per ton of carbon. This price is pushed up to US$ 12.6 per ton when trading in hot air is not allowed. The increase in the international price is partly because any sales for permits by the former Soviet Union are generated by no cost-free abatement undertaken to earn export permits additional to the amount of hot air, and partly because preventing trading in hot air increases the OECD countries' demand for certified CDM credits. When supplementarity restrictions are imposed on the acquisitions, the purchases of permits are restricted. This will push down the market price. Thus, the international prices of permits are much lower under the two supplementarity scenarios considered here than under no limits scenario. Moreover, because no account is taken of the differences in the marginal costs of domestic abatement among the Annex I countries, all the countries are required to comply with the same supplementarity rules. This could lead to a distinction between the international price and domestic prices of buying countries. The lesser extent it is allowed to purchase permits abroad, the higher the domestic prices, and hence the larger the distinction between the international price and domestic prices. As indicated in Table 7, because the autarkic marginal abatement cost for Japan is highest, the EU proposed restrictions lead to the highest ratio of the domestic price in Japan to the international price of permits. On the other hand, because the official projections of baseline GHG emissions in 2010 by most EU member countries are very close to their targets, the EU only needs to purchase a vey small amount of permits to meet its targets. As a result, the supplementarity restrictions examined here on the EU are much less severe than on Japan and the US. Consequently, domestic prices for the EU are very close to or even equal the international price of permits when the EU is allowed to purchase more than needed.

Because autarkic marginal abatement costs for the OECD countries excluding the EU are much higher than the market price of permits, trading can help these countries to lower their compliance costs by avoiding more costly domestic actions. The extent to which the compliance costs can be lowered depends on the relative differential between the autarkic marginal cost of the country in question and the international price of emissions permits. In percentage terms, the countries whose autarkic marginal costs are much higher than the market price will benefit more than those countries whose autarkic marginal costs are closer to the market price. As indicated in Table 8, because Japan and the US have the highest autarkic marginal abatement costs, the two countries benefit the most from trading both under no limits scenario and under no hot air scenario. Measured as percentages of the total abatement costs in the no trading case, the abatement costs of Japan and the US are cut by 93.1% and 85.2% under no limits scenario, and 91.0% and 81.0% under no hot air scenario, respectively. By contrast, because the autarkic marginal costs for the EU are very closer to the market price, it achieves only small gains from trading under the above two scenarios. Besides, restrictions on the use of flexibility mechanisms tend to lower the gains from trading. For the OECD as a whole, the reductions in abatement costs, namely, the gains from emissions trading, decrease from 86.5% under no limits scenario to 79.6% under 50% reduction from BAU emissions scenario and further down to 66.0% under the EU ceilings scenario.

**Table 8 The Reductions in the Total Abatement Costs under the Four Trading Scenarios (%)**

| Scenarios | United States | Japan | European Union | Other OECD | OECD |
|---|---|---|---|---|---|
| No limits | 85.2 | 93.1 | 0.2 | 45.3 | 86.5 |
| 50% of reduction from BAU emissions | 81.1 | 77.4 | 19.1 | 68.8 | 79.6 |
| EU ceilings | 63.7 | 71.9 | 39.2 | 70.8 | 66.0 |
| No hot air | 81.0 | 91.0 | 2.3 | 33.5 | 82.4 |

*Source:* Own calculations.

### 4.2 The Size of the CDM Market and the Shares of China and India

Multiplying the international price of permits by the supply of certified CDM credits from each non-Annex I country and summing over all the corresponding product, we can derive the value of the CDM market in 2010. As indicated in Table 9, our estimate ranges from US$ 456.9 million under the EU ceilings scenario to US$ 4512.8 million under no hot air scenario. Subtracting their own abatement costs, the net value of the CDM market in 2010, or the net gain of non-Annex I countries is estimated to be in the range of US$ 244.6 million under the EU ceilings scenario to US$ 2559.1 million under no hot air scenario. The finding that the net gain of non-Annex I countries is highest when trading in hot air is not allowed indicates that to prevent trading in hot air, although in practice it is very difficult to distinguish real emissions reductions from hot air, is beneficial to the expanding of the CDM market as well as to the global climate. With respect to the geographical distribution of the CDM flows, because of a great deal of low-cost abatement opportunities available in the energy sectors of China and India and their sheer sizes of population, the two countries are expected to emerge as the dominant host countries of CDM projects. This is confirmed in Table 9, which shows that about 60% and 16% of the total CDM flows go to China and India, respectively. Because of relatively high abatement costs and relatively small size, the remaining four non-Annex I regions account for only 25% of the total non-Annex I countries' exported permits to the Annex I regions.

**Table 9 The Value of the CDM Market and the Shares of China and India in 2010 under the Four Trading Scenarios**

| | No limits | 50% of reduction from BAU emissions | EU ceilings | No hot air |
|---|---|---|---|---|
| CDM market (million US$) | 2795.6 | 797.4 | 456.9 | 4512.8 |
| of which: | | | | |
| China | 60.3% | 59.9% | 59.6% | 60.4% |
| India | 15.1% | 15.7% | 15.9% | 14.9% |
| Net CDM market (million US$) | 1565.0 | 432.4 | 244.6 | 2559.1 |
| of which: | | | | |
| China | 59.9% | 59.4% | 59.2% | 60.1% |
| India | 15.5% | 16.1% | 16.3% | 15.3% |

*Source:* Own calculations.

Because the CDM has an important role in helping Annex I countries to meet their Kyoto targets at a lower overall cost, some studies have estimated the potential size of the CDM market. As indicated in Table 10, these estimates vary. Assuming the contributions from domestic abatement actions and hot air and dividing the remaining demand between emissions trading and JI among Annex I countries and the CDM within non-Annex I countries in proportion to the estimated potential of supply, Haites (1998b) estimates that the size of the CDM market in 2010 ranges from 265 MtC under 50% reduction from BAU emissions scenario to 575 MtC under no limits scenario. The size of the market estimated by the four economic modelling studies examined ranges from 397 MtC with the OECD GREEN model (Van der Mensbrugghe, 1998) to 723 MtC with the EPPA model (Ellerman and Decaux, 1998). Austin *et al.* (1998) argue that such estimates derived from these global modelling exercises tend to overestimate CDM flows because, in practice, political limitations and transaction costs will probably keep CDM activity at the lower end of such estimates. Of the studies examined in Table 10, the estimate by Vrolijk (1999) is at the low end of the range. In absolute terms, our estimate is at the low to middle end. This is mainly because, as indicated in Table 10, our estimate of total emissions reductions required of Annex I countries, which is based on compilation of the national communications from 35 Annex I countries, is lower than those estimates from economic modelling studies. As discussed in Section 2, the main reason is that the official projections of baseline GHG emissions in 2010 by most EU member countries are very close to their targets, thus leading to low demand for emissions reductions. In percentage terms, our estimate of the contribution of the certified CDM credits is broadly in line with other estimates. Our upper bound estimate comes from no hot air scenario. If the supply of hot air is included as other estimates from economic modelling studies do, then our upper bound estimate will come down to 47.1% under no limits scenario.

**Table 10  Estimates of the Size of the CDM Market in 2010**

| | Size of the CDM market (MtC) | Total emissions reductions required of Annex I countries (MtC) | Contribution of the CDM |
|---|---|---|---|
| EPPA | 723 | 1312 | 55% |
| Haites | 265-575 | 1000 | 27-58% |
| G-Cubed | 495 | 1102 | 45% |
| GREEN | 397 | 1298 | 31% |
| SGM | 454 | 1053 | 43% |
| Vrolijk | 67-141 | 669 | 10-21% |
| **Our projection** | 132-358 | 621 | 21-58% |

*Sources:* Edmonds *et al.* (1998); Ellerman and Decaux (1998); Haites (1998b); McKibbin *et al.* (1999); Van der Mensbrugghe (1998); Vrolijk (1999); Own calculations.

Can the CDM actually produce the amount of certified credits as we estimate here? This is not that easy to answer, but experience with activities implemented jointly (AIJ) might give us some indications. The first Conference of the Parties to the UNFCCC in Berlin in April 1995 endorsed a pilot AIJ phase. During the AIJ pilot phase, emission reductions achieved are not allowed to be credited to current national commitments of investor countries under the UNFCCC. By the time (30 June 1998) of the UNFCCC's second synthesis report on AIJ, 95 projects were listed as AIJ projects (UNFCCC, 1998b). These projects are located in 24 host countries, with Africa hosting only one certified AIJ project. If all the projects were fully implemented and operating as designed, they would generate a combined GHG offset of 162 million tons of $CO_2$ equivalent, namely, 44 MtC equivalent, over an average lifetime of 16.5 years (UNFCCC, 1998b). Translated into an annual GHG offset, it amounts to 2.7 MtC. By contrast, the projected contribution of the certified CDM credits implies as much as a 100-fold increase in this type of project-based activities. Although lack of adequate incentives for the private sector participation in AIJ project financing limits the role of the AIJ, to achieve such a substantial scale of increase in the quantity of emissions reductions, although not impossible, poses great institutional challenges for developing countries, given that most non-Annex I countries have not experienced an AIJ project within their own countries.

Another way to view the predicted CDM contribution is to compare it with the baseline GHG emissions in developing countries in 2010. To this end, we need to estimate the total GHG emissions in developing countries in 2010. In accordance with Article 12.5 of the Convention, each non-Annex I Party is required to prepare its initial national communications and to make its communications within three years of the entry into force of the Convention for that Party, or of the availability of financial resources in accordance with Article 4.3 (UNFCCC, 1992). This could be interpreted as meaning that one non-Annex I Party shall make its communications within three years of the entry into force of the Convention for that Party. It could also be interpreted as meaning that one non-Annex I Party shall make its communications within three years of the availability of financial resources in accordance with Article 4.3. The differing interpretations lead implicitly to differentiated timetable for the submission of initial national communications from non-Annex I Parties. By 5 November 1999, there were only 22 non-Annex I countries (Argentina, Armenia, Cook Islands, Egypt, Georgia, Indonesia, Jordan, Kazakstan, Kiribati, Lebanon, Marshall Islands, Mauritius, Mexico, Micronesia, Nauru, Republic of Korea, Samoa, Senegal, Tuvalu, Uruguay, Vanuatu and Zimbabwe) that had submitted their initial national communications. These communications only cover the information about GHG emissions inventories, and no projections of future emissions have been included. Moreover, major GHG emitters from developing countries have not yet submitted their national communications. Thus, it is impossible to derive the total GHG emissions in non-Annex I countries in 2010 in the same way as we have done for Annex I countries. Consequently, we have to resort to the projections from some global studies. Table 11 summarizes such projections from a variety of global studies. It can be seen that the total $CO_2$

emissions in developing countries are projected to range from 3547 MtC to 5200 MtC in 2010. Assuming the baseline emissions of 4000 MtC in developing countries in 2010, the projected contribution of the certified CDM credits, which might be a low estimate of potential because Article 12.10 of the Kyoto Protocol allows certified emissions reductions from CDM projects to be banked for later use as from 2000, implies as much as 9% of the total baseline emissions in developing countries.

**Table 11 Estimates of the Total $CO_2$ Emissions in Developing Countries in 2010 (MtC)**

| GREEN | EIA | IEA | EPPA | IPCC |
|---|---|---|---|---|
| 3467 | 3547 | 3639 | 4142 | 4000-5200 |

*Sources:* Ellerman and Decaux (1998); EIA (1999); IEA (1998); IPCC (1999); Van der Mensbrugghe (1998).

Finally, it should be pointed out that, from the perspective of maximizing the developing countries' revenues from CDM credits, selling more in quantity may not always be better. This can be illustrated in Figure 1. It shows an aggregated downward-sloping demand curve of Annex I countries and an aggregated upward-sloping supply curve of non-Annex I countries to supply the total quantity of CDM credits at various price levels (for simplicity, we draw linear demand and supply curves here). The point $E^o$ where the two curves labelled as *Demand* and $Supply^o$ cross gives the market cleaning price of CDM credits $P^o$ and the total quantity of CDM credits traded $Q^o$. The area $OE^oP^o$ represents the net gain to non-Annex I countries. Then, how to increase the net gain to non-Annex I countries? As shown in Figure 1, this could be achieved by shifting supply curve upward from $Supply^o$ to *Supply**. At the new equilibrium *E** where the new supply curve *Supply** crosses the same demand curve *Demand*, although the total quantity of CDM credits traded drops to *Q**, the net gain *OE*P** is greater than $OE^oP^o$ because the market clearing price *P** rises faster than the quantity falls. This has a very important policy implication, as it suggests that if the market clearing price could be held up to the reasonable level, relatively costly CDM projects could be undertaken early with international partners. This would leave low-cost abatement options (the so-called low-hanging fruits) available for later use of their own if developing countries would be subsequently required to reduce their own emissions.

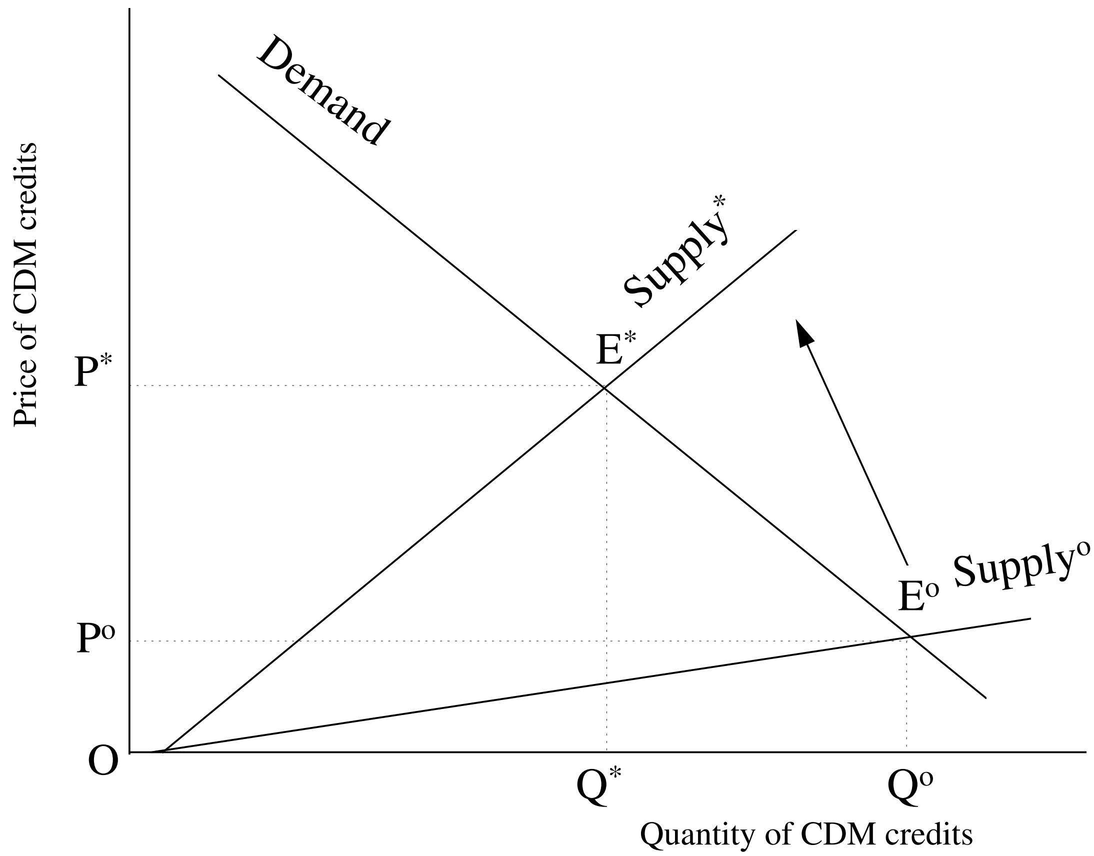


**Figure 1  Aggregated Demand and Supply Curves of CDM Credits**

**5. Conclusions**

The Kyoto Protocol is the first international environmental agreement that sets legally binding GHG emissions targets and timetables for Annex I countries. It incorporates emissions trading and two project-based flexibility mechanisms, namely JI and the CDM. According to the Buenos Aires Plan of Action, decisions on rules governing these flexibility mechanisms are to be made in the year 2000 at the latest. If properly designed, these flexibility mechanisms can effectively reduce their abatement costs while assisting Annex I countries in achieving their Kyoto obligations.

To what extent the abatement costs can be lowered depends on the size of the market for all three flexibility mechanisms under the Protocol. Taking the year 2010 as representative of the first commitment period and based on compilation of the national communications from 35 Annex I countries, this paper first estimates the size of the market on the demand side. This involves three steps. The first step is to determine GHG emissions for each Annex I country in the base year. The second step is to determine the Kyoto target for each Annex I country in 2010. The third step is to estimate baseline GHG emissions for each Annex I country in 2010. By adding up the demand from the countries whose emissions targets are below their business-as-usual emissions, the aggregate magnitude of emissions reductions required of Annex I countries in 2010 is estimated to be 620.6 MtC equivalent. In comparison with other estimates ranging from 669 MtC to 1312 MtC, our estimate based on compilation of the national communications is at the low end. This is mainly because the official projections of baseline GHG emissions in 2010 by most EU member countries are very close to their targets, thus leading to low demand for emissions reductions. We point out that the low EU baseline projections are attributable in large part to internal burden sharing of the Kyoto commitments among the member countries, having incorporated the impacts of energy policies that are currently being either implemented or negotiated in response to climate change, and to the choice of base year.

In contrast with countries whose emissions targets are well below their business-as-usual emissions, some countries are allocated assigned amounts under the Kyoto Protocol that exceed their anticipated emissions requirements even in the absence of any limitation. The so-called hot air problem is particularly acute in Russia and Ukraine whose emissions are expected to remain below their 1990 levels until 2010. By comparing with other estimates, we conclude that the official Russian projections based on optimistic expectations for economic growth and continued use of outdated technology may underestimate the amount of hot air available for sale. Nevertheless none of the existing estimates indicates that the size of hot air in 2010 is sufficiently large that all of the advanced Annex I countries can comply with their Kyoto targets merely through acquisitions of hot air.

Given that each of the Articles defining the three flexibility mechanisms carries wording that the use of the mechanism must be supplemental to domestic actions, the supplementarity provisions have been the focus of the international climate change negotiations subsequent to Kyoto. Whether the supplementarity clauses will be translated into a concrete ceiling, and if so, how should a concrete ceiling on the use of the three flexible mechanisms be defined remain to be determined. At the June 1999 Sessions of the Subsidiary Bodies of the UNFCCC, the EU has tabled a proposal for concrete ceilings on the use of flexibility mechanisms. Given the great policy relevance to the ongoing negotiations on the overall issues of flexibility mechanisms, the paper has provided a quantitative assessment of the implications of the EU proposal. Our results suggest that if the bottom line of the EU proposal were that at least 50% of GHG emissions reductions must be achieved via domestic actions for the Annex I countries as a whole, the EU demand will be met because the aggregate allowed acquisitions in 2010 from all three flexibility mechanisms under the two alternatives are well below 50% of the difference between the projected baseline emissions and the target in 2010. However, the EU proposed restrictions to each country vary, in some case even substantially. Under either of the two alternatives, the US is not allowed to acquire more than one third of the difference between its projected baseline emissions and the target in 2010. For the JUSSCANNZ countries as a whole, the restriction is 34.7%. On the other hand, the EU proposal allows, in percentage terms, some countries, particularly its member countries, to undertake a significant amount of acquisitions. This can be attributed to certain extreme weather conditions in some member countries, projected baseline 2010 emissions by most EU member countries very close to their targets, and/or to largely unrelated political events or policies of a one-off nature.

Using the 12-region's marginal abatement cost-based model, Section 4 estimates how many of the emissions reductions required of Annex I countries in 2010 will be met through domestic abatement actions, emissions trading and JI with other Annex I countries, and acquisitions of the certified CDM credits from non-Annex I countries under the EU ceilings scenario as well as under other three trading scenarios. Our results suggest that, of the total emissions reductions required of Annex I countries in 2010, domestic actions account for 27.7% under no limits scenario, 32.8% under no hot air scenario, and 62.5% under the EU ceilings scenario. The contributions of the certified CDM credits in 2010 are estimated to range from 21.2% under the EU ceilings scenario to 47.1% under no limits scenario and to 57.6% under no hot air scenario. In absolute terms, the supply of certified CDM credits in 2010 ranges from 131.8 MtC under the EU ceilings scenario to 292.1 MtC under no limits scenario and to 357.5 MtC under no hot air scenario, respectively. Although it is at the low to middle end of those estimates derived from economic modelling studies, our projected contribution of the certified CDM credits implies as much as a 100-fold increase in the type of project-based activities in comparison with an annual GHG offset through the AIJ of 2.7 MtC, and as much as 9% of the total baseline emissions in developing countries in 2010. No doubt, to achieve such a substantial scale of increase in the quantity of emissions reductions, although not impossible, poses great institutional challenges for developing countries. With respect to the geographical distribution of the CDM flows, because of a great deal of low-cost abatement opportunities available in the energy sectors of China and India and their sheer sizes of population, we found that the two countries account for about three-quarters of the total non-Annex I countries' exported permits to the Annex I regions. Besides, our results clearly indicate that the use of flexibility mechanisms helps to lower the OECD countries' compliance costs by avoiding more costly domestic actions. However, the magnitude of reductions in compliance costs differs substantially among the OECD countries, depending on the relative differential between the autarkic marginal cost of the country in question and the international price of emissions permits. In percentage terms, the countries whose autarkic marginal costs are much higher than the market price will benefit more than those countries whose autarkic marginal costs are closer to the market price. Because Japan and the US have the highest autarkic marginal abatement costs, the two countries benefit the most from trading both under no limits scenario and under no hot air scenario. Measured as percentages of the total abatement costs in the no trading case, the abatement costs of Japan and the US are cut by 93.1% and 85.2% under no limits scenario, and 91.0% and 81.0% under no hot air scenario, respectively. By contrast, because the autarkic marginal costs for the EU are very closer to the market price, it achieves only small gains from trading under the above two scenarios. Furthermore, restrictions on the use of flexibility mechanisms tend to lower the gains from trading. For the OECD as a whole, the gains from trading decrease from 86.5% under no limits scenario to 79.6% under 50% reduction from BAU emissions scenario and further down to 66.0% under the EU ceilings scenario. Thus, from the perspective of husbanding the world's limited resources, the fewer the restrictions on trading the gains from trading are greater.

Finally, it should be pointed out that because the Protocol as it stands now leaves many questions, including rules governing three flexibility mechanisms, open, it is thus important to bear in mind that without clear rules on how three flexibility mechanisms will be implemented in practice, our estimates should be understood as tentative.

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**Appendix 1. Derivations of Projected Baseline GHG Emissions in Annex I Countries in 2010**

In estimating GHG emissions for each Annex I country over the commitment period, we have drawn projections for GHG emissions in 2010 from most Annex I countries' national communications to the UNFCCC. For those Annex I countries whose estimates of aggregate GHG emissions in 2010 are not provided, their rule of thumb estimates are derived as follows.

**Austria**: As Austria only provides aggregate emissions of $CO_2$, $CH_4$ and $N_2O$ in 1990, its total GHG emissions in 1990 are first estimated, assuming that its ratio of $CO_2$, $CH_4$ and $N_2O$ emissions to total GHG emissions is the same as the ratio in 1995. For projections for $CO_2$ emissions in 2010 are provided under the "without measures" scenario, the "current measures" scenario (assuming that only the currently implemented measures will continue to be effective), the "additional measures" scenario (assuming the start of policy actions in 1997 to meet the Toronto target by 2005), and the "additional measures delayed" scenario (assuming a delayed start of policy actions in 2000), respectively (Austria, 1998). Given the assumption that the "current measures" scenario is realistic, we choose the projection for $CO_2$ emissions in 2010 under the "current measures" scenario. Its total GHG emissions in 2010 are then based on a linear extrapolation from 1990 level using the projected average growth of $CO_2$ emissions over the period 1990-2010.

**Belgium**: emissions in 2010 are based on a linear extrapolation from the projected 2000 level using the projected average annual growth rate over the period 1990-2000, the latter of which is drawn from its national communication to the UNFCCC.

**Estonia**: As Estonia only provides aggregate emissions of $CO_2$, $CH_4$ and $N_2O$ in its inventory, its total GHG emissions in 1990, 1995 and 1996 are first estimated, assuming that its ratio of $CO_2$, $CH_4$ and $N_2O$ emissions to total GHG emissions is the same as the ratio for Czech Republic in 1996. Two projections for $CO_2$ emissions in 2010 are provided under the moderate growth scenario called WEST-West (WW) and the high growth scenario called West-East (WE). The WW scenario assumes that Estonia's close integration with western political and economic structures, especially with the European Union, but relation with Russia and other CIS countries are relatively weak. The WE scenario assumes that Estonia's market is oriented towards both the west and the east and Estonia could become a transit country. In the two cases $CO_2$ emissions in 2010 are estimated well below its 1990 levels. Considering that Estonia's actual economic growth during 1996-97 exceeded even what the optimistic WE scenario is assumed, and that significant changes in the energy sector have not taken place yet, $CO_2$ emissions will hardly be lower than the WE projection in the near future. So we choose the WE projection for $CO_2$ emissions in 2010, which are expected to be 11.5% lower than its 1995 level (Estonia, 1998). Its total GHG emissions in 2010 are then based on a linear extrapolation from 1995 level using the projected average growth of $CO_2$ emissions over the period 1995-2010 under the WE scenario.

**France**: Due to revisions of the inventory, differences in 1990 levels between inventory and the base level used for projections are up to 17.4%. The projection for GHG emissions in 2010 that is presented at its national communication to the UNFCCC is adjusted up by 17.4%.

**Greece**: Assuming that the ratio of $CO_2$ emissions to non-$CO_2$ emissions remains unchanged, total GHG emissions in 2010 are estimated by multiplying its emissions in 1990 by the projected average growth of $CO_2$ emissions over the period 1990-2010 under the Conventional Wisdom scenario. Greece's national communication to the UNFCCC presents five scenarios for $CO_2$ emissions. The reason why the Conventional Wisdom scenario is chosen is that it is in line with the government's stated intention to restrict the increase $CO_2$ emissions to 13% in 2010 (Greece, 1997).

**Hungary**: Assuming that its ratio of $CO_2$, $CH_4$ and $N_2O$ emissions to total GHG emissions is the same as the ratio for Czech Republic in 1996 and remains unchanged, total GHG emissions in 2010 are estimated by multiplying its emissions in 1990 by the projected average growth for Bulgaria and Czech Republic over the period 1990-2010, the latter of which is drawn from their national communications to the UNFCCC.

**The Netherlands**: emissions in 2010 are drawn from the Update of the second national communication on climate change policies (VROM, 1998).

**Poland**: Projection for $CO_2$ emissions in 2010 and all GHG emissions in 1996 are provided in the national communication to the UNFCCC. Assuming that the ratio of $CO_2$ emissions to non-$CO_2$ emissions remains unchanged, total GHG emissions in 2010 are estimated by multiplying its emissions in 1996 by the projected average growth of $CO_2$ emissions over the period 1996-2010.

**Slovenia**: As Slovenia only provides aggregate emissions of $CO_2$, $CH_4$ and $N_2O$ in its inventory, its total GHG emissions in 1990 are first estimated, assuming that its ratio of $CO_2$, $CH_4$ and $N_2O$ emissions to total GHG emissions is the same as the ratio for Czech Republic in 1996. Assuming that the ratio of $CO_2$, $CH_4$ and $N_2O$ emissions to total GHG emissions remains unchanged, total GHG emissions in 2010 are then estimated by multiplying its emissions in 1990 by the projected average growth for Bulgaria and Czech Republic over the period 1990-2010.

**Ukraine**: As Ukraine only provides aggregate emissions of $CO_2$, $CH_4$ and $N_2O$ in 1990, its total GHG emissions in 1990 are first estimated, assuming that its ratio of $CO_2$, $CH_4$ and $N_2O$ emissions to total GHG emissions is the same as the ratio for Russian Federation in 1990. Assuming that the ratio of $CO_2$, $CH_4$ and $N_2O$ emissions to total GHG emissions remains unchanged, total GHG emissions in 2010 are then estimated by multiplying its total GHG emissions in 1990 by the projected average growth of $CO_2$, $CH_4$ and $N_2O$ emissions over the period 1990-2010.

**Appendix 2. The 12-region's Marginal Abatement Cost-based Model for Determining the Division of Abatement Actions at Home and Abroad**

To start with, we assume that the marginal abatement cost function for region $i$ is of the quadratic form:

$$MCA_i = a_i Q_i^2 + b_i Q_i$$

where $MCA_i$ is the marginal cost of domestic abatement for region $i$, $Q_i$ is the amount of greenhouse gas abatement undertaken domestically in million tons of carbon, and $a_i$ and $b_i$ are coefficients. By integration, the total cost of domestic abatement, $TCD_i$, is:

$$TCD_i = \int_0^{Q_i} (a_i q_i^2 + b_i q_i) dq_i = \tfrac{1}{3} \times a_i Q_i^3 + \tfrac{1}{2} \times b_i Q_i^2 \qquad \text{for every } i. \qquad (1)$$

Denoting the total emissions reductions required of the Kyoto-constrained Annex I region $i$ by $D_i$ and the amount of hot air that is allocated to region $i$ by $H_i$, the total autarkic abatement cost, that is, the total abatement cost in the no trading case, $TCA_i$, is calculated as

$$TCA_i = \int_0^{D_i - H_i} (a_i q_i^2 + b_i q_i) dq_i = \tfrac{1}{3} \times a_i (D_i - H_i)^3 + \tfrac{1}{2} \times b_i (D_i - H_i)^2$$

$$\text{for } i = US, JP, EU, OOE, EE. \qquad (2)$$

Emissions trading helps a region with high autarkic marginal cost to lower its compliance cost by avoiding more costly domestic actions. In this case, the region undertakes domestic abatement $Q_i$ ($Q_i < D_i$) at the marginal cost

$$a_i Q_i^2 + b_i Q_i = MCA_i \qquad \text{for } i = US, JP, EU, OOE, EE, \qquad (3)$$

and meets the remaining demand ($D_i$ - $Q_i$ - $H_i$) via purchasing the "right to emit" at the international price $p$. So, the total remaining demand of all purchasing regions, $TD$, is:

$$TD = \sum_i (D_i - Q_i - H_i) \qquad i = US, JP, EU, OOE, EE. \qquad (4)$$

Measured as percentages of the total abatement costs in the no trading case, the reductions in abatement costs for purchasing region $i$ is:

$$G_i = \frac{TCA_i - (TCD_i + p(D_i - Q_i - H_i))}{TCA_i} \qquad i=US, JP, EU, OOE, EE \qquad (5)$$

where $G_i$ is the gains from emissions trading for purchasing region *i*. On the other hand, for the Kyoto-unconstrained region with lower marginal cost, emissions trading provides it an incentive to undertake abatement and sell to those higher cost regions at the international price *p*

$$a_i Q_i^2 + b_i Q_i = p \qquad \text{for } i=FSU, EEX, CN, IN, DAE, BR, ROW. \qquad (6)$$

Thus, the total amount of emissions permits available for sale, *TS,* are:

$$TS = \sum_i Q_i \qquad i=FSU, EEX, CN, IN, DAE, BR, ROW, \qquad (7)$$

of which, the value of the total non-Annex I countries' sales for permits to the Annex I regions, that is, the value of the CDM market, *VCDM*, is:

$$VCDM = \sum_i pQ_i \qquad i= EEX, CN, IN, DAE, BR, ROW. \qquad (8)$$

Subtracting their own abatement costs, the net value of the CDM market, or the net gain of non-Annex I regions, *NCDM,* is derived as

$$NCDM = \sum_i (pQ_i - TCD_i) \qquad i= EEX, CN, IN, DAE, BR, ROW. \qquad (9)$$

At the equilibrium, the total amount of demand for emissions permits are equal to the total supply so that we have

$$\sum_i H_i + TS = TD \qquad i=US, JP, EU,OOE, EE, FSU. \qquad (10)$$

Using the EPPA model, Ellerman and Decaux (1998) have estimated the marginal abatement cost (at 1985 US$ per ton of carbon) function for each of the above twelve regions. The results are given in Table 12. It can be seen that the assumed cost functions fit very well to the results from the EPPA runs because $R^2$ is very close to one. Inserting the estimated coefficients, we solve a set of the simultaneous equations (1) to (10) using GAMS, a widely distributed nonlinear programming package (Brooke *et al*, 1996).

**Table 12 Coefficients of the marginal abatement cost functions of the form**: $MCA_i = a_i Q_i^2 + b_i Q_i$

| Region | $a_i$ | $b_i$ | $R^2$ | Region | $a_i$ | $b_i$ | $R^2$ |
|---|---|---|---|---|---|---|---|
| USA | 0.0005 | 0.0398 | 0.9923 | EEX | 0.0032 | 0.3029 | 0.9983 |
| JPN | 0.0155 | 1.8160 | 0.9938 | CHN | 0.00007 | 0.0239 | 0.9992 |
| EEC | 0.0024 | 0.1503 | 0.9951 | IND | 0.0015 | 0.0787 | 0.9970 |
| OOE | 0.0085 | -0.0986 | 0.9981 | DAE | 0.0047 | 0.3774 | 0.9996 |
| EET | 0.0079 | 0.0486 | 0.9973 | BRA | 0.5612 | 8.4974 | 0.9997 |
| FSU | 0.0023 | 0.0042 | 0.9938 | ROW | 0.0021 | 0.0805 | 0.9967 |

*Source:* Ellerman and Decaux (1998).

This completes the summarized description of the general model. When it is used to examine the following cases, some specific settings are involved.

**A. No Limits Scenario**

Even if no limits are imposed on the use of flexibility mechanisms, it is still in the interest of a purchasing country to abate its own emissions up to the point where the marginal cost of doing so is equal to the prevailing price of permits. Thus, Eq. (3) merges with Eq. (6) so that we have

$$a_i Q_i^2 + b_i Q_i = MCA_i = p \qquad \text{for every } i. \tag{11}$$

This implies that the marginal cost of domestic abatement for each region is the same and that there is no distinction between the international price and domestic prices.

**B. Supplementarity Restrictions Scenarios**

When a uniform formula defining the restrictions on the use of flexibility mechanisms is applied to all the regions, some regions might be allowed to purchase more than needed. Put another way, it is more costly for the regions to purchase part of the allowed acquisitions than to abate them domestically. To remove the unnecessary part, we set Eq. (3) into

$$a_i Q_i^2 + b_i Q_i = MCA_i \geq p \qquad \text{for } i = US, JP, EU, OOE, EE. \tag{12}$$

As a result, a region is going to purchase permits only if it becomes more costly to undertake emissions abatement on its own. By contrast, for a region that is allowed to meet part of its commitments via the purchase of emissions permits, it must rely on domestic abatement capabilities. The lesser extent it is allowed to purchase permits abroad, the higher the domestic prices, and hence the larger the distinction between the international price and domestic prices.

### C. No Hot Air Scenario

Under no hot air scenario, trading in hot air is not allowed. Thus, Eq. (10) becomes

$$TS = TD. \tag{13}$$