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KYOTO MECHANISMS

The Role of Joint Implementation, the Clean Development Mechanism and Emissions Trading in Reducing Greenhouse Gas Emissions

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Abstract

This study analyses the potential role and impact of the Kyoto Mechanisms - i.e. Joint Implementation, the Clean Development Mechanism and Emissions Trading - in meeting the commitments of Annex I countries to limit their greenhouse gas (GHG) emissions in the period 2008-2012. It is based on a quantitative analysis that covers all GHGs, all Kyoto Mechanisms and all major countries and regions of the world within an integrated, bottom-up model framework.

The role and impact of the Kyoto Mechanisms in limiting GHG emissions depend on a large variety of factors, notably (a) national differences in emission reduction requirements, potentials and costs, and (b) the specific characteristics of each Kyoto Mechanism - including its relative advantages and disadvantages - as determined by the specific guidelines, rules, and procedures regarding its operation. These factors are discussed in the first, qualitative part of the report.

The second, quantitative part analyses the trade and cost effects of the Kyoto Mechanisms for a large variety of countries and regions in the world. It shows that these effects may be very substantial. If Kyoto Mechanisms may be used unrestrictedly, Annex I countries will meet, on average, 70 to 90% of their reduction requirements by means of foreign transactions. As a result, global abatement costs will tumble from 76 billion US$ 'before trade' to 1.5-10 billion US$ 'after trade' (i.e. after relying on the Kyoto Mechanisms).

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SUMMARY

In the Kyoto Protocol, three international mechanisms have been introduced in order to enable Annex I countries to reduce the costs of meeting their emission limitation commitments by means of transactions abroad. These so-called ‘flexible instruments’ or ‘Kyoto Mechanisms’ include Joint Implementation, the Clean Development Mechanism and Emissions Trading. *Joint Implementation (JI)* refers to the opportunity of an Annex I country to achieve (part of) its Kyoto commitment through investments in GHG abatement projects in another Annex I country. The *Clean Development Mechanism (CDM)* intents a) to encourage the sustainable development of non-Annex I countries by means of capacity building and technology transfers, and b) to enable Annex I countries to meet part of their Kyoto commitments cost-effectively by means of abatement projects in non-Annex I countries. Finally, *Emissions Trading (ET)* allows Annex I countries to exchange part of their emission commitments and, hence, to redistribute the division of allowed emissions between them.

At present, the potential role and impact of the Kyoto Mechanisms in achieving GHG abatement commitments is highly uncertain. The main objectives of the present study are, therefore, to increase the insight in the role and operation of the Kyoto Mechanisms - including their interaction – and to analyse the contribution and cost effects of the Kyoto Mechanisms in meeting the commitments of Annex I countries. In contrast to most other studies dealing with this subject – which are usually focussed on one GHG (mostly CO_2), one mechanism and/or one particular country or region - the present study is based on a quantitative analysis that covers all GHGs, all Kyoto Mechanisms and all major countries and regions of the world. Nevertheless, the analysis may still be called ‘partial’ as macroeconomic effects of emission mitigation policies, both within and between countries - are not included.

The methodology applied in this study is based upon a ‘bottom-up’ approach developed in previous ECN studies of Kyoto Mechanisms. A market for trading *emission credits* has been simulated by means of a spreadsheet model. The term ‘emission credits’ is used as the collective concept for credits generated and transferred by JI, CDM and/or ET. It is assumed that this basic commodity is traded on a common, integrated market characterised by no trade restrictions, no transaction costs, no risks or uncertainties, no institutional changes, and no strategic behaviour of market parties. Demand and supply curves for emission credits have been established by estimating, on the one hand, the required emission reductions in Annex I countries and, on the other hand, the emission abatement potentials and costs in both Annex I and non-Annex I countries/regions. This approach has resulted in the determination of the equilibrium price of emission credits, the amount of emissions reduced at home and traded abroad, and the savings in abatement costs involved.

The main findings of the study are:

Characteristics of Kyoto Mechanisms are still uncertain

- The role and impact of the Kyoto Mechanisms in limiting GHG emissions depend on a large variety of factors, including a) national differences in emission reduction requirements, potentials and costs, and b) the specific characteristics of each Kyoto Mechanism – including its relative advantages and disadvantages – as determined by the specific guidelines, rules, and procedures regarding its operation. The latter factors, however, are often yet not clear, as they still have to be defined more specifically by ongoing policy negotiations as part of the further elaboration of the Kyoto Protocol. Because Annex I countries may apply one or more of the Kyoto Mechanisms to meet their commitments, interaction - notably competition - between these instruments is likely to occur.

Substantial reduction requirements for Annex I countries

- Total GHG emissions of all countries are expected to increase from almost 31 billion tonnes CO_2 eq. in 1990 to more than 38 billion tonnes in 2010 (+25%). In Annex I countries, emissions over this period will increase from 17.5 to 19.5 billion tonnes CO_2 eq. (+11%), while in non-Annex I countries they will rise from approximately 13 to 19 billion tonnes (+42%).
- Reduction requirements of all (western) Annex I countries for the first budget period, 2008-2012, are estimated at 2.7 billion tonnes CO_2 eq. At the national level, these requirements are particularly high in absolute terms for the US (almost 2 billion tonnes), Japan (334 million tonnes) and Italy (113 million tonnes).

Large differences in reduction potentials and costs

- There are large potentials of reduction options in both non-Annex I and CEE/FSU Annex I countries at significantly lower costs than in western Annex I countries. In both the non-Annex I region and the CEE/FSU Annex I region, there is even a substantial potential of 'no-regret' options – i.e. reduction options with 'negative' costs – estimated at some 800 Mt in each region.

Large potential role and impact of Kyoto Mechanisms

- If all Kyoto Mechanisms and all relatively cheap reduction potentials – including the above-mentioned no-regret options - can be used unrestrictedly, the equilibrium price of trading emission credits will be 3 US$ per tonne CO_2 eq. (case B). Excluding no-regret options (case A) will raise this price to 8 US$.
- In case A, Annex I countries will meet, on average, 70% of their reduction requirements by means of foreign transactions. This share will even be 88% if no-regret options are included (case B). In both cases, Annex I countries will import emission credits mainly through CDM transactions with non-Annex I countries, followed by JI transactions with countries in the CEE/FSU Annex I region, and hardly by ET transactions within the western Annex I region.
- In case A, global abatement costs are estimated to tumble from 76 billion US$ 'before trade' to 10 billion US$ after trade' (i.e. after relying on the Kyoto Mechanisms). Including no-regret options in the non-Annex I and CEE/FSU Annex I regions (case B) results in a further decrease of total abatement costs to 1.5 billion US$. Hence, it may be concluded that the Kyoto decision to introduce JI, CDM and ET may result in tremendous global savings of total abatement costs, particularly if no-regret options in non-Annex I and CEE/FSU Annex I regions are included in global abatement strategies.

Some countries benefit more

- In absolute terms, the US, Japan and Italy benefit most from relying on the Kyoto Mechanisms to meet their reduction requirements. However, in all cases considered, these countries account for the major share (88-91%) of total abatement costs born by western Annex I countries. In relative terms, i.e. as a share of GDP, the countries that benefit most include Italy, Japan, Austria and Denmark, mainly due to their relatively high domestic reduction costs. Some countries, however, can even make real profits by exporting emission credits to Annex I countries. Such profits will be mainly realised by CDM countries in Asia and JI countries in the CEE/FSU Annex I region.

The above-mentioned results should be interpreted carefully as the underlying analysis is characterised by several limitations regarding the methodology and data used. For instance, assumptions made have often been rather strict, and several factors have not been accounted for such as 'sinks', 'hot air', as well as risks, uncertainties and potential future developments regarding the specific design and implementation of the Kyoto Mechanisms. These factors may have a significant impact on the trade and cost effects of the Kyoto Mechanisms.

1. INTRODUCTION

1.1 Background

The possibility of human influence on climate change was first recognised by the Swedish chemist Arrhenius in 1896. He observed increasing emissions of carbon dioxide (CO_2) due to the industrial revolution and predicted that if the atmospheric concentration of CO_2 would double, the Earth would warm up several degrees. For many years, however, little attention was paid to this fact because many scientists were of the opinion that the oceans would absorb any extra CO_2 emitted by human activity.

Systematic measurements of CO_2 concentrations in the atmosphere started in 1957. Although there was heated debate on climate change among atmospheric scientists through the 1970s and 1980s, it would last until 1988 that this topic became a political issue. In that year, the United Nations established the Intergovernmental Panel on Climate Change (IPCC). The First Assessment Report of the IPCC, published in 1990, showed a broad scientific consensus that the possibility of human-induced climate change had to be taken seriously, leading to an intensification of international policy negotiations to address this issue.

Rio Earth Summit
The above-mentioned negotiations resulted in the United Nations Framework Convention on Climate Change (UNFCCC) signed at the Rio Earth summit of June 1992. There, the first steps were taken towards an international agreement 'to stabilise greenhouse gas concentrations in the atmosphere at such levels that would prevent dangerous anthropogenic interference with the climate system' (Art. 2). The Convention provides an international legal framework, sets widely accepted principles, and reassures developing countries that addressing the problem of climate change is primarily a responsibility of industrialised countries. By December 1993, the Convention had already been ratified by 50 countries (among which the US), the minimum required for entry into force. From that moment, the institutional procedures started, leading to the first annual Conference of the Parties (COP-1) in Berlin in March 1995. At this meeting, the 120 governments present drew up a plan to further elaborate the UNFCCC, which did not contain any legally binding targets yet.

Kyoto and beyond
A two-year process of negotiations led to legally binding targets and timetables laid down in the Kyoto Protocol, the result of COP-3 in December 1997. The basis of the Kyoto agreement is a set of country-specific commitments to limit the average annual emissions of greenhouse gases over the first budget period (2008-2012) compared to the emission level in the reference or base year (in most cases 1990/1995). These commitments apply only to the industrialised countries listed in Annex I of the UNFCCC.

Although more than 84 countries have signed the Kyoto Protocol, it will become legally binding only after ratification. So far, most countries have not taken this step and, therefore, the protocol has not yet entered into force. In the negotiations leading up to the protocol, the involvement and position of the United States was a very important one, because the USA is one of the biggest emitters of CO_2 in the world. Although the US administration dominated the design of the Kyoto Protocol, many in the US legislature remain relatively isolated from global realities and responsibilities, and reflect the deep resistance in US policy circles to emission restrictions (Grubb et al., 1999). It is expected, however, that in the end (almost) all countries will ratify.

The Kyoto Protocol was a big step forward, although some parts of the protocol have been left very vague, in particular the parts dealing with the three so-called ‘Kyoto Mechanisms’, the topic of this report. These mechanisms – Joint Implementation, the Clean Development Mechanism, and Emissions Trading – are treated briefly in Articles 6, 12 and 17 of the Kyoto Protocol, respectively. The elaboration of these articles has been discussed during the following COP-4 (Buenos Aires, 1998) and COP-5 (Bonn, 1999). However, progress has been slow and many unresolved issues have remained. It is the intention that some of these issues will be clarified at COP-6 in The Hague in November 2000.

Flexibility in the Kyoto Protocol

In the Kyoto agreement, a number of flexibility mechanisms has been introduced in order to reduce the abatement costs of the Annex I countries as well as to encourage the sustainable development of non-Annex countries by means of technology transfers and institutional capacity building (and, hence, to facilitate an agreement among all countries involved). Following Skea (1999), one can distinguish between the ‘what’ flexibility, the ‘when’ flexibility and, finally, the ‘where’ flexibility (see Table 1.1).

Table 1.1 *Summary of major flexibility mechanisms in the Kyoto Protocol*

‘What’ flexibility	Basket of six Greenhouse Gases (GHGs) Consideration of sinks
‘When’ flexibility	5-year commitment period Base year choice Banking/early crediting
‘Where’ flexibility (Kyoto Mechanisms)*	Joint Implementation (JI) Clean Development Mechanism (CDM) Emissions Trading (ET)

* The option of *‘joint fulfilment of targets’ or ‘bubbles’* (art. 4 in the Kyoto Protocol) could also be considered as ‘where’ flexibility. This option concerns an arrangement by which Parties may redistribute their collective emission reduction target according to an internal burden-sharing agreement. In Kyoto, the European Union has used this option to differentiate its collective commitment for the first budget period among its Member States.

The ‘what’ flexibility refers to the number and type of gases considered in the policy package to control the greenhouse effect. In addition to carbon dioxide (CO_2), five other greenhouse gases are included in this package, namely methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphurhexafluoride (SF_6). Together, these gases account for a significant share of total global GHG emissions (see Chapter 4). The flexibility here lies in the possible trade-off of emission reductions between the six GHGs. An additional kind of ‘what’ flexibility in the Kyoto Protocol concerns the inclusion of so-called *‘sinks’*, i.e. the storage or absorption of GHGs by - for instance - agro-forestry projects.

The ‘when’ flexibility includes a number of facilities with regard to the timing of GHG emissions. First, the *commitment period* is 5 years (2008-2012), implying an averaging of yearly emission levels. Secondly, countries can choose either 1990 or 1995 as the *base year* for the three ‘minor’ GHGs (HFCs, PFCs and SF_6)[1]. Hence, they will self-evidently select the base year that minimises their emission reduction commitments (Skea, 1999). Finally, other forms of ‘when’ flexibility concern *early crediting* and *banking* of CDM emission reductions (see Section 2.3).

[1] Some countries in Central and East Europe (CEE) and the Former Soviet Union (FSU) are even free to choose another year (1987/89).

The ‘where’ or ‘international’ flexibility refers to the possibility of achieving national emission reduction targets not only through domestic measures but also through abatement options abroad. In principle, this kind of flexibility opens the way to find global, least-cost solutions as the greenhouse issue depends neither on the location where GHGs are emitted nor on the place where emission reduction options are implemented.

The UNFCCC already recognised the principle of ‘global cost-effectiveness of emission reduction’ in its Art. 3.3, which opened the way to international flexibility. Therefore, in order to facilitate cost-effective abatement strategies, the Kyoto Protocol has introduced three mechanisms - or ‘flexible instruments’ - which enable Annex I countries to meet (part of) their Kyoto commitment by means of emission reduction activities abroad. These so-called ‘Kyoto Mechanisms’ include Joint Implementation (JI), the Clean Development Mechanism (CDM) and Emissions Trading (ET). As these mechanisms are the main subject of the present study, they will be discussed in more detail in Chapter 2.

1.2 Objectives, characteristics and major research questions of the study

At present, the potential role and impact of the Kyoto Mechanisms in achieving GHG abatement commitments is highly uncertain due to a variety of factors. Firstly, the regulatory and institutional framework of the Kyoto Mechanisms is still obscure as several guidelines, rules, procedures and institutions involved are yet not clearly defined and implemented. Secondly, in order to analyse the role and costs effects of the Kyoto Mechanisms, there is a serious lack of reliable data on emission levels, reduction potentials and abatement costs in both Annex I and non-Annex I countries.

Up to now, almost every study on the role or impact of the Kyoto Mechanisms – including those conducted by ECN – has focussed its analysis on one GHG (usually CO_2), one mechanism and/or one particular region in the world. The intention of the present study is to analyse the role and impact of the Kyoto Mechanisms by means of an integrated model framework that covers all GHGs, all Kyoto Mechanisms and all regions in the world. Despite its wide scope, however, the analysis conducted in this study may still be called ‘partial’, as macroeconomic effects of emission mitigation policies – both within and between countries – are not included.

Another major characteristic of the present study is that it is based upon a so-called ‘bottom-up’ methodology, in contrast to comparable studies based upon a ‘top-down’ approach. In fact, given the present state of climate change research – notably the above-mentioned data limitations and other uncertainties – the development of this ‘bottom-up’ methodology is probably even more significant than the (tentative) research findings stated in absolute, quantitative terms.

Within the context of the above-mentioned qualifications, the main objectives of the present study are:
1. To increase the insight in the role and operation of the Kyoto Mechanisms, including their interaction.
2. To analyse the contribution and cost effects of the Kyoto Mechanisms in meeting the commitments of Annex I countries to limit their GHG emissions.

In order to achieve the above-mentioned objectives, the present study addresses the following research questions:

- What are the major characteristics of the Kyoto Mechanisms? How will these mechanisms most likely operate in the near future? What might be the interaction or competition between the Kyoto Mechanisms?
- What are the major conditions, uncertainties and other (limiting) factors that may influence the potential role and impact of the Kyoto Mechanisms in meeting national reduction requirements?
- What are the expected trends in GHG emissions in the major regions of the world in the period 1990-2012? What will be the emission reduction requirements of the Annex I countries?
- What are the potentials and costs of reducing GHG emissions in major regions of the world?
- Which part of the national Kyoto requirements will be achieved by domestic measures, and which part by activities abroad?
- What will be the impact of using the Kyoto Mechanisms on emission levels and abatement costs of the major countries and regions involved? Which countries are likely to benefit most of using the Kyoto Mechanisms?

1.3 Outline of the report

The structure of the present report is as follows. Chapter 2 will provide a qualitative analysis of the role and operation of the Kyoto Mechanisms, whereas a more quantitative approach will be presented in Chapters 3 and 4. More specifically, Chapter 2 will first of all describe the major characteristics – including some unresolved issues or 'open questions' - of each Kyoto Mechanism separately (Sections 2.2-2.4). Subsequently, it will discuss the factors affecting the role and interaction of the three mechanisms as well as the factors influencing their potential impact on achieving the Kyoto objective to limit global GHG emissions (Sections 2.5-2.7).

Chapter 3 can be mainly regarded as an introduction to the quantitative analysis of the present study. A brief outline of the methodology and data used will be presented in Sections 3.3 and 3.4, respectively. In addition, Section 3.5 summarises the major results of previous ECN studies concerning the role and operation of the Kyoto Mechanisms. In general, the scope of these studies has been more restricted than the present study – i.e. focusing on one GHG (CO_2), one mechanism and/or one particular region – leading to different, occasionally more detailed research findings which can be compared or added to the results of the present study discussed in Chapter 4. More particularly, Chapter 4 will analyse trends in global and regional GHG emissions (Section 4.2) as well as potentials and costs of reducing these emissions either by domestic measures or by activities abroad (Sections 4.3 and 4.4). The major limitations of the quantitative analysis of the present study and possible consequences for the results concerned are briefly discussed in Section 4.5. Finally, Chapter 5 will present the main findings and some suggestions for further research.

2. THE POTENTIAL ROLE OF THE KYOTO MECHANISMS

2.1 Introduction

This chapter provides a qualitative analysis of the role and operation of the Kyoto Mechanisms. First of all, it describes the major characteristics – including some unresolved issues or 'open questions' - of each Kyoto Mechanism separately (Sections 2.2-2.4). Subsequently, it discusses the factors affecting the role and interaction of the three mechanisms as well as the factors influencing their potential impact on achieving the Kyoto objective to limit global GHG emissions (Sections 2.5-2.7).

2.2 Joint Implementation

2.2.1 Major characteristics

Joint Implementation (JI) refers to the opportunity of an Annex I country to meet (part of) its Kyoto commitment through investments in GHG abatement projects in another Annex I country. Such investments result in the generation of so-called 'credits' or 'Emission Reduction Units' (ERUs). Depending on the agreements made on 'credit-sharing' between the parties involved, these ERUs are fully or partially added to the amount of assigned GHG emissions of the investing country, while they are subtracted from the assigned amount of the host country. The amount of credits generated is usually an estimate of the emission reductions achieved by a JI project relative to a 'baseline' situation. The latter refers to the estimated level of GHG emissions that would occur without the JI project (see Section 2.2.2 below).

JI projects will start generating credits in 2008, although the projects themselves may begin earlier. Definite crediting of ERUs will only occur after annual reporting requirements and other obligations have been met (Art. 6 of the Kyoto Protocol). In order to gain experience with emission abatement projects abroad, several countries have participated over the past years in a test phase of such projects called 'Activities Implemented Jointly' (Van Harmelen et al., 1997; and OECD, 1999).

2.2.2 Open questions

Art. 6 of the Kyoto Protocol contains a number of issues that still need to be clarified. Art. 6.1.b states that JI projects should provide a reduction of GHG emissions 'additional to any that would otherwise occur'. Art. 6.1.d. states that JI shall be 'supplemental to domestic actions'. These stipulations, however, are rather vague and need to be worked out more specifically. Art. 6.2 mentions that the CoP may further elaborate guidelines for the implementation of JI, including verification and reporting.

Baseline

The guidelines for the project baseline are a topic for discussion. The baseline is supposed to describe the level of emissions that would occur in the absence of the JI project. It is used to estimate the credits earned by a project. However, it is not always easy to define a baseline. One of the questions to be solved is what will happen if ideas regarding the baseline situation change during the preparation or implementation of a project. Can the project still claim the previous estimated ERUs, or does this change as the baseline changes? In the latter case ('dynamic baseline'), the costs per tonne CO_2 equivalent may be higher or lower than anticipated.

To simplify the baseline problem, some authors have proposed to define standardised baselines for specific countries and technologies (Michaelowa, 1998). For instance, all electricity-generation projects of a country would have to apply the same amount of GHG emissions per kWh, unless it can be proven that it should be differentiated for each project. However, as there are differences between regions and possibly other differences that need to be taken into account, it may be a problem to define these standard baselines. A compromise must be found between, on the one hand, a detailed project-specific approach - which is costly – and, on the other hand, a generic approach - which is cheaper but less accurate.

Additionality and supplementarity
The issue of 'additionality' is also still unclear. What is meant by 'additional to what otherwise would occur'? Does this mean that any profit-making project is unfit to become a JI project, as it would be carried out anyway, at least according to economic theory?

Another unresolved problem concerns the issue of 'supplementarity'. The Kyoto Protocol specifies that emission abatement activities abroad 'shall be supplemental to domestic actions'. This 'open question' is not only related to the issue of cost-effectiveness of GHG emission reductions at home versus abroad, but also touches upon a more ethical topic: should a country be allowed to buy all ERUs abroad, without reducing GHG emissions at home? One advocated approach has been to implement a ceiling for the amount of credits achieved through JI or by all Kyoto Mechanisms together (see Section 2.7.4)[2].

2.3 The Clean Development Mechanism

2.3.1 Major characteristics

The Clean Development Mechanism (CDM) is defined in Article 12 of the Kyoto Protocol. Its main objectives are a) to encourage the sustainable development of non-Annex I countries by means of institutional capacity building and technology transfers, and b) to enable Annex I countries to meet part of their Kyoto commitments cost-effectively by means of abatement projects in non-Annex I countries. This instrument was adopted rather unexpectedly at Kyoto since it had not been part of any formal proposal during the 30-month negotiation period prior to the conference. CDM is still very much under development and will be subject to the authority and guidance of the CoP, which has the responsibility to 'elaborate modalities and procedures to ensure transparency, efficiency and accountability through independent auditing and verification of project activities'.

CDM has much in common with JI as both mechanisms enable Annex I countries to meet (part of) their Kyoto targets by means of cross-border investments in GHG abatement projects. The most important difference, however, is that the host countries of JI are Annex I countries, whereas those of CDM projects are non-Annex I countries (i.e. mainly non-industrialised countries which are not committed to reduce their GHG emissions).

[2] See also Van Harmelen et al. (1997) for a more detailed discussion of problematic aspects of JI projects, including the definition of project costs, the sharing of JI credits between investing and host countries, and the monitoring and verification of JI projects.

Another difference is that JI credits can be accrued from 2008, whereas CDM credits can be earned much earlier, i.e. already from 2000. CDM credits generated before 2008 can be banked in order to use them during the first budget period 2008-2012[3]. This provides CDM projects a significant advantage compared to JI projects as if may have a substantial impact on the average costs of CDM versus JI credits[4].

2.3.2 Open questions

The rules and modalities of CDM are yet not clarified. Unresolved issues regarding baselines, additionality and supplementarity are similar to JI (see Section 2.2.2, as well as Van der Linden et al., 1999). In contrast to JI, however, CDM is characterised by some specific problems regarding emission reduction monitoring and verification because non-Annex I countries do not have a limitation commitment. As a result, the risks of fake abatement projects and other kinds of 'leakages' are higher for CDM than JI since in case of JI projects both host and investing countries have an interest in correct emission monitoring and verification.

In addition, there are two other major 'open questions' with regard to CDM. Firstly, according to the Kyoto Protocol, CDM should not only benefit Annex I countries by meeting their abatement commitments at lower costs, but also non-Annex I countries by promoting their 'sustainable development'. However, it is not clearly indicated how to achieve the latter purpose. Credit-sharing between host and sponsoring countries is hardly an option as non-Annex I countries do not have an abatement commitment. Besides selling CDM credits at profitable prices, host countries may benefit from CDM investment funds and technologies – including knowledge and experience – transferred from Annex I to non-Annex I countries.

Secondly, a share of the proceeds of CDM projects will be used to cover administrative expenses and assistance to non-Annex I countries – notably small island states – that are particularly vulnerable to the adverse effects of climate change such as floods or droughts. However, the modalities of these 'administrative levies' and 'adaptation funds' are still obscure.

2.4 Emissions Trading

2.4.1 Major characteristics

Within the context of the Kyoto Protocol, Emissions Trading (ET) refers to the ability of Annex I countries to exchange part of their emission commitment and, hence, to redistribute in effect the division of allowed emissions between them (Grubb et al., 1999)[5]. In contrast to JI and CDM, ET is not a project related instrument but rather a facilitating mechanism to enhance market efficiency with regard to reducing GHG emissions: those countries – or companies – that can more cheaply or easily reduce emissions should be able to sell these abatements to those which face higher costs in meeting emission reductions. In fact, an optimal system of ET minimises overall abatement costs by ensuring that emission reductions take place where marginal costs are lowest.

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[3] In the official language of the Kyoto Protocol, JI credits are called 'Emission Reduction Units' (ERUs), whereas the term 'Certified Emission Reductions' (CERs) is used for CDM credits.

[4] Other differences between CDM and JI as well as their impact on the performance of these mechanisms are discussed by Michaelowa (1999).

[5] In fact, the Kyoto Protocol speaks of 'Annex B countries' rather than 'Annex I countries'. Whereas the former category refers to countries mentioned in Annex B of the Kyoto Protocol, the latter category concerns countries listed in Annex I of the UNFCCC. Annex B includes all countries recorded in Annex I, except Belarus and Turkey that did not accept an emission abatement target at the Kyoto Conference. Unless stated otherwise, this report will speak of Annex I countries, implying those countries that have accepted an official commitment to limit their GHG emissions. Countries not having such a commitment are called 'non-Annex I countries.

In the Kyoto Protocol, Emissions Trading is treated briefly in Art. 17. It mainly urges the Conference of the Parties to define 'the relevant principles, modalities, rules and guidelines, in particular for verification, reporting and accountability for Emissions Trading'. In addition, it states that ET 'shall be supplemental to domestic actions'. Hence, the unresolved issue of defining supplementarity is also relevant here.

2.4.2 Open questions

Besides the unresolved issue of supplementarity, there are some other open questions related to ET. These questions concern mainly the institutional and operational aspects of an ET market system (Koutstaal et al., 1998). For instance, should it be a transparent auction-type system, or should non-transparent bilateral deals also be allowed? Another question is which entities – public agencies and/or private companies – are allowed to participate in an ET market system. Countries such as Canada, Denmark or the US have already started domestic systems for 'Tradable Emission Permits' (TEPs) between private companies. Some countries want to link these domestic systems directly to some international ET market so that companies can trade freely amongst each other at the international level. Other countries, on the contrary, are more interested in a more officially controlled and restricted ET system so that they can keep better track of what is happening within this system.

Another set of open questions concerns the monitoring, verification and certification of GHG emission reductions. A well functioning national system of ET between countries or governments requires a reliable, adequate system of recording, reporting and verifying emission data at the aggregated, macro level. This requirement may be hard to meet for some less developed Annex I countries in Central and Eastern Europe (CEE) and the Former Soviet Union (FSU). Hence, in first instance, these countries will most likely rely on JI transactions – because GHG emissions may be more easily monitored and verified at the project level – whereas a national ET system will probably apply mainly to western Annex I countries.

In addition, some GHG emissions – for instance, CHP-related CO_2 emissions – are more easily to measure than others, such as CO_2 sinks related to land use changes. Hence, in a more disaggregated ET system – allowing private companies to trade emission permits – the former emissions are more likely to be included than the latter.

2.5 Factors influencing the role and impact of Kyoto Mechanisms

2.5.1 Reduction requirements, potentials and costs

The role of the Kyoto Mechanisms is influenced by differences between countries regarding their emission reduction requirements, potentials and costs (see Chapters 3 and 4). Differences in national reduction costs are even the *raison d'être* of the Kyoto Mechanisms as their common objective is to increase the cost-effectiveness of national reduction requirements by means of activities abroad[6].

With regard to the costs of abatement projects – including technology transfers, institutional capacity building and other measures to address human-induced climate change - one can distinguish between those costs that are directly related to the projects as such, and transaction costs. The breakdown of direct project costs can differ for different types of projects. In the power sector, for instance, these costs include investment costs, operation and maintenance costs, saved fuel costs etc. Several difficulties arise when estimating the costs of emission reduction projects such as uncertainties with regard to the baseline, large differences between projects, and lack of data on new or rare project options.

[6] It should be noted that cost of emission reduction options refer to *net costs*, i.e. costs minus benefits.

Transaction costs are costs for defining the baseline, verification, monitoring, reporting and other administrative costs to identify, prepare and implement abatement projects. They are often hard to estimate because of i) lack of experience, ii) the wide varying and sometimes 'general' character of these costs, and, iii) the on-going development of the Kyoto Mechanisms. For instance, transaction costs of future JI projects will most likely differ from transaction costs of projects realised during the pilot phase called Activities Implemented Jointly.

2.5.2 Differentiation between greenhouse gases

As noted in Section 1.1, the Kyoto Protocol covers six categories of greenhouse gases (GHGs). Details on the five categories of non-CO_2 gases are provided in Table 2.1. The Global Warming Potential (GWP) of these non-CO_2 gases is significantly higher than for CO_2. The main emission sources for the EU as a whole are also indicated in Table 2.1.

Table 2.1 *Non-CO_2 GHG characteristics and emission sources (EU-15)*

Substance	Chemical formula	GWP[1]	Main sources in Western Europe. Percentage indicates the relevance for the reference year.
Methane	CH_4	21	Ruminants 40%, landfills 40%, fugitive fuel 20%
Nitrous oxide	N_2O	310	Fertilisers 40%, chemical industry 35%, combustion processes 25%
HFC-23	CHF_3	11700	CFC[2] alternatives: insulation and packaging foams, cooling
HFC-32	CH_2F_2	650	Equipment, fire extinguisher, dry cleaning, aerosol. Some
HFC-41	CH_3F	150	process emissions in the chemical industry (HFC-23)
HFC-43-10	$C_5H_2F_{10}$	1300	
HFC-125	C_2HF_5	2800	
HFC-134	CHF_2CHF_2	1000	
HFC-134a	CH_2FCF_3	1300	
HFC-143	CHF_2CH_2F	300	
HFC-143a	$C_2H_3F_3$	3800	
HFC-152a	$C_2H_4F_2$	140	
HFC-227ea	C_3HF_7	2900	
HFC-236fa	$C_3H_2F_6$	6300	
HFC-245ca	$C_3H_3F_5$	500	
HFC-356	$C_4H_4F_6$	Unknown	
Perfluoromethane	CF_4	6500	Primary Aluminium production 80%, CFC alternatives
Perfluoroethane	C_2F_6	9200	
Sulphurhexafluoride	SF_6	23900	High voltage switches 80%, magnesium casting

1 In accordance with the Kyoto Protocol, emissions for non-CO_2 GHGs are converted into CO_2 equivalents, based on a Global Warming Potential for 100 years (GWP values are based on IPCC guidelines)
2 CFC = ChloroFluoroCarbons
Source: Gielen and Kram (1998).

The emission sources of non-CO_2 GHGs are rather diverse (Table 2.1; see also Appendix A). The bulk of non-CO_2 emissions is not related to energy use but to a wide array of economic activities. As a consequence, different strategies must be developed for effective emission reductions in all categories. CO_2 abatement is predominantly an energy policy issue, while the reduction of other GHG emissions involves a number of other policy areas.

The differentiation of GHGs is relevant for the role of the Kyoto Mechanisms as emission reduction activities abroad should not only focus on CO_2 but also on other GHGs, notably CH_4 and HFCs[7].

7 See Chapter 4, which discusses trends in GHG emissions by gas and region (Section 4.2) as well as differences in potentials and costs to reduce CO_2 versus other GHGs (Sections 4.3 and 4.4). See also Appendix B.

2.6 Interaction of the Kyoto Mechanisms

2.6.1 Introduction

The three Kyoto Mechanisms trade in nominally different 'commodities', namely JI credits called 'Emission Reduction Units' (ERUs), CDM credits called 'Certified Emission Reductions' (CERs), and ET credits called 'Tradable Emission Permits' (TEPs). At first sight, these commodities seem to be traded on separate markets, which are distinguished institutionally by different systems of governance, monitoring, validation, etc. In fact, however, these markets are closely interrelated as they deal in the same basic commodity, namely additions to - or subtractions from - the amount of GHG emissions assigned to Annex I countries for the period 2008-2012. Hence, as Annex I countries may apply one or more of the Kyoto Mechanisms to meet this assigned amount, interaction - particularly competition – between the three Kyoto Mechanisms is likely to occur (see Figure 2.1). In addition to the comparative cost advantages of each mechanism, this interaction depends on a variety of other factors - such as the specific design and implementation of each mechanism – resulting in a set of relative advantages (or disadvantages) of each mechanism. Whereas the quantitative cost aspects of the Kyoto Mechanisms will be analysed in Chapters 3 and 4, the other, more qualitative advantages affecting the interaction and competition between the Kyoto Mechanisms will be discussed in the following Sections 2.6.2-2.6.4.

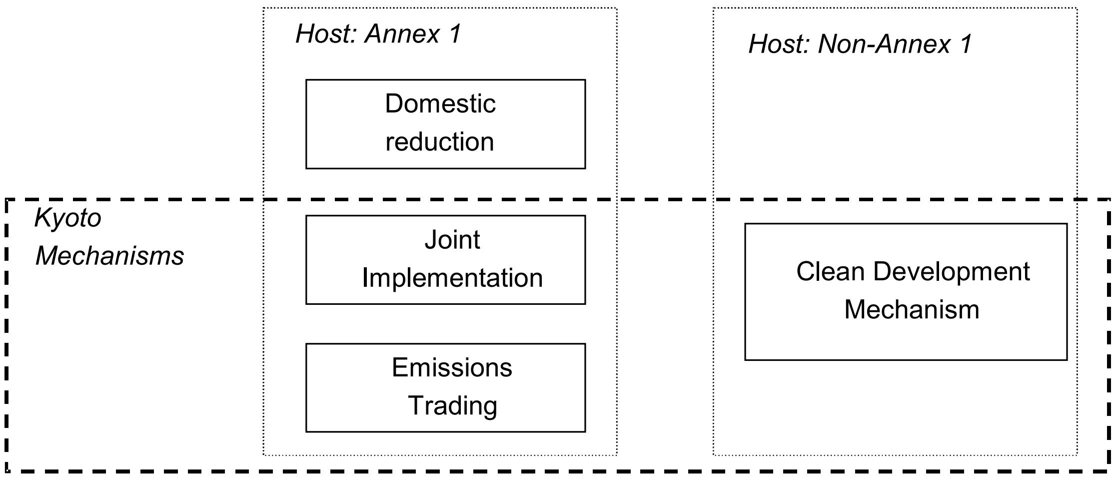

Figure 2.1 *Kyoto Mechanisms*

2.6.2 Advantages of Joint Implementation

Supplementarity

Depending on how the Kyoto Protocol is interpreted, the supplementarity requirement for CDM may be stricter than for JI and ET. While it is only generally stated that acquisition of JI and ET credits shall be 'supplemental to domestic actions', acquisition of CDM credits shall only cover a 'part' of the emission target. If the supplementarity requirement for CDM will indeed be stricter defined than for the other two mechanisms, this may be advantageous for both JI and ET transactions.

Sequestration projects

Sinks or sequestration projects may cost less in non-Annex I countries than in Annex I countries. However, whereas JI credits can accrue from sequestration projects, this is not yet clear for CDM credits.

Transaction costs
Transaction costs are likely to differ significantly for each Kyoto Mechanism although, at this stage, hard to quantify. Probably, transaction costs will generally be highest for CDM and lowest for ET (see Section 2.6.4). Compared to ET, CDM and JI will likely have higher administration costs due to the project-specific and other institutional procedures involved. The eligibility criteria, however, could be simpler for JI projects because there are no specifications for 'long-term benefits' or 'the purpose of sustainable development' as stipulated for CDM projects. Moreover, CDM transaction costs will be higher in order to meet the adaptation costs of non-Annex I countries that are particularly vulnerable to the adverse effects of climate change. As noted in Section 2.4.2, however, it is yet not clear how high these adaptation costs might be.

2.6.3 Advantages of the Clean Development Mechanism

Apart from possible advantages regarding reduction potentials and costs (see Chapters 3 and 4), the main advantage of CDM is that its credits can be accrued and banked starting from 2000, whereas JI and ET crediting is allowed only from 2008. As a result, the costs per tonne emission reduction may be smaller for CDM. A CDM project that starts in 2000, runs for 13 years and has each year the same amount of CERs can claim 13/5 more credits than a similar JI project, decreasing the price per tonne emission reduction by the same amount. As a consequence, CDM projects may be more attractive.

2.6.4 Advantages of Emissions Trading

The most important advantage of ET is that its transaction costs are likely to be significant lower than for JI or CDM. This applies particularly to more developed Annex I countries that have already made substantial progress in establishing well functioning systems of monitoring and verifying GHG emissions (see Section 2.4.2). Other advantages of ET are that several western Annex I countries have already some experience with domestic ET systems and that ET transactions between these countries are likely to be less political sensitive than generating and transferring JI/CDM credits.

2.7 The impact of Kyoto Mechanisms on the Kyoto objective

2.7.1 Introduction

Annex I countries have adopted the commitments of the Kyoto Protocol in order to limit their overall GHG emissions. The Kyoto Mechanisms have been introduced to achieve this target cost-effectively by enabling abatement transactions abroad. Hence, the Kyoto agreement - if ratified and implemented – provides, in principle, a cost-effective international framework for tackling human-induced climate change. In some cases, however, the spirit or overall objective of the Kyoto Protocol may by undermined by the Kyoto Mechanisms. These cases refer particularly to the 'hot air' issue and the potential danger of 'extensive' use of the Kyoto Mechanisms, notably of the Clean Development Mechanism. While the 'hot air' problem will be treated in Section 2.7.2 below, the potential danger of extensively using CDM will be dealt with in Section 2.7.3. Finally, the question whether these cases can be averted by introducing so-called 'ceilings' on the use of the Kyoto Mechanisms will be addressed in Section 2.7.4.

2.7.2 The 'hot air' problem

For some Annex I countries – notably Russia and the Ukraine – the assigned amounts of GHG emissions have been set high compared to expected emission levels in the first commitment period 2008-2012. In these countries, the recent economic crisis has caused a large decrease of GHG emissions since the base year 1990/95. The term 'hot air' refers to the (expected) difference between the assigned amount and the actual level of GHG emissions in the period 2008-2012, resulting from economic stagnation rather than real abatement efforts. As a result, a large volume of emission credits may be available for emissions trading (so-called 'hot air' trading). Estimates of the potential amount of hot air vary widely from several thousands of tonnes CO_2 equivalents to as much as 10% of total Annex I allowed emissions in 2008-2012 (Michaelowa, 1999, and Grubb et al., 1999). If the latter, highest estimates would be correct and the amounts of hot air involved would be available for ET, it would have far-reaching consequences for climate change policies. Firstly, it would induce large-scale ET from Russia and the Ukraine to major Annex I countries such as the US, Canada and Japan. Secondly, depending on the market behaviour of the major parties involved, it would have a significant impact on the international equilibrium price of emission credits traded via one or all of the Kyoto Mechanisms. Finally, it would undermine the spirit and overall objective of the Kyoto Protocol as hardly any Annex I country would be obliged to reduce its GHG emissions by real policy-driven abatement efforts.

2.7.3 The danger of using the Clean Development Mechanism improperly

According to some authors (Grubb et al., 1999, Michaelowa, 1999), the spirit or overall objective of the Kyoto Protocol may also be violated by an 'extensive', i.e. large-scale use of the CDM. Estimates of the CDM potential in non-Annex I countries vary widely from less than 30 million tonnes CO_2 to more than 1,600 Mt (idem, as well as Van der Linden et al., 1999, discussed in Section 3.5.4)[8]. About half the latter estimate consists of reduction options characterised by 'negative' abatement costs – the so-called 'profitable potential' – while the other half would be available at relatively low costs (Van der Linden et al., 1999). If correct, using these potentials fully on behalf of the first budget commitments would indeed imply that a structural reduction of GHG emissions in Annex I countries would hardly occur. However, whether and to what extent this will happen depends highly on a large variety of factors – especially the further elaboration of CDM rules and modalities – as well as on tackling several other institutional and political barriers to implement CDM projects in non-Annex I countries.

Moreover, the key problem concerning the Clean Development Mechanism is not an 'extensive' but rather an 'improper' use of this mechanism resulting in all kinds of 'leakages' and 'figurative' or 'phoney' abatement projects. Probably the best way to avoid an improper use of CDM is to formulate a list of criteria to which CDM projects must comply in order to ensure that only genuine reduction activities are accepted to generate and trade CDM credits.

2.7.4 Ceilings as a solution?

The introduction of so-called 'ceilings' might be a solution to the above-mentioned problem of using the Kyoto Mechanisms unrestrictedly. There are a variety of options to implement a ceiling (Ybema et al., 1999, see Section 3.5.5). Moreover, ceilings could refer to the use of each mechanism separately or to all mechanisms together. The EU and many environmental NGOs have lobbied hard for a strict definition of the supplementarity issue through fixed ceilings on the use of all Kyoto Mechanisms.

[8] To compare, total CO_2 emissions of all Annex I countries in 1990 amounted to some 14,000 Mt (Section 4.2).

More specifically, the EU has proposed an overall ceiling on the use of all mechanisms together to a maximum of 50% of the national reduction requirements, implying that at least 50% of this requirements has to be achieved by domestic actions. The US, on the contrary, argues that 10 or 20% would comply with the Kyoto Protocol in both letter and spirit. For the time being, this issue remains unresolved.

The most important advantage of introducing ceilings on the use of Kyoto Mechanisms is that it would force industrialised countries to reduce GHG emissions by domestic actions and, hence, to develop new abatement technologies that could spread globally and really address the greenhouse issue in the long run. On the other hand, the main disadvantage of ceilings is that they will raise abatement costs, notably in the short and medium term. In response, Annex I countries such as the US may refuse to ratify the Kyoto Protocol if the ceilings are too strict, or they may be willing to accept lower reduction commitments after the first budget period. Moreover, ceilings will reduce the international price of emission credits, which harms countries exporting these credits, notably those countries in Central and Eastern Europe, the Former Soviet Union and the non-Annex I region that need foreign exchange heavily. In addition, due to ceilings, these countries will also suffer from less foreign investments and technology transfers inherent to JI or CDM projects.

Another qualification to introducing 'supplementary' ceilings upon countries that import emission credits is that it will hardly solve the problem of 'hot air' trading as exporting countries would spread their hot air more widely among acquiring countries (Grubb et al., 1999). A more effective approach could be the introduction of direct ceilings upon exporting countries of hot air, but this may be hard to accept for countries such as Russia or the Ukraine which need foreign exchange badly to cope with their economic crisis. Hence, solving the issue of ceilings – notably on trading hot air – will require a cumbersome process of negotiating and compromising between the major parties involved.

3. KYOTO MECHANISMS: A REVIEW OF ECN STUDIES

3.1 Introduction

This chapter discusses previous ECN studies regarding the role and impact of Kyoto Mechanisms. Section 3.2 starts with a short overview of these studies, including their relationship with the underlying study. Next, Section 3.3 provides a brief outline of the methodological approach used in the present and previous ECN studies of Kyoto Mechanisms. Subsequently, the major sources, limitations and other qualifications of data used in these studies are treated in Section 3.4. The major results of the previous studies are considered briefly in Section 3.5, whereas Chapter 4 outlines in more detail the main findings of the present study. In addition, Chapter 4 discusses the most important limitations of the analysis and indicates some potential consequences for the major research findings.

3.2 ECN Studies of Kyoto Mechanisms

Over the past three years, the unit Policy Studies of the Netherlands Energy Research Foundation (ECN) has conducted several studies of the potential role and operation of the Kyoto Mechanisms in achieving national commitments to reduce GHG emissions. Notably, the main studies include:

- A study of the opportunities and limitations of Joint Implementation (JI) with countries in Central and Eastern Europe (CEE), notably with regard to realising the Dutch CO_2 emission reduction target in the year 2010 (Van Harmelen et al., 1997).
- A study regarding the role of Emissions Trading (ET). This study concerns a quantitative analysis of a CO_2 system of Tradable Emission Permits (TEPs) among the major countries of the OECD (Koutstaal et al., 1998).
- A study concerning the potential and cost of the Clean Development Mechanism (CDM). This study inventories and analyses the options in non-Annex I countries to reduce GHG emissions, especially of CO_2 emissions in the energy sector (Van der Linden et al., 1999).
- A 'Post-Kyoto' study concerning the impact of the Kyoto Protocol on the Member States of the European Union (EU), notably with regard to the distribution and cost of national targets to reduce emissions of both CO_2 and five other greenhouse gases (Gielen et al., 1998). In addition, another 'Post-Kyoto' study has analysed the consequences for EU Member States of potential ceilings on the use of Kyoto Mechanisms to achieve national emission reduction targets (Ybema et al., 1999).
- The present study regarding the role of Kyoto Mechanisms. In this study, the analysis covers all three mechanisms, all six greenhouse gases, and all major countries/regions of the world within an integrated approach.

An overview of the above-mentioned ECN studies of the role and operation of Kyoto Mechanisms – classified according to regional coverage and GHG emissions – is included in Figure 3.1.

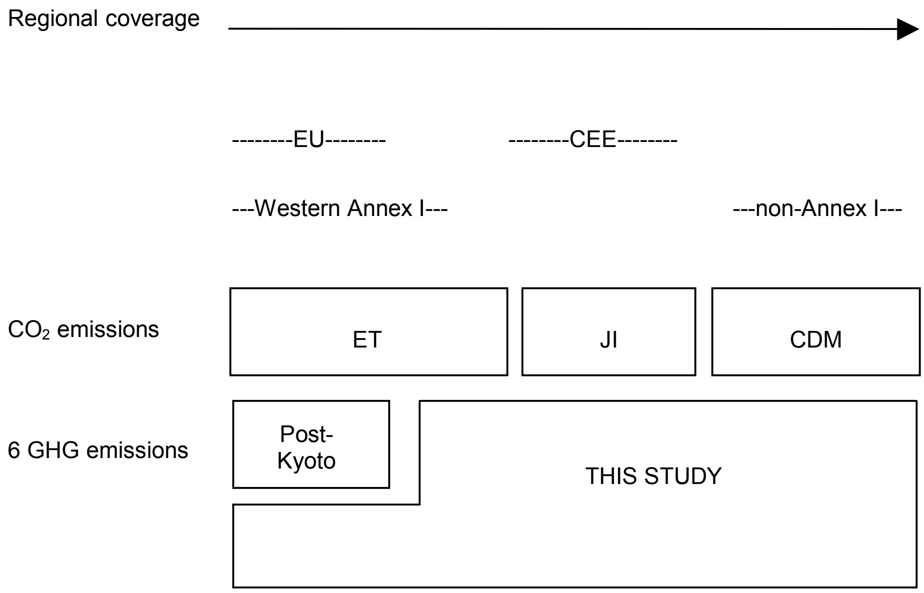

Figure 3.1 *Overview of ECN studies regarding Kyoto Mechanisms*

3.3 Methodological approach

The approach followed in this study is based upon the methodology applied in previous ECN studies of Kyoto Mechanisms. A spreadsheet model has been developed to simulate a market for trading *emission credits* in order to indicate the potential role and cost impact of each Kyoto Mechanism separately and, subsequently, for all mechanisms together in a global setting. The term 'emission credits' is used as the collective concept for credits generated and transferred by JI, CDM and/or ET (see Section 2.6.1). It is assumed that this basic commodity is traded on an integrated market. In addition, the methodological approach outlined below is based on the following assumptions:

- no restrictions on trading emission credits,
- no transaction costs for generating and trading emission credits,
- no risks and uncertainties, i.e. information is fully and freely available,
- no institutional changes affecting the market of emission credits,
- no strategic or dominant behaviour of market parties,
- market parties act rationally, i.e. they are maximising socio-economic objectives while minimising costs.

As a first step in the approach followed, data have been gathered or estimated with regard to:

- National or regional GHG emissions in a reference year (i.e. 1990/95) and a future year (i.e. 2010, as representative of the period 2008-2012). By means of these data and certain reduction targets – such the Kyoto commitments for 2010 – national or regional reduction requirements have been calculated (in terms of physical quantities of GHG emissions).
- The potential and costs to reduce GHG emissions in a certain country or region. These data have been used to determine individual cost curves for the reduction of GHG emissions in a particular country or region. Subsequently, these individual curves have been added up and combined into aggregated cost curves covering several or all GHGs, countries and/or regions. Finally, this process of adding up cost curves has resulted in the construction of a world-wide cost curve for the reduction of all GHG emissions (see Chapter 4).

As noted, the data on emission reduction requirements, potentials and costs have been used to simulate a market for trading emission credits. For an individual country (or region), the methodology applied can be illustrated graphically by means of Figure 3.2. Quantities of emission credits – in tonnes of CO_2 equivalents - are indicated by the X-axis, whereas the price or cost of emission credits is reflected by the Y-axis. The set of emission reduction options and corresponding marginal cost levels is represented in Figure 3.2 by the marginal cost curve. This MC curve can be regarded as the supply curve of emission credits of the country concerned.

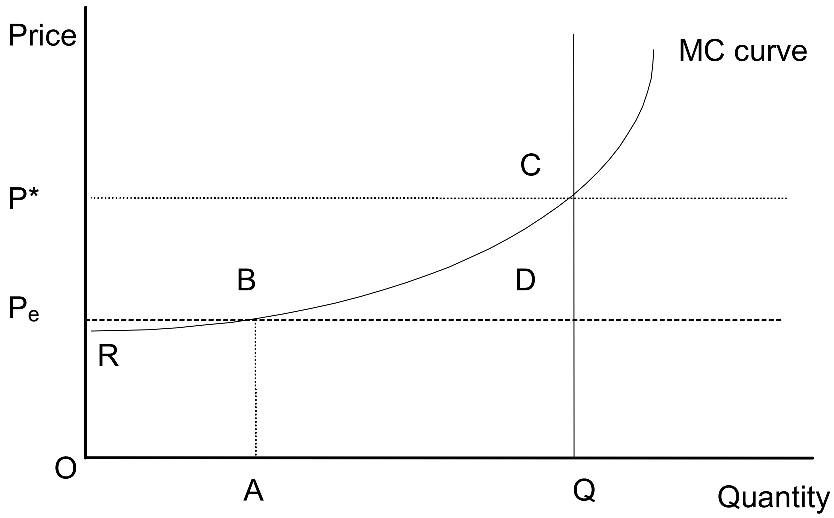

Figure 3.2 *Market of emission credits for an importing country*

The demand curve of emission credits depends on the amount of emissions that a country is obliged to reduce according to the Kyoto Protocol. In Figure 3.1, this curve is represented by a vertical line, expressing the amount Q of GHG emissions to be reduced. In case of 'no trade' (i.e. no use of Kyoto Mechanisms), the interSection of this line and the MC curve determines the equilibrium price (P^*) on the domestic market of emission credits. Whereas the marginal cost to achieve the required amount of emission reductions is – by definition – equal to this price level, the total abatement costs are represented by the integral below the MC curve (i.e. area OQCR in Figure 3.2).

By aggregating the supply and demand curve of all countries concerned, the same procedure has been used to determine the equilibrium price on the international market of emission credits. As an example, this price level is indicated as P_e in Figure 3.2. If a country is allowed to trade emission credits, it will reduce its domestic GHG emissions up to the point where its domestic marginal abatement costs are equal to P_e (see line AB). In the example of Figure 3.2, the country concerned will reduce OA amounts of emissions at home and buy (import) AQ amounts of emission credits abroad – through ET/JI/CDM - in order to achieve its total Kyoto objective of OQ. In this case, total abatement costs are equal to the area OQDBR. Compared to the case of 'no trade', this implies a decrease of total abatement costs corresponding to area BCD.

Figure 3.2 represents the case where a country imports emission credits due to the fact that the international equilibrium price P_e is below its domestic price level P^*. However, if $P_e > P^*$, a country will export emission credits. This case is illustrated graphically in Figure 3.3 where all the symbols and curves have the same meaning as in Figure 3.2. In this case, the amount of domestic reductions will be A, whereas only Q is required, resulting in exports of emission credits equal to QA of the country concerned and an increase of its gross domestic abatement costs by QABC. However, the revenues of emission credit exports - via ET, JI or CDM - is equal to QABF, leading to a net gain of CBF. Hence, the use of Kyoto Mechanisms is profitable for both importing and exporting countries of emission credits[9].

9 Non-Annex I countries are not obliged to reduce GHG emissions. In that case, Q is equal to O, whereas the net gains from trading emission credits correspond to area RBP_e in Figure 3.3.

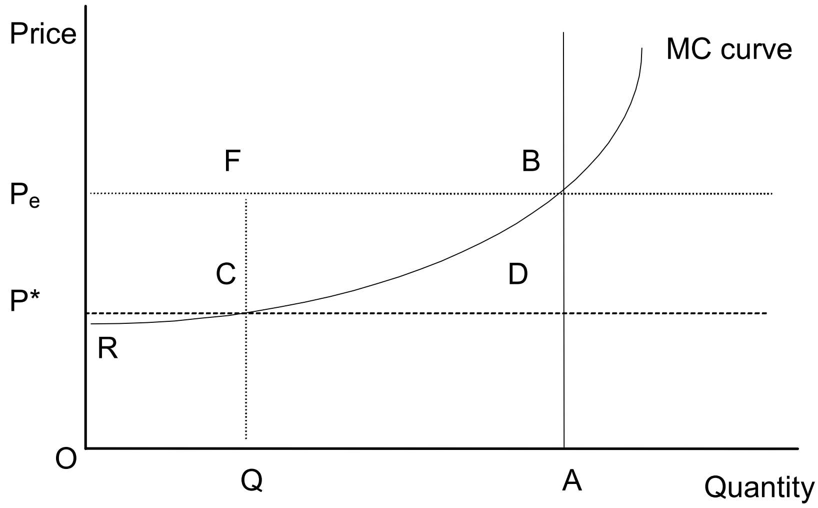

Figure 3.3 *Market of emission credits for an exporting country*

To summarise, the methodological approach outlined above enables one to determine the emission reduction requirements for a particular country or region, the equilibrium price of emission credits both ‘before trade’ and ‘after trade’, the marginal and total abatement costs before and after trade, the amounts of emissions reduced at home and traded abroad, and the cost savings or ‘net gains’ of importing or exporting emission credits by means of the Kyoto Mechanisms ET, JI or CDM. Moreover, by adding data on GDP or population to the spreadsheet programme, a variety of additional indicators – such as emissions per capita or abatement costs as a percentage of GDP – can be calculated. In addition, this approach enables one to analyse the impact of so-called ‘ceilings’ on using Kyoto Mechanisms as well of the effects of alternative burden sharing rules to reduce GHG emissions (compared to those agreed as part of the Kyoto Protocol)[10].

3.4 Data sources and qualifications

The present study relies heavily on the availability and reliability of a large variety of data for a large number of countries and regions. The most important data concern estimates of GHG emissions in 1990/95 and 2010 as well as of cost curves representing the potential and costs of emission reduction options. Table 3.1 provides an overview of the major sources of the data used for the present study. The main limitations and other qualifications of these data will be discussed below. More details can be found in the data sources and references mentioned in Table 3.1.

In general, data on emission levels are less uncertain for CO_2 than for the other GHGs[11]. In addition, emission data seem to be more reliable, more readily available and more detailed for OECD countries than for countries in Central and Eastern Europe (CEE), the Former Soviet Union (FSU), and – particularly – the non-Annex I region. Moreover, estimates of emission levels for the reference year (1990/95) are less uncertain compared to baseline projections for the year 2010 as the latter are based on assumptions regarding trends in economic growth, economic structure and technological innovations. These assumptions vary per study. The consequences of these uncertainties are two-fold.

[10] See the studies mentioned in Section 3.1, notably Van Harmelen et al. (1997), Koutstaal et al. (1998), Gielen et al. (1999) and Ybema et al. (1999).
[11] See Appendix A for a discussion of the uncertainties regarding non-CO_2 GHG emission data.

Firstly, data on emission levels have to be interpreted with the necessary prudence. Secondly, estimates of emission levels may sometimes vary (significantly) by source or reference used, depending on the method of estimation, the major assumptions applied and adjustments made in the course of time. In general, the present study has tried to use the most reliable data, occasionally updated or adjusted to more recent information and insights[12].

Table 3.1 *Overview of major data used in present study*

	Western Annex I	CEE/FSU Annex I	Non-Annex I
Emissions:			
CO_2 1990	2, 4, 5	1	6
2010	2, 4, 5	1	6, 7
N_2O/CH_4 1990	4, 5, 6	6	6
2010	4, 5, 6, 7	6, 7	6, 7
Other GHG[13] 1990/5	4, 5, 8	8	8
2010	4, 5, 8	8	8
Cost Curves:			
CO_2	2, 4, 5	1	3
Other/Total GHGs	4	4	4
Other Data:			
GDP 1990	9, 10, 11, 12	9, 10, 11, 12	9, 10, 11, 12
2010	9, 10, 11, 12	9, 10, 11, 12	9, 10, 11, 12
Population 1990	9, 10, 11	9, 10, 11	9, 10, 11
2010	9, 10, 11	9, 10, 11	9, 10, 11

1 =Van Harmelen et al. (1997), 2 =Koutstaal et al. (1998), 3 =Van der Linden et al. (1999), 4 =Gielen et al. (1998), 5 =Ybema et al. (1999), 6 =Olivier et al. (1996), 7 =Alcamo et al. (1998)[14], 8 =Fennhann (2000), 9 =World Bank (1997), 10 =World Bank (1999), 11 =CIA (1999), 12 =IEA (1998).

Marginal cost curves for reducing CO_2 emissions are available for most western Annex I countries. These curves have been derived from ETSAP and COHERENCE studies, based on detailed energy and technology bottom-up models such as MARKAL and EFOM. This type of model studies offers a long-term strategy to achieve national emission reduction targets given certain economic and technological prior conditions such as international energy prices, characteristics of the energy sector, available emission reduction options, and expectations regarding future energy demand and economic structure. Hence, cost estimates of future emission reductions based on such models are uncertain as they depend critically on assumptions made regarding these prior conditions. Moreover, the comparability of these model studies is subject to several limitations as country-specific circumstances, socio-political preferences and national assessments regarding emission reduction options and costs are not always fully and uniformly accounted for[15].

[12] For additional remarks and other details on emission data of EU Member States, see Gielen et al. (1999) and Ybema et al. (1999).
[13] Excluding sinks, i.e. changes in GHG emissions due to land use changes and forestry activities.
[14] Scenario B.
[15] More details can be found in Van Harmelen et al. (1997) and Koutstaal et al. (1998).

For Annex I countries in the CEE/FSU region, CO_2 marginal reduction cost curves are scarcely available. As part of the Joint Implementation study (Van Harmelen et al., 1997), ECN has estimated the potential and cost of reducing CO_2 emissions by means of two types of studies. Estimates of the demand-side potential and costs of CO_2 emission reductions have been based on energy-efficiency studies of the OECD (1996a and 1996b), whereas the supply-side potential and costs have been estimated by means of model simulations constructed by ECN for Slovakia and the Czech Republic (Van Harmelen et al., 1994a and b; IEA, 1995; and De Kruijk et al., 1993). These estimates, however, have to be treated with caution as they suffer from several uncertainties, notably with regard to the availability of the so-called ‘profitable reduction potential’ (i.e. ‘no-regret’ options characterised by negative reduction costs). Therefore, ECN has developed two variants, one including and one excluding this profitable potential in the year 2010[16].

For the non-Annex I region as a whole, an emission abatement cost curve has been derived from information on the costs and potential of reducing GHG emissions in this region (Van der Linden et al., 1999). This information has been collected from a large variety of abatement costing studies covering some 300 GHG reduction options in non-Annex I countries. As these options concern mainly energy-related CO_2 emissions, the final result can be regarded as predominantly a CO_2 reduction cost curve. This result, however, has to be interpreted cautiously because of several critical limitations involved[17]:

- The total potential of reduction options is based on abatement costing studies in 24 non-Annex I countries – accounting for two-thirds of total GHG emissions in the non-Annex I region – and extended to the rest of this region, using a simple extrapolation method (i.e. scaling up potential by a factor 1.5).
- On the one hand, the total potential of reduction options may be heavily underestimated as numerous abatement costing studies excluded significant reduction options, notably outside the energy sector. On the other hand, it may be largely overestimated as actual investor costs are likely to substantially exceed economic costs represented in the abatement studies.
- Different assumptions and approaches across abatement costing studies make it difficult to reconcile and combine results.
- Estimates of abatement potential and costs depend very sensitively on assumptions about the baseline scenarios.
- Definition of costs is not consistent across studies.
- Transaction costs of potential CDM projects have often been excluded.

The potential and costs of reducing emissions of non-CO_2 GHGs are based on a variety of studies as described briefly in Appendix B. These studies only focus on emission abatement options in EU Member States. Due to lack of data, estimates of non-CO_2 reduction cost curves for non-EU countries and regions have also been based on these studies.

[16] It should be noted that the present study has aggregated the Annex I countries of CEE/FSU into one region, whereas the JI study has also analysed CO_2 emission levels, reduction potentials and costs for individual countries. For details, see Van Harmelen et al. (1997).

[17] For details and some other, less important limitations, see Van der Linden et al. (1999).

3.5 Results of previous studies of Kyoto Mechanisms

3.5.1 Introduction

As outlined in Section 3.2, ECN has conducted several previous studies of the role of Kyoto Mechanisms in achieving national emission reduction targets. The major results of these studies will be briefly presented below. In general, the scope of these studies has been more restricted than the present study – i.e. focusing on CO_2 and/or one particular region – leading to different, occasionally more detailed research findings which can be compared or added to the results of the present study discussed in Chapter 4.

3.5.2 The Emissions Trading study

The study of Emissions Trading (ET) – or Tradable Emission Permits (TEPs) – concerned a quantitative analysis of a CO_2 ET-system among the major countries of the OECD (i.e. the western Annex I countries). This study was undertaken before the Kyoto conference. Therefore, as a starting point for the different cases studied, it was assumed that all Annex I countries together should reduce their CO_2 emissions by 10%. The cases studied have been: a flat rate of 10% for each country, a differentiated EU distribution scheme combined with a 10% reduction for the other OECD countries, and the so-called Triptych approach applied to all OECD countries. Two trading systems have been considered, one covering only OECD countries and one including also Central and Eastern European countries. Furthermore, two extreme cases have been studied for the OECD trading scheme: equal costs per unit of GNP (after trade) and equal emissions per capita (before trade). With regard to the role of ET, the major results of this study include:

- ET will considerably reduce total abatement costs compared to a situation without trade by about 50%.
- The EU will be a net exporter of TEPs in an OECD trading scheme, mainly because of low cost options for reducing CO_2 emissions in Germany and the United Kingdom. Japan will be the main importer of TEPs.
- Countries which benefit most of ET are those countries where marginal reduction costs before trade diverge widely (either positively or negatively) from the equilibrium price coming about on a TEP-market. Within an OECD trading scheme, these countries include Japan, Australia, Italy and Germany.
- For the US, ET will be limited and hardly profitable within an OECD trading scheme. It will be far more important and lucrative for the US, however, if ET is extended to countries of Central and Eastern Europe because the reduction potential is large and the costs relatively low in these countries.
- For most countries analysed, the value of buying and selling TEPs represents less than 2% of their total imports or exports of goods and services.

3.5.3 The Joint Implementation study

The JI study has analysed the potential contribution of Joint Implementation with CEE countries to the Dutch CO_2 emission reduction target in the year 2010. The study was carried out before the third Conference of the Parties in Kyoto. The most important findings of this study have been:

- A substantial JI potential of 1,200 to 2,000 Mt emission reductions in CEE countries is available at relatively low costs.
- The largest JI potentials in CEE can be found in Russia (52% of total potential) and to a lesser extend in Poland (15%), Ukraine (12%), the Czech Republic (6%), Romania (4%), and Bulgaria (2%). However, given the high investment risks in Russia and the Ukraine and the expected measures which need to be undertaken by Poland and the Czech Republic to fulfil their own reduction targets, it seems sensible to focus on JI projects in Romania and Bulgaria.

- The JI potential in CEE depends highly on various yet undermined factors such as the rules and procedures regarding monitoring and verification of JI projects. Also on the issue of additionality, the baseline method, the emission reduction potential in non-Annex I countries, and the problem of credit sharing, i.e. the distribution of emission credits between the host and donor (investing) countries.
- The cheapest reduction options in CEE include forestry projects which absorb CO_2 (less than 3 US$ per tonne CO_2 equivalents) and fuel-switch and energy-efficiency projects, notably in the Baltic States (2-10 US$ per tonne CO_2 equivalents).
- Transaction costs of JI projects are estimated at 13 to 20% of total investment costs. These costs include (a) general project costs such as costs for project identification, feasibility studies and administration, and (b) specific JI costs such as costs to determine emission reference scenarios or costs to monitor and verify emission reduction performance.

3.5.4 The Clean Development Mechanism study

The objective of the CDM study has been to inventory and analyse the potential and costs of GHG emission reduction options in non-Annex I countries in order to assess the opportunities and limitations of CDM as an instrument to meet national Kyoto requirements of Annex I countries. The study is based on a comprehensive compilation of abatement costing studies, projects carried out within the framework of Activities Implemented Jointly (AIJ) and projects under the Global Environment Facility (GEF). Its major results include:

- The abatement potential in non-Annex I countries is significant compared to Annex I reduction requirements, and a considerable fraction of this potential can be harnessed at low cost. Subject to the limitations explained in Section 3.4, an annual abatement potential in the non-Annex I countries in the first budget period (2008-2012) at costs up to 50 US$ per tonne CO_2 equivalents has been projected of approximately 2.3 Gigatonnes of CO_2 (costs are expressed in 1990 US$). The GHG abatement costing studies further suggest that approximately 1.7 Gt CO_2 equivalents per year would be available during the 2008-2012 budget period at net marginal costs below 10 US$/tonne CO_2. The potential of 'no-regret' options is estimated at some 0.8 Gt. If emission credits are banked from projects implemented during the 2000-2008 period, the annual reduction potential increases accordingly.
- A large fraction of the total identified abatement potential can be realised in a relatively small number of non-Annex I countries. The identified abatement potential for China and India already constitutes nearly 70% of the total identified potential.
- Two types of activities are indicated to encompass most abatement potential, i.e. energy efficiency measures in the power sector and demand-side energy-efficiency measures (together 66%). The role of renewable energy is limited to 14% of identified abatement measures and the role of fuel switch (from oil or coal to natural gas) is 17%.
- Based on (partial) market simulations of buying and selling CDM-based emission credits, it was estimated that the global trading price of emission credits could decrease from 18-29 US$ per tonne CO_2 equivalents (including ET and JI) to a level of 4-15 US$ per tonne (adding CDM options, assuming that these options would be available to Annex I countries at the scale and costs indicated above).

3.5.5 The Post-Kyoto studies

As noted in Section 3.2, two so-called 'Post-Kyoto' studies have been conducted by ECN to analyse the impact of the Kyoto Protocol on the Member States of the EU. The main purpose of the first study (Gielen et al., 1998) has been to provide insight in alternative possibilities for dividing the 8% emission reduction target of the EU among its Member States (Burden Sharing), as was laid down in the Kyoto Protocol.

The variants examined have been: (i) distribution on the basis of a flat rate of 8% for all Member States, (ii) distribution on the basis of equal burden per unity GNP, (iii) distribution on the basis of equal marginal reduction costs, and (iv) a so-called 'adjusted March97' differentiation[18]. The major findings of this study have been:

- Projections show that EU emissions in 2010 will be more or less stabilised. This is explained by a relatively low growth rate of CO_2 emissions (mainly as a consequence of a decrease in CO_2 emissions in Germany) and by a decrease of the two other major non-CO_2 GHG emissions, CH_4 and N_2O.
- In an analysis covering a basket of 6 greenhouse gases and sinks, the EU burden of greenhouse gas reduction is considerably less than in analysis based exclusively on CO_2. On the one hand, this is the result of a decrease of the emission level of CH_4 and N_2O over the period 1990-2010 and, on the other hand, the presence of relatively inexpensive options for reducing emissions of CH_4, N_2O and HFCs.
- Estimates of total abatement costs show no substantial differences between distributions on the basis of equal burden per unity of GNP and equal marginal costs (variants ii and iii). For the EU as a whole, however, the costs of these variants are considerably less compared to the other two burden sharing variants. The total abatement costs of the most efficient distribution (equal marginal costs) are no less than 8 times smaller than the emission reduction costs of the adjusted March97 differentiation.

A major characteristic of the above-mentioned Post-Kyoto study is that it covers not only CO_2 but also the other GHGs in estimating the costs to meet the Kyoto commitment of EU Member States. On the other hand, it did not consider the use of Kyoto Mechanisms in achieving this commitment. However, this issue has been the subject of another 'Post-Kyoto' study of ECN (Ybema et al., 1999). More specifically, this study has analysed the cost consequences for EU Member States of ceilings on the use of Kyoto Mechanisms. The purpose of these ceilings is to limit the purchase of emission credits abroad in order to safeguard that domestic actions will be the main means for reaching national reduction requirements (see Section 2.7.4). The ceilings considered concern different percentages of either (i) the reference year emissions in 1990/95, (ii) the assigned amounts of emissions in 2010, (iii) the required emission reduction in 2010, or (iv) the difference between the baseline and assigned amounts of emissions in 2010. The most important insights of this study include:

- All types of ceilings considered limit the contribution of Kyoto Mechanisms to meeting national reduction commitments. The largest effect on the demand for emission credits by individual EU Member States is a decrease by almost 70% compared to a situation without a ceiling.
- The ceilings considered can be divided in those having a large impact and those having a modest impact. A large impact on the demand for emission credits occurs for the following ceilings:
  - 2.5% of assigned amount,
  - 2.5% of base year emissions,
  - 50% of required reduction.
- A modest impact on the demand for emission credits occurs for the following ceilings:
  - 10% of assigned amount,
  - 10% of base year emissions,
  - 50% of the difference between the baseline and assigned amounts.

[18] In March 1997, the European Union agreed upon an internal differentiation among its Member States of a common reduction target of 10%. After the Kyoto conference, adjustment of this agreement was needed due to i) a lower reduction target for the EU as a whole – i.e. 8% - and ii) the inclusion of three additional GHGs and sinks. This resulted in the so-called 'adjusted March97' differentiation.

- For the EU as a whole, the cost consequences of ceilings on using Kyoto Mechanisms are most substantial for ceilings with a large impact on the demand for emission credits. Then, the abatement costs will typically increase by 100-300% compared to a situation without ceilings. For ceilings having a modest impact on the demand for emission credits, these costs will increase by 10 to 40%. The cost effects for the EU as a whole will be least for the ceiling which limits the use of Kyoto Mechanisms to 50% of the difference between the baseline and assigned amounts of emissions in 2010.
- Imposing ceilings on the use of Kyoto Mechanisms will lower the equilibrium price of emission credits.
- The impact of ceilings on national abatement costs depends on the stringency of the ceiling, the way the ceiling is designed, and the equilibrium price of emission credits on the international market. In general, this impact will be more significant if the international price of emission credits is lower.
- The cost consequences of ceilings differ per EU Member State. Four groups of countries can be distinguished:
  - Countries that will have fewer benefits from selling emission credits due to lower sale prices of these credits. According to the present analysis, this will be the case for Germany, France, Portugal, Spain, Ireland and Luxembourg.
  - Countries that will have lower costs for all ceilings and market prices considered. Such countries are net purchasers of emission credits, for which none of the ceilings is binding while it is binding for other countries. These countries can purchase emission credits at lower prices than in a situation without ceilings. This is the case for the United Kingdom.
  - Countries for which the cost effects depend on the kind of ceilings and the equilibrium price of emission credits. For some of the ceilings considered, the purchase of emission credits will be constrained. In that case, the net effect on total abatement costs depends on the difference between the additional costs of domestic measures and possible less costs via the lower purchase price of emission credits. This is the case for the Netherlands, Belgium, Italy, Sweden, Finland and Greece.
  - Some countries will have higher costs for all prices of emission credits and ceilings considered. This will be the case for Denmark and Austria.

If interpreted with prudence, the above-mentioned results of the previous studies on the role of Kyoto Mechanisms can be compared or added to the main findings of the present study, which will be discussed in the next chapter.

4. KYOTO MECHANISMS: A QUANTITATIVE ANALYSIS

4.1 Introduction

This chapter will discuss the quantitative results of the present study. In contrast to previous ECN studies on the role and impact of the Kyoto Mechanisms – which focus mainly on only CO_2 emissions, one particular mechanism and/or one particular region – the major distinguishing characteristic of the present study is that it covers all GHGs, all Kyoto Mechanisms and all major regions in the world. Its major results concern particularly the trade and cost effects of the Kyoto Mechanisms in meeting the reduction requirements of Annex I countries with regard to the first budget period 2008-2012. As explained in the previous chapter, these results have been achieved by means of a spreadsheet model developed by ECN, using a wide variety of data on emission trends, reduction requirements, abatement potentials and costs covering a large sample of countries and regions in the world.

The structure of this chapter runs as follows. First of all, Section 4.2 will analyse trends in GHG emissions over the period 1990-2010 in order to estimate reduction requirements of Annex I countries in the year 2010 (which stands for the annual average of the period 2008-2012). Subsequently, Section 4.3 will present some aggregated cost curves, indicating abatement potentials and reduction costs at both the regional and global level. Thereupon, Section 4.4 will discuss the major results of the present study with regard to the trade and cost effects of the Kyoto Mechanisms in meeting Annex I reduction requirements. Finally, the major limitations of the present quantitative analysis and some possible consequences for its major results will be discussed in Section 4.5.

4.2 Trends in GHG emissions

4.2.1 Distribution of GHG emissions

Table 4.1 shows the expected trends in emissions of all six greenhouse gases in the period 1990-2010. The total GHG emissions are expected to rise from almost 31 billion tonnes CO_2 eq. in 1990 to 38 billion tonnes in 2010 (+25%). This global trend, however, hides major differences by region and by gas. For instance, total GHG emissions in the CEE/FSU Annex I region slightly decrease in the period 1990-2010. This decrease is mainly due to the economic crisis in several countries within this region. In the western Annex I countries, total GHG emissions increase by some 16% in that period, whereas in the non-Annex I region this increase is even 42%. As a result, the share of non-Annex I countries in total GHG emissions increases from 44% in 1990 to 49% in 2010 (see Figure 4.1). Of all regions considered, Africa shows the largest growth in total GHG emissions (+81%), which is mainly caused by a large growth in CO_2 emissions (+145%).

Compared to other estimates, the CO_2 emission level for non-Annex I countries in 2010 is slightly conservative. This results from the assumptions regarding the growth of CO_2 emissions which were taken from the 'B scenario' of Alcamo et al. (1988). Likewise, the level of N_2O emissions for non-EU countries – based on the EDGAR database (Olivier et al., 1996) – is low compared to recent insights on measurement of emissions and relevant sources that should be included.

Table 4.1a *Trends in GHG emissions 1990-2010 by region and by gas [in CO_2 eq.]*

	GHG 1990 [Mt]	GHG 2010 [Mt]	Growth [%]	CO_2 1990 [Mt]	CO_2 2010 [Mt]	Growth [%]	CH_4 1990 [Mt]	CH_4 2010 [Mt]	Growth [%]
Western Annex I	12588	14645	16	9920	11702	18	1628	1596	-2
CEE/FSU Annex I	4885	4813	-1	4124	3962	-4	500	565	13
Total Annex I	*17473*	*19458*	*11*	*14044*	*15664*	*12*	*2128*	*2161*	*2*
Latin America	2141	2572	20	1021	1284	26	657	749	14
Africa	1589	2877	81	767	1876	145	483	630	30
Asia	7290	10535	45	4051	6337	56	2238	2746	23
FSU (Non-Annex I)	1232	1330	8	341	442	30	696	690	-1
Middle East	1113	1702	53	838	1317	57	190	289	52
Oceania	9	13	40	4	4	5	3	3	2
Total non-Annex I	*13374*	*19028*	*42*	*7022*	*11260*	*60*	*4268*	*5106*	*20*
WORLD	30848	38486	25	21065	26924	28	6396	7267	14

Table 4.1b *Trends in GHG emissions 1990-2010 by region and by gas [in CO_2 eq.]*

	N_2O 1990 [Mt]	N_2O 2010 [Mt]	Growth [%]	PFC 1990 [Mt]	PFC 2010 [Mt]	Growth [%]	HFC 1990 [Mt]	HFC 2010 [Mt]	Growth [%]	SF_6 1990 [Mt]	SF_6 2010 [Mt]	Growth [%]
Western Annex I	815	820	1	66	51	-23	71	383	438	88	92	5
CEE/FSU Annex I	215	215	0	23	25	8	1	29	2362	23	18	-22
Total Annex I	1030	1034	0	89	76	-15	72	412	469	111	110	-1
Latin America	445	477	7	10	19	92	0	31	6171	8	13	69
Africa	337	366	9	1	1	92	0	2	5400	1	1	68
Asia	974	1280	31	12	50	322	2	76	4675	13	45	239
FSU (Non-Annex I)	190	190	0	3	3	8	0	3	2362	3	2	-22
Middle East	81	81	0	3	5	92	0	9	6171	1	1	68
Oceania	0	0	32	1	1	92	0	2	5400	1	1	68
Total non-Annex I	2028	2395	18	29	80	180	2	123	4963	26	64	149
WORLD	3058	3429	12	117	156	33	75	535	615	137	174	27

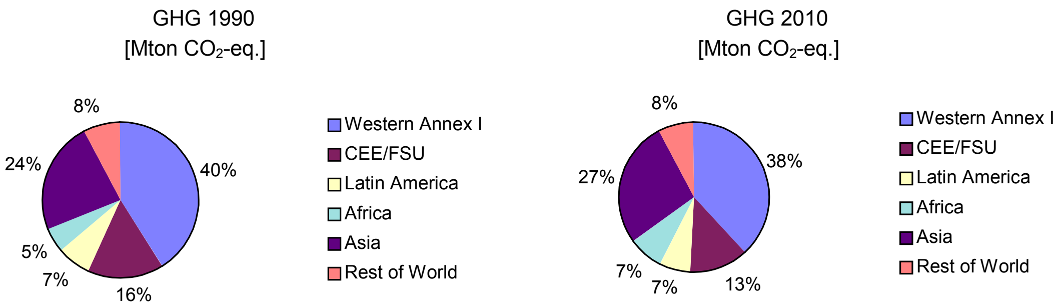

Figure 4.1 *Distribution of greenhouse gas emissions by region*

Another significant trend is the major expected percentage increase of HFC/SF_6/PFC emissions over the years 1990-2010, notably in the non-Annex I regions. This large increase results mainly from replacement of ozone gases by HFC gases. Nevertheless, the share of HFC/SF_6/PFC in total GHG emissions will only increase from 1% in 1990 to 2% in 2010. On the other hand, whereas the shares of CH_4 and N_2O in total GHG emissions will decline over the period considered, CO_2 will most likely increase its already dominant share from 68% in 1990 to 70% in 2010 (see Figure 4.2). Hence, although there seems to be a large potential of relatively low-cost non-CO_2 reduction options – see Section 4.3 - meeting long-run environmental goals will unchangeably require strong CO_2 reduction policies.

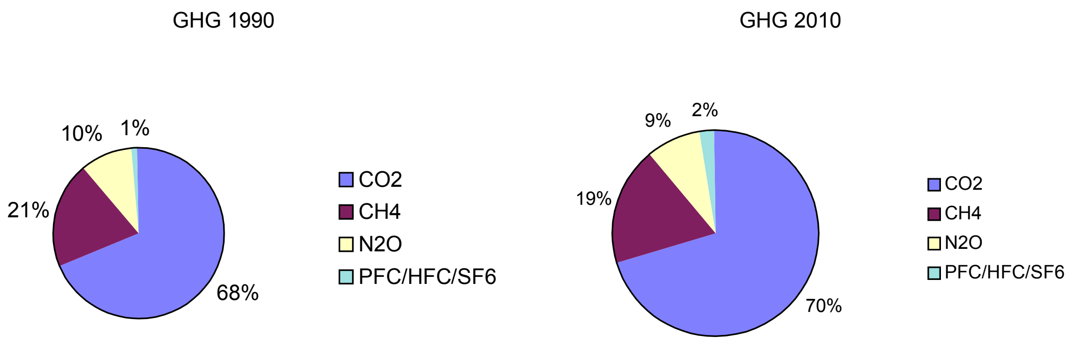

Figure 4.2 *Contribution of individual gases to total GHG emissions, 1990 and 2010*

Finally, it is interesting to indicate some differences in the distribution of GHG emissions by major regions. CO_2 accounts for more than 80% of all GHG emissions in the Annex I region, whereas its share in total GHG emissions in non-Annex I countries is less than 60%. On the other hand, as a share of total emissions, CH_4 and N_20 are far more important in the non-Annex I region than in the Annex I countries (Figure 4.3).

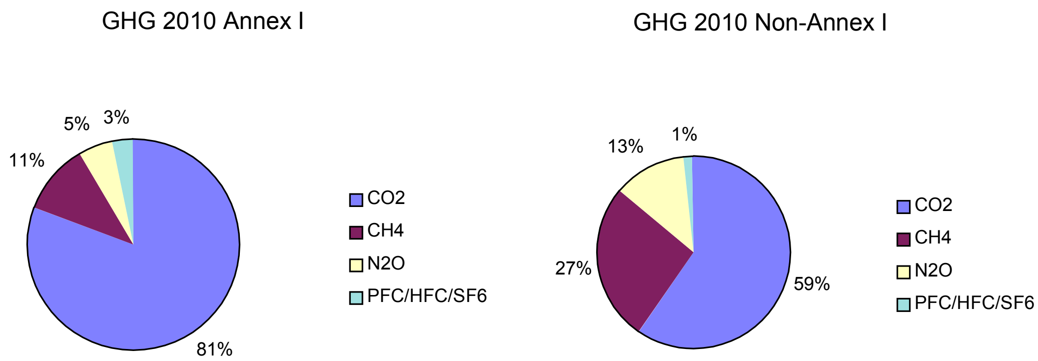

Figure 4.3 *Distribution of GHG emissions by gas in Annex I and non-Annex I regions in 2010*

4.2.2 Emissions per capita and per GDP

Population growth and economic wealth are among the main factors influencing emission trends. Hence, in addition to the emission trends discussed above, Table 4.2 presents aggregated data of GHG emissions per capita for a variety of regions.

Table 4.2 *GHG emissions per capita and per GDP*

	GHG emissions/capita [Tonnes of CO_2 eq.]		GHG emissions/GDP [KGs per US$]	
	1990	2010	1990	2010
Western Annex I	15.3	16.8	0.6	0.5
CEE/FSU Annex I	16.2	16.0	8.3	4.2
Total Annex I	*15.5*	*16.6*	*0.9*	*0.6*
Latin America	4.9	4.4	1.5	0.9
Africa	2.6	2.8	3.8	4.2
Asia	2.6	3.0	2.8	2.1
FSU Non-Annex I	12.6	11.2	11.0	6.2
Middle East	5.8	5.6	1.4	1.3
Oceania	1.8	2.1	1.8	1.4
Total non-Annex I	*3.3*	*3.4*	*2.5*	*1.9*

Table 4.2 shows that GHG emissions per capita will likely increase over the period 1990-2010 in Africa, Asia, Oceania and the western Annex I region. On the other hand, they will probably decrease in the Middle East and the CEE/FSU region (including both Annex I and non-Annex I countries). These opposing trends may be due to differences in population growth and economic development in the regions concerned.

In some regions, the trend in emissions per GDP shows quite a different picture. In Asia, Oceania and the western Annex I region, for instance, GHG emissions increase in per capita terms over the years 1990-2010, whereas they decrease in GDP terms. For the other regions, the decrease in emissions per GDP is significantly larger than the decrease in emissions per capita.

4.2.3 Reduction requirements

As explained in Chapter 3, international trade in emission credits results from national differences in emission reduction costs, potentials and requirements. Whereas costs and potentials will be discussed in Section 4.3 below, this section will analyse emission reduction requirements of Annex I countries as agreed in the Kyoto Protocol. These requirements are defined as the difference between the expected (baseline) emissions in the year 2010 and the so-called ‘Kyoto target’, i.e. the assigned amount of GHG emissions in 2010 based on a certain percentage – for instance, 90 or 95% – of the emission level in the reference year. Table 4.3 summarises the estimated GHG emission levels in 1990 and 2010, the Kyoto target and the resulting emission reduction requirements for each western Annex I country

In absolute volumes, the US and Japan face the largest reduction requirements. In relative terms these requirements are expected to be small for Germany, France, the UK, Luxembourg, Spain and Portugal.

Table 4.3 *Emission trends, Kyoto targets and emission reduction commitments of western Annex I countries [Mt]*

	Emissions 1990	Emissions 2010	Kyoto target	Reduction requirements	Reduction requirements [% of 2010 emissions]
Netherlands	225	258	212	47	18
Belgium	130	144	120	24	16
Germany	1203	976	951	25	3
Italy	511	592	478	113	19
Sweden	67	76	69	7	9
Finland	64	83	64	19	23
Denmark	73	79	58	21	27
France	501	515	501	14	3
Greece	101	147	126	22	15
Portugal	68	86	84	2	3
Spain	294	358	338	19	5
United Kingdom	752	699	658	42	6
Austria	79	86	69	17	20
Ireland	53	69	60	9	13
Luxembourg	16	12	12	0	0
Switzerland	53	66	49	17	26
Norway	43	52	44	8	16
Japan	1333	1587	1253	334	21
USA	6187	7751	5754	1997	26
Australia	423	496	456	40	8
Canada	340	402	320	82	20
New Zealand	69	105	69	36	34
Iceland	3	4	3	1	29

4.3 Reduction potentials and costs

As noted, to analyse international trade in emission credits, one needs not only data on reduction requirements but also on abatement costs and potentials in different countries or regions of the world. Chapter 3 has shown that emission reduction costs and potentials can be expressed graphically by means of marginal cost curves. As part of the present study, marginal cost curves have been constructed for a variety of countries and regions, including:

- each individual western Annex I country (western Annex I),
- the Annex I region of Central and East Europe/Former Soviet Union (CEE/FSU Annex I),
- each non-Annex I region, notably the FSU non-Annex I region, Africa, Asia, Oceania and the Middle East (non-Annex I).

Figure 4.4 shows the aggregated marginal reduction cost curves for both CO_2 and total GHG emissions in the western Annex I region, the non-Annex I region and the CEE/FSU Annex I region.

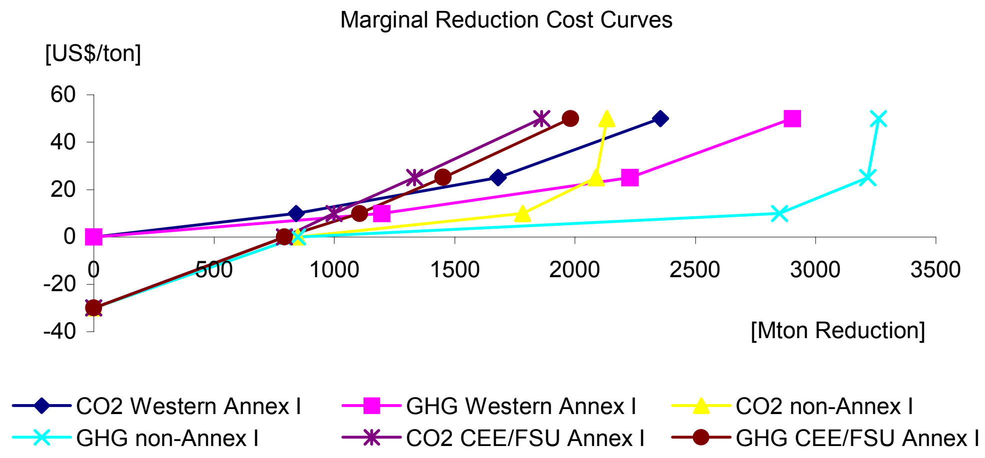

Figure 4.4 *Marginal reduction cost curves in major regions of the world [2010]*

In general, there are large potentials of reduction options in both non-Annex I and CEE/FSU Annex I countries at significantly lower costs than in western Annex I countries (for details, see Van Harmelen, 1997, discussed in Section 3.4 and Van der Linden et al., 1999). As indicated by Figure 4.4, both the non-Annex I region and the CEE/FSU Annex I region have each a large potential of about 800 Mt of no-regret options, i.e. reduction options with negative marginal costs.

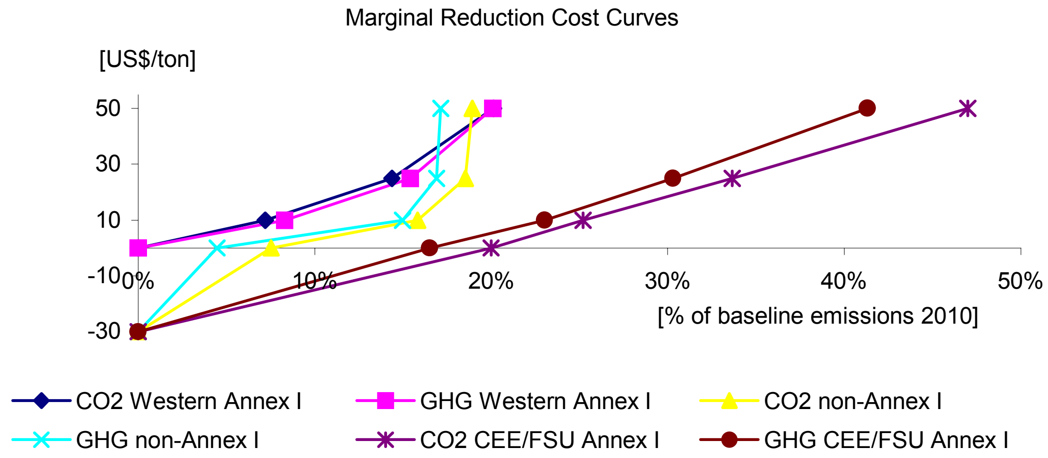

Figure 4.5 *Marginal reduction cost curves as percentage of baseline emissions [2010]*

In addition, Figure 4.5 expresses the marginal reduction cost curves as a percentage of the expected baseline emissions in the year 2010. This figure illustrates that, at 10 US$ per tonne, the western Annex I countries can only reduce about 8% of their baseline GHG emissions. At the same cost level, non-Annex I countries can reduce up to 15% of their baseline emissions and CEE/FSU Annex I countries even up to 22%.

By aggregating the regional costs curves of Figure 4.4, similar curves for the reduction of CO_2 and total GHG emissions can be designed for the world as a whole. The result is presented in Figure 4.6. A comparison of these curves indicates that the Kyoto decision to extend the basket of emission abatement options from CO_2 to six GHGs will lead to substantial cost savings as costs are generally significantly higher to reduce emissions of CO_2 than the other GHGs (see also Section 4.4.2).

For instance, Figure 4.6 point outs that at the global level a potential of some 5,000 Mt GHG emission reductions is available at relatively low costs (less than 10 US$ per tonne), whereas a similar potential to reduce only CO_2 emissions will lead to substantially higher costs (about 25 US$ per tonne).

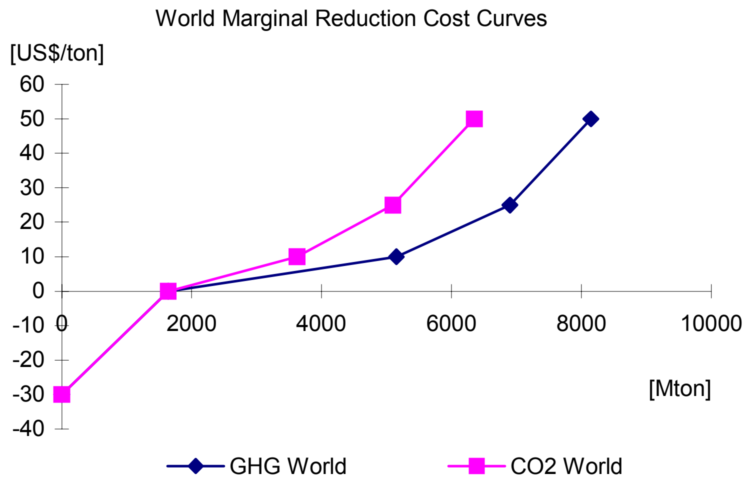

Figure 4.6 *World marginal cost curves for reducing CO_2 and GHG emissions [2010]*

4.4 Trade and costs effects

This section will analyse the trade and cost effects of another Kyoto decision, namely to introduce the Kyoto Mechanisms in order to achieve reduction requirements of Annex I countries cost-effectively at the global level. First of all, the main results of this analysis will be addressed briefly in Section 4.4.1, followed by a more detailed discussion of the trade and cost effects of the Kyoto Mechanisms in meeting Annex I reduction requirements. These effects will be compared for 2 cases. In case A, reduction options at negative marginal costs in non-Annex I and CEE/FSU Annex I countries are excluded from the analysis, whereas this 'profitable potential' is included in case B.

4.4.1 Main results

Table 4.4 presents the main quantitative results of the present study for cases A and B. Both cases have been analysed for reducing only CO_2 and for mitigating all GHGs. The first row of Table 4.4 provides the estimated reduction requirements of the Annex I countries to meet their Kyoto commitments for the period 2008-2012. For all GHGs and Annex I countries together, these requirements are estimated at almost 2,700 Mt[19]. In case of free trade (i.e. unrestricted use of all Kyoto Mechanisms), this target will be met at an equilibrium price of emission credits equal to 8 US$ per tonne CO_2 eq. in case A-GHG and 3 US$ in case B-GHG (row 2 of Table 4.4). If non-CO_2 reduction options are excluded, however, the equilibrium price of CO_2 emission credits will be significantly higher, i.e. 15 and 4 US$, respectively.

[19] Annex I countries of Central and East Europe (CEE) and the Former Soviet Union (FSU) have been grouped and analysed as one region (CEE/FSU Annex I). As a result, potential reduction requirements of some of these countries have been offset by possible emission surpluses ('hot air') of others. In fact, the reduction requirements of the CEE/FSU region is 0 as expected emissions levels of this region is estimated to be nearly equal to its collective assigned amount of GHG emissions in 2010.

Table 4.4 *Main results of present study*

		Case A-CO_2	Case B-CO_2	Case A-GHG	Case B-GHG
Reduction requirements Annex I	[Mt]	2470	2470	2692	2692
Equilibrium price of emission credits	[US$/t]	15	4	8	3
Total trade in emission credits	[Mt]	1362	2119	1878	2365
As % of Annex I reduction requirements		*55%*	*86%*	*70%*	*88%*
ET within western Annex I region	[Mt]	10	2	90	17
JI export CEE/FSU Annex I region	[Mt]	317	878	254	900
CDM export non-Annex I region	[Mt]	1035	1239	1534	1447
Total reduction costs before trade	[mUS$95]	90766	90766	75753	75753
Total reduction costs after trade	[mUS$95]	13358	1393	10002	1453
Average costs per tonne before trade	[US$95/t]	37	37	26	26
Average costs per tonne after trade	[US$95/t]	5.4	0.6	3.5	0.5
Average costs per capita before trade	[US$95/t]	17	17	14	14
Average costs per capita after trade	[US$95/t]	2.0	0.2	1.5	0.2

In the present study, the equilibrium price of emission credits is significantly lower than in similar, previous ECN studies focussing only on one particular region, one GHG or one Kyoto Mechanism (Section s 3.5.2-3.5.4). In summary, the major differences include:

1. If Emissions Trading (ET) would be confined to CO_2 trade between the western Annex I countries, the resulting equilibrium price of credits would be 57 US$/tonne.
2. If both ET and JI within the Annex I region would be allowed, the equilibrium price of CO_2 emission credits would range from 18 to 29 US$/tonne, depending on whether or not no-regret options are included.

These findings show that the costs to meet Kyoto requirements will be reduced if the potential to use (cheap) abatement options by means of the Kyoto Mechanisms will be enlarged.

Depending on the equilibrium price of emission credits, countries will determine the optimal level of both their domestic emission reductions and their foreign trade transactions in emission credits. For instance, in case A-GHG (i.e. an equilibrium price of 8 US$ per tonne), the Annex I countries will reduce 814 Mt GHG emissions at home and import emission credits equal to an amount of 1878 Mt (row 3 of Table 4.4). In case B-GHG, however, the equilibrium price of emission credits will be lower (3.0 US$ per tonne). As a result, Annex I countries will reduce less GHG emissions at home (327 Mt) and import more emission credits abroad (2365 Mt). In all cases considered in Table 4.4, emission credits are mainly achieved through CDM transactions with non-Annex I countries, followed by JI transactions with countries in the CEE/FSU Annex I region, and hardly by ET transactions within the western Annex I region (row 5-7)[21].

In addition to the above-mentioned trade effects, Table 4.4 also presents the main cost effects of the Kyoto decision to enable Annex I countries to meet their reduction requirements by means of Kyoto Mechanisms[22]. It shows that, in case A-GHG, global abatement costs are estimated to tumble from almost 76 billion US$ 'before trade' to 10 billion US$ after trade' (i.e. after relying on the Kyoto Mechanisms). Including no-regret options in the non-annex I and CEE/FSU Annex I regions (case B-GHG) results in a further decrease of total abatement costs to 1.5 billion US$ (row 9).

[21] Based on considerations outlined in Section 2.4, it is assumed that Emissions Trading (ET) will mainly occur within the western Annex I region, and Joint Implementation (JI) between this region and the CEE/FSU Annex I region.

[22] By comparing the 'CO_2' and 'GHG' cases, Table 4.4 provides also an indication of the cost effects of the Kyoto decision to extend the basket of reduction options from only CO_2 to six GHGs. Reduction requirements of CO_2 emissions only are based on the assumption that the reduction target as a percentage of base-year emissions is the same for both CO_2 and all GHGs.

In the latter case, the average reduction costs per tonne will be only 0.5 US$ compared to 26 US$ 'before trade' (row 10 and 11). Hence, it may be concluded that the Kyoto decision to introduce JI, CDM and ET may result in tremendous global savings of total abatement costs, particularly if no-regret options in non-Annex I and CEE/FSU Annex I regions are included in global abatement strategies.

In the following two sub-sections, the trade and cost effects of the Kyoto Mechanisms will be analysed at a more disaggregated level. The analysis will be focussed on the mitigation of all GHGs, both for case A (excluding no-regret options) and case B (including no-regret options).

4.4.2 Disaggregated trade effects

Disaggregated results with regard to the trade effects of the Kyoto Mechanisms are presented in Table 4.5 for each western Annex I country and the other regions in the world. These trade effects concern the optimal levels of domestic emission reductions and foreign trade transactions in emission credits. Table 4.5 shows that, in case A, most western Annex I countries will achieve 60 to 80% of their reduction requirements by importing emission credits – through one or all Kyoto Mechanisms – and the remaining share by domestic measures. Together, the western Annex I countries will import 1878 Mt of emission credits, i.e. about 70% of their total reduction requirements (Table 4.4).

Table 4.5 *Domestic reductions and foreign trade effects of using Kyoto Mechanisms*

	Reduction requirements [Mt]	Domestic reductions [Mt]		Trade in emission credits [Mt]		Trade [% of requirements]	
		Case A	Case B	Case A	Case B	Case A	Case B
Netherlands	47	19	10	-27	-36	59	78
Belgium	24	8	4	-16	-20	66	84
Germany	25	59	29	34	4	-135	-14
Italy	113	25	11	-88	-102	78	90
Sweden	7	2	1	-5	-6	76	87
Finland	19	7	3	-13	-17	65	86
Denmark	21	4	2	-17	-19	83	91
France	14	36	17	22	3	-158	-22
Greece	22	11	6	-10	-16	48	74
Portugal	2	7	4	4	1	-183	-49
Spain	19	28	14	9	-5	-48	26
United Kingdom	42	20	10	20	10	-48	-23
Austria	17	5	3	-13	-14	73	80
Ireland	9	6	3	-3	-6	29	64
Luxembourg	0	0	0	0	0	N.A.	N.A.
Switzerland	17	3	3	-14	-15	80	84
Norway	8	3	2	-6	-7	70	78
Japan	334	57	48	-278	-286	83	86
USA	1997	734	341	-1263	-1656	63	83
Australia	40	23	13	-17	-27	43	69
Canada	82	31	18	-51	-64	63	78
New Zealand	36	21	9	-15	-27	43	76
Iceland	1	1	0	-1	-1	81	108
CEE+ FSU Annex I	0	254	900	254	900	N.A.	N.A.
Latin America	0	151	177	151	177	N.A.	N.A.
Africa	0	113	68	113	68	N.A.	N.A.
Asia	0	1116	1001	1116	1001	N.A.	N.A.
FSU non-Annex I	0	96	41	96	41	N.A.	N.A.
Middle East	0	57	159	57	159	N.A.	N.A.
Oceania	0	1	0	1	0	N.A.	N.A.

N.A. Data not available since reduction requirements are equal to zero.

Case A is also illustrated graphically in Figure 4.7. Note that in this case, with an equilibrium price level of 8 US$ per emission credit, it would be most efficient for some western Annex I countries to export emission credits. These countries include particularly the UK, France, Spain, Portugal and Germany. Their total export of emission credits, however, is equivalent to only 90 Mt (Table 4.4). In case A, the main exporters of emission credits are CDM countries in Asia (1116 Mt) and JI countries in the CEE/FSU Annex I region (254 Mt).

In case B (including no regret options), the equilibrium price of emissions credits will be much lower (3 US$). In this case, western Annex I countries will even rely more on the use of Kyoto Mechanisms as, on average, some 88% of their reduction requirements (2.7 Gt) will be covered by imports of emissions credits (2.4 Gt; see Table 4.4). Compared to case A discussed above, the inclusion of no-regret options would triple exports of emission credits by JI countries in the CEE/FSU Annex I region from 254 Mt to 900 Mt (Table 4.5). On the other hand, the export volume of the CDM countries would fall from approximately 1.5 to 1.4 Gt. However, within the non-Annex I region, exports of emission credits would increase for Latin America and the Middle East, whereas it would fall for the other non-Annex I regions, notably for Asia (Table 4.5).

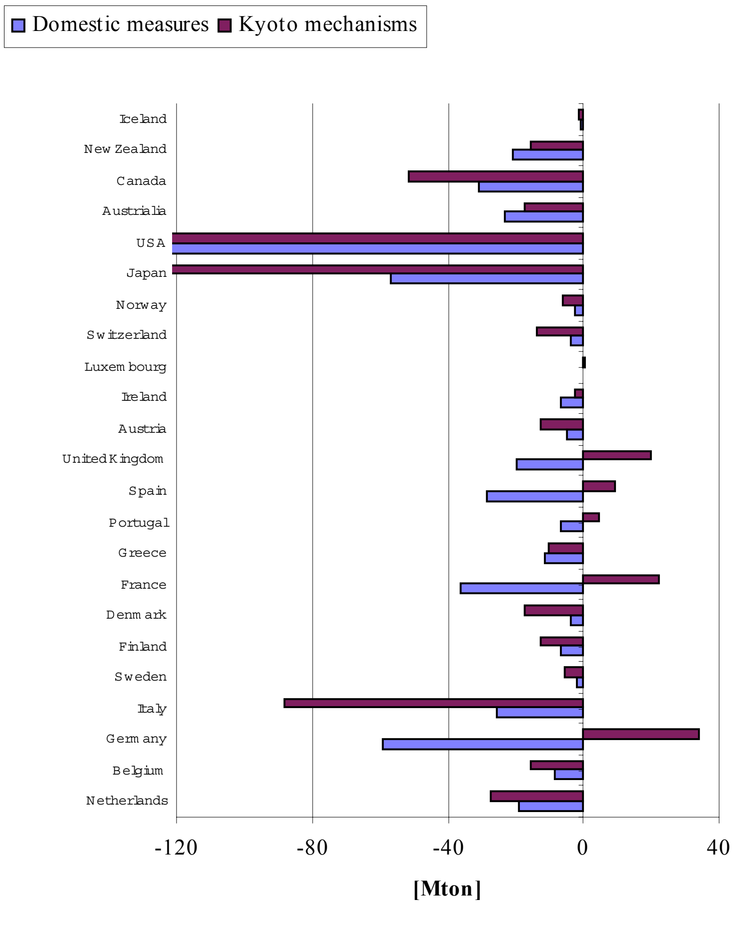

Figure 4.7 *Domestic and foreign emission reduction options [Mton]*

4.4.3 Disaggregated cost effects

As indicated above, owing to the Kyoto Mechanisms, global abatement costs to meet reduction requirements of Annex I countries are estimated to tumble from 76 billion US$ 'before trade' to 10 billion US$ 'after trade' (case A, excluding no-regret options), and even to 1.5 billion US$ if these options are included (case B, Table 4.4, Section 1.4.1). Table 4.6 provides a more detailed picture of these cost effects for the individual western Annex I countries, the western Annex I region, the CEE/FSU Annex I region and the other, non-Annex I regions of the world. It shows that, before trade, abatement costs in absolute terms are mainly born by major western Annex I countries such as Italy, Japan and the US due to either high reduction requirements or relatively high domestic reduction costs (or a combination of both factors). Total abatement costs of these three countries amount to 69 billion US$, i.e. some 91% of all cost to meet the reduction requirements of the western Annex I countries.

After trade, however, total abatement costs of the western Annex I countries fall from 76 billion US$ to 17 billion US$ (case A). Although, in absolute terms, the US, Japan and Italy benefit most from using the Kyoto Mechanisms to meet their reduction requirements, they still account for the major share (i.e. 15 billion US$ or more than 89%) of total abatement costs born by western Annex I countries. Moreover, whereas western Annex I countries benefit from trade in the sense that they have to make less costs to meet their reduction requirements, the other countries of the world may benefit in the sense that they can make real profits by exporting emission credits to Annex I countries. In case A, such profits will be mainly realised by countries in Asia (4.3 billion US$) and in the CEE/FSU Annex I region (1.0 billion US$)[23].

Table 4.6 *Costs effects of using Kyoto Mechanisms*

	Reduction costs before trade [mUS$95]	Costs after trade [mUS$95]		Net gains of trade [mUS$95]		Net gains [% of GDP 2010]	
		Case A	Case B	Case A	Case B	Case A	Case B
Netherlands	506	266	117	240	389	0.04	0.07
Belgium	298	147	64	151	234	0.04	0.06
Germany	20	-69	19	88	1	0.00	0.00
Italy	7551	764	320	6788	7232	0.46	0.49
Sweden	128	46	19	82	109	0.03	0.04
Finland	266	122	54	144	212	0.09	0.13
Denmark	859	143	58	715	800	0.31	0.35
France	11	-50	9	60	1	0.00	0.00
Greece	162	115	53	47	109	0.04	0.09
Portugal	0	-13	0	13	0	0.01	0.00
Spain	33	19	29	14	4	0.00	0.00
United Kingdom	595	-88	-19	683	614	0.05	0.04
Austria	1167	104	43	1063	1125	0.34	0.36
Ireland	46	40	20	6	26	0.01	0.03
Luxembourg	0	-1	0	1	0	0.00	0.00
Switzerland	1061	111	44	950	1017	0.23	0.25
Norway	242	49	20	193	222	0.10	0.11
Japan	32222	2179	864	30043	31357	0.45	0.47
USA	28830	12154	5341	16676	23490	0.18	0.25
Australia	371	196	92	175	278	0.04	0.06
Canada	1090	474	205	616	886	0.08	0.11
New Zealand	282	192	93	90	190	0.13	0.28
Iceland	14	10	5	4	9	0.04	0.10
Tot. western Annex I	*75753*	*16911*	*7449*	*58842*	*68304*	*0.20*	*0.23*
CEE+ FSU Annex I	0	-1029	-2557	1029	2557	0.09	0.23
Total Annex I	*75753*	*15882*	*4892*	*59871*	*70861*	*0.20*	*0.23*
Latin America	0	-580	-442	580	442	0.02	0.02
Africa	0	-432	-138	432	138	0.06	0.02
Asia	0	-4277	-2347	4277	2347	0.08	0.05
FSU non-Annex I	0	-370	-68	370	68	0.17	0.03
Middle East	0	-217	-444	217	444	0.02	0.03
Oceania	0	-5	-1	5	1	0.05	0.01
Total non-Annex I	*0*	*-5881*	*-3439*	*5881*	*3439*	*0.06*	*0.03*
World	75753	10002	1453	65751	74299	0.16	0.18

[23] Note that some western Annex I countries, which export emission credits – such as Germany, France, Portugal, the UK and Luxembourg – will also realise real trade profits owing to the Kyoto Mechanisms.

The distribution of net gains owing to the use of Kyoto Mechanisms will show some significant changes, however, if no-regret options are included (case B). Total abatement costs of all western Annex I countries will fall from 76 billion US$ to 7.5 billion US$. Again, the US, Japan and Italy will benefit most in absolute terms, but still they account for almost 88% (i.e. 6.5 billion US$) of all costs born by the western Annex I countries. Net real profits of exporting countries in the non-Annex I and CEE/FSU Annex I regions will decrease from 6.9 billion US$ in case A to 6.0 billion US$ in case B. This decrease is explained by the fact that, due to the inclusion of no-regret options, the quantity of emission credits exported by these regions indeed increases, but this effect is more than offset by the resulting decrease in the equilibrium price of these credits. However, whereas the countries in the non-Annex I region – notably in Asia – suffer most from the inclusion of no-regret options, the countries in the CEE/FSU Annex I region benefit as their real trade profits increase from 1.0 billion US$ to 2.6 billion US$.

The last two columns of Table 4.6 express net gains of using Kyoto Mechanisms as a share of the estimated GDP in 2010. In these terms, the countries that benefit most include Italy, Japan, Austria and Denmark, mainly due to their relatively high domestic reduction costs.

Table 4.7 *Average costs to meet Kyoto requirements*

	Average costs per tonne before trade [US$/t]	Average costs per tonne after trade [US$/t]		Average costs per capita before trade [US$95/CAP2010]	Average costs per capita after trade [US$95/CAP2010]	
		Case A	Case B		Case A	Case B
Netherlands	10.8	5.7	2.5	33.7	16.7	7.3
Belgium	12.6	6.2	2.7	29.8	14.7	6.4
Germany	0.8	-1.2	0.6	0.2	-0.8	0.2
Italy	66.6	6.7	2.8	130.2	13.6	5.7
Sweden	18.2	6.5	2.7	16.0	5.1	2.1
Finland	13.7	6.3	2.8	53.3	24.4	10.8
Denmark	41.0	6.8	2.8	171.8	28.7	11.7
France	0.7	-1.4	0.6	0.2	-0.8	0.2
Greece	7.5	5.3	2.5	16.2	10.4	4.8
Portugal	0.0	-2.0	-0.1	0.0	-1.3	0.0
Spain	1.7	0.7	1.5	0.8	0.5	0.7
United Kingdom	14.3	-1.4	-0.4	10.4	-1.5	-0.3
Austria	67.4	6.0	2.5	145.9	13.0	5.3
Ireland	5.1	4.4	2.3	11.5	9.9	5.0
Luxembourg	0.0	-4.0	-1.6	0.0	-1.0	-0.2
Switzerland	61.0	6.4	2.6	151.6	15.8	6.3
Norway	28.7	5.8	2.4	60.5	9.9	4.0
Japan	96.4	6.5	2.6	251.7	17.0	6.8
USA	14.4	6.1	2.7	106.8	40.9	18.0
Australia	9.3	4.9	2.3	21.8	9.8	4.6
Canada	13.3	5.8	2.5	40.4	14.8	6.4
New Zealand	7.9	5.3	2.6	94.1	48.1	23.2
Iceland	10.6	7.9	3.5	13.8	10.3	4.5
CEE/FSU Annex I	0.0	-4.0	-2.8	0.0	-3.4	-8.5
Latin America	0.0	-3.8	-2.5	0.0	-1.0	-0.8
Africa	0.0	-3.8	-2.0	0.0	-0.4	-0.1
Asia	0.0	-3.8	-2.3	0.0	-1.2	-0.7
FSU non-Annex I	0.0	-3.8	-1.6	0.0	-3.1	-0.6
Middle East	0.0	-3.8	-2.8	0.0	-0.7	-1.5
Oceania	0.0	-3.8	-1.5	0.0	-0.8	-0.1
World	26.1	3.5	0.5	14.5	1.5	0.2

Finally, Table 4.7 presents the average costs per tonne and per capita of meeting reduction requirements, both before and after trade, for the cases A and B. It shows, that average abatement costs at the global level decrease from 26.1 US$/tonne before trade to 3.5 and 0.5 US$ after trade in cases A and B, respectively. In per capita terms, these costs decline from 14.5 US$ to 1.5 and 0.2 US$, respectively. These average figures, however, hide major differences between countries and regions. In case B, for instance, average abatement costs per tonne or per capita hardly decrease due to the trade option in countries such as Germany or France, whereas they tumble significantly in countries such as Japan and Iceland. Of all countries exporting emission credits, those in the CEE/FSU regions benefit most of the Kyoto Mechanisms – both in 'negative' abatement costs per tonne and per capita – whereas the least developed countries of the non-Annex I region benefit less.

4.5 Limitations of present analysis

The results of the present study should be treated with care as its underlying analysis – including the methodological approach and data used – is characterised by several limitations. In the present stage of climate policy research, the attention should be mainly focussed on the mutual, causal relationships of the major results and variables involved, as well as on their magnitude in relative rather than absolute terms. In brief, the major uncertainties and other limitations of the present study and some possible consequences for its major results, include:

- As outlined in Section 3.4, the data used are often not certain, notably with regard to emission levels in 2010 as well as to reduction costs and potentials. Higher estimates of emission levels in Annex I countries – due to higher economic growth rates than assumed – will result in higher reduction requirements of these countries and, hence, to higher abatement costs. Moreover, more reliable data on reduction potentials and costs may significantly influence the results of the present study.
- The analysis has excluded 'sinks', i.e. changes in GHG emissions due to forestry activities and other land use changes. Including sinks will probably result in larger abatement potentials – especially in CDM countries – and, hence, to lower costs to meet Annex I reduction requirements.
- In the present study, only 'real' reduction options have been considered, thereby excluding trade in 'hot air' (Section 2.7.2). Including 'hot air' will most likely lead to a fall in the equilibrium price of emission credits and, hence, to less abatement costs for all countries importing these credits, but also to less revenues for all countries exporting 'real' credits.
- Annex I countries of Central and East Europe (CEE) and the Former Soviet Union (FSU) have been grouped and analysed as one region (CEE/FSU Annex I). As a result, potential reduction requirements of some of these countries have been offset by possible emission surpluses ('hot air') of others. Analysing these countries individually would most likely influence the trade and cost effects of the Kyoto Mechanisms.
- Estimates of abatement potentials are based on reduction options that are assumed to be technically feasible. The present quantitative analysis, however, has not considered all kinds of political and institutional constraints to realise abatement projects, particularly in non-Annex I and CEE/FSU Annex I countries. Moreover, the Kyoto Mechanisms are still characterised by several unresolved issues with regard to their design and implementation (Sections 2.2-2.4). As a result, abatement potentials may be smaller or more expensive than supposed in this study, leading to less trade in emission credits and higher reduction costs. On the other hand, there might be a large potential of (cheap) reduction options – particularly in non-Annex I countries – which have not yet been identified and, hence, not included in the present analysis, implying that reduction costs may be estimated too high and trade options too low.
- The present study has not considered the option to restrict trade in emission credits by imposing 'ceilings' on the use of Kyoto Mechanisms (Section 2.7.4). However, depending on the specific design and implementation of such ceilings, they may have varying, but significant trade and cost effects on different groups of countries (Section 3.5.5).

- The analysis conducted in this study has been static and exclusively based on direct abatement costs. Dynamic and feed-back effects at the macroeconomic level have not been considered.
- The analysis is based on a methodological approach that assumes the existence of a so-called 'perfect' market for trading emission credits, i.e. a fully integrated market with no trade restrictions, no transaction costs, no strategic behaviour of market parties, no risks and uncertainties, etc. In practice, however, both transaction costs, risks and uncertainties of generating and transferring emission credits may be very substantial, major countries – such as Russia, the US, Japan, China or India – may act politically or show oligopolistic behaviour, and markets of emission credits may be characterised by sequential, bilateral, secret and 'out-of-equilibrium' trading. These factors may significantly affect the results of the present study in the sense that trading volumes of emission credits will probably be lower and 'equilibrium' prices of these credits will most likely be higher.

Some of the above-mentioned limitations may be relieved by means of further research, a subject that will be treated as part of the next, final chapter of this study.

5. MAIN FINDINGS AND SUGGESTIONS FOR FURTHER RESEARCH

5.1 Main findings

The present study has analysed the role and impact of the Kyoto Mechanisms in meeting the commitments of Annex I countries to limit their GHG emissions. The main findings are:

Characteristics of Kyoto Mechanisms are still uncertain

- The role and impact of the Kyoto Mechanisms in limiting GHG emissions depend on a large variety of factors, including (a) national differences in emission reduction requirements, potentials and costs, and (b) the specific characteristics of each Kyoto Mechanism – including its relative advantages and disadvantages – as determined by the specific guidelines, rules, and procedures regarding its operation. The latter factors, however, are often yet not clear, as they still have to be defined more specifically by ongoing policy negotiations as part of the further elaboration of the Kyoto Protocol. Because Annex I countries may apply one or more of the Kyoto Mechanisms to meet their commitments, interaction – notably competition – between these instruments is likely to occur.

Substantial reduction requirements for Annex I countries

- Total GHG emissions of all countries are expected to increase from almost 31 billion tonnes CO_2 eq. in 1990 to more than 38 billion tonnes in 2010 (+25%). In Annex I countries, emissions over this period will increase from 17.5 to 19.5 billion tonnes CO_2 eq. (+11%), while in non-Annex I countries they will rise from approximately 13 to 19 billion tonnes (+42%).
- Reduction requirements of all (western) Annex I countries for the first budget period, 2008-2012, are estimated at 2.7 billion tonnes CO_2 eq. At the national level, these requirements are particularly high in absolute terms for the US (almost 2 billion tonnes), Japan (334 million tonnes) and Italy (113 million tonnes).

Large differences in reduction potentials and costs

- There are large potentials of reduction options in both non-Annex I and CEE/FSU Annex I countries at significantly lower costs than in western Annex I countries. In both the non-Annex I region and the CEE/FSU Annex I region, there is even a substantial potential of 'no-regret' options – i.e. reduction options with 'negative' costs – estimated at some 800 Mt in each region.

Large potential role and impact of Kyoto Mechanisms

- If all Kyoto Mechanisms and all relatively cheap reduction potentials – including the above-mentioned no-regret options - can be used unrestrictedly, the equilibrium price of trading emission credits will be 3 US$ per tonne CO_2 eq. (case B). Excluding no-regret options (case A) will raise this price to 8 US$ per tonne.
- In case A, Annex I countries will meet, on average, 70% of their reduction requirements by means of foreign transactions. This share will even be 88% if no-regret options are included (case B). In both cases, Annex I countries will import emission credits mainly through CDM transactions with non-Annex I countries, followed by JI transactions with countries in the CEE/FSU Annex I region, and hardly by ET transactions within the western Annex I region.

- In case A, global abatement costs are estimated to tumble from 76 billion US$ 'before trade' to 10 billion US$ after trade' (i.e. after relying on the Kyoto Mechanisms). Including no-regret options in the non-Annex I and CEE/FSU Annex I regions (case B) results in a further decrease of total abatement costs to 1.5 billion US$. Hence, it may be concluded that the Kyoto decision to introduce JI, CDM and ET may result in tremendous global savings of total abatement costs, particularly if no-regret options in non-Annex I and CEE/FSU Annex I regions are included in global abatement strategies.

Some countries benefit more

- In absolute terms, the US, Japan and Italy benefit most from relying on the Kyoto Mechanisms to meet their reduction requirements. However, in all cases considered (before/after trade, cases A/B), these countries account for the major share (88-91%) of total abatement costs born by western Annex I countries. In relative terms, i.e. as a share of GDP, the countries that benefit most include Italy, Japan, Austria and Denmark, mainly due to their relatively high domestic reduction costs. Some countries, however, can even make real profits by exporting emission credits to Annex I countries. Such profits will be mainly realised by CDM countries in Asia and JI countries in the CEE/FSU Annex I region.

The above-mentioned results should be interpreted carefully as the underlying analysis is characterised by several limitations regarding the methodology and data used. For instance, assumptions made have often been rather strict, and several factors have not been accounted for such as 'sinks', 'hot air', as well as risks, uncertainties and potential future developments regarding the specific design and implementation of the Kyoto Mechanisms. These factors may have a significant impact on the trade and cost effects of the Kyoto Mechanisms.

5.2 Some suggestions for further research

The limitations of the present study can, to some degree, be relieved by means of further research. A major condition for upgrading the present state of climate policy research is an improvement of the availability and quality of the data, notably to obtain more reliable estimates of reduction requirements, potentials and costs. Although the improvement of these data is largely the responsibility of other institutes, some suggestions for further research by ECN in this field concern:

- Sensitivity analyses with regard to the emission levels of Annex I countries in 2008-2012 – and, hence, their reduction requirements for this period – in order to assess the impact of changes in these emission levels and reduction requirements on the trade and costs effects of the Kyoto Mechanisms. Such analyses can be conducted by assuming different scenarios of economic growth in Annex I countries.
- Improved estimates of reduction potentials and costs in major countries and regions in the world, for instance by including or gathering a) more detailed and more reliable data of these potentials and costs, b) political, institutional and other constraints to use technically and/or economically feasible reduction options, and c) other restrictions on the use of potential reduction options resulting from the further elaboration of the Kyoto Protocol in general and the guidelines, rules and procedures regarding the Kyoto Mechanisms in particular.

In addition, some other suggestions for further research include:

- A study concerning the availability and reliability of data on 'sinks'. If available, these data could be added to the present analysis in order to assess the impact of 'sinks' in the basket of abatement options and, hence, on the trade and costs effects of the Kyoto Mechanisms.
- A study with regard to the impact of 'hot air' on the trade and costs effects of the Kyoto Mechanisms, based on different assumptions concerning a) the availability and tradability of 'hot air', and b) the market behaviour of major parties involved such as Russia or the Ukraine.

- A study of the trade and cost effects of imposing ceilings on the use of Kyoto Mechanisms. Based on a similar, previous ECN study covering only EU Member States (Ybema et al., 1999), such a study could analyse the impact of different kinds of ceilings, while covering all major countries and regions in the world.
- A more theoretical study of the potential cost and trade effects of the Kyoto Mechanisms under different market conditions, for instance by including the impact of differentiated markets, strategic behaviour of market parties, and risks or uncertainties in generating and trading emission credits.

APPENDIX A DATA UNCERTAINTY OF NON-CO_2 GHG EMISSIONS IN EU MEMBER STATES

The uncertainty regarding non-CO_2 GHG emissions in 1990[24] is higher than the uncertainty regarding CO_2 emissions. The higher uncertainty is caused by the different accounting practice CO_2 emissions are in proportion with the consumption of fossil energy carriers (plus some corrections). Energy statistics are well established for all Western European countries. The uncertainty in CO_2 emissions is estimated to be in the range of 2-5%. The emissions for the other greenhouse gases are process emissions. They are either calculated on the basis of the consumption of substances (part of the HFC emissions, SF_6) or they are calculated on the basis of proportionality to certain process inputs or outputs (CH_4, N_2O, PFC, part of the HFC emissions). Emissions (and storage) caused by land use change are based on land-use statistics and biomass growth estimates.

The emissions related to consumption (HFCs and SF_6) are measured according to different methods. In some cases/countries, the apparent consumption is measured (Tier 1-A method). In other cases/countries, the apparent consumption is adjusted for imports and exports of the substances within products (extended Tier 1-A method). Finally, some countries report estimates for actual emissions (on the basis of leakages and/or waste product statistics) (Tier 2 method). Different methods result in different estimates. If different countries use different calculation methods, the comparability is limited. Assuming that the actual emission is the 'accurate' value, the difference between the accounted and the reported emission may be a factor 2-5. In the following analysis, the actual emission is selected as accounting guideline, because it is thought to be in line with the IPCC guidelines.

Emissions related to process activities can be influenced by the specific emission coefficient. The different emission categories will be discussed separately.

The PFC emissions for new or refurbished aluminium smelters with point-feeders is one order of magnitude lower than the emissions from older types of smelters. Some countries account for such differences, while other countries use a more crude emission estimate. The emission is further influenced by the housekeeping of the smelter (control of the smelting bath composition). This adds another factor 2 to the uncertainty. The total uncertainty is a factor 3-4.

The most important N_2O sources are agriculture, transport and industry. The use of nitrogen fertiliser in the agricultural sector is a source of 30-50% of the total emission. This emission depends highly on the soil type. The application of fertilisers on grassland with high groundwater levels (like parts of the Netherlands) result in emissions that are one order of magnitude higher than the emissions from the same fertilisers. applied on dry cropland. It is not clear to which extent these differences are accounted for in the current national emission estimates. It is estimated that the uncertainty regarding N_2O from agriculture is a factor 2-3. Regarding industrial emissions, the production of adipic acid and the production of nitric acid (HNO_3) are major emission sources. To some extent these emissions depend on the applied technology. Emissions can be reduced by end-of-pipe technology. The uncertainty in the emission estimates is a factor 1.5. Regarding emissions from transportation, the use of catalytic converters will result in increasing emissions. The uncertainty is estimated to be a factor 1.5. In conclusion, the uncertainty in the total N_2O emission is a factor 2.

[24] From: Gielen and Kram (1988).

The main CH_4 emission sources are agriculture, waste and volatile fuel. The uncertainty is not as high as for the other non-CO_2 GHGs. It is estimated that the uncertainty is 25%. It is interesting to note the different accounting practices for CH_4 from landfill use. The Netherlands uses a time dependent first order model to estimate emissions. Most other countries use a time independent zero order model. As a consequence the emissions cannot be compared. Again, such differences are neglected in the current discussion.

Regarding carbon storage due to land use change, the forestry statistics are well established. It is thought that the uncertainty is 20%.

Given the composition of the non-CO_2 GHG emissions and of their sources in the EU Member States, the uncertainties regarding non-CO_2 GHG emissions are in the range of a factor 1.5-2.

APPENDIX B REDUCTION OPTIONS OF NON-CO_2 GHG EMISSIONS IN EU MEMBER STATES

CH_4

Waste

Costs for methane recovery from waste disposal sites (landfills) range from 0.12 to 0.49 ECU per kg methane (i.e. 6-23 ECU/t CO_2 equivalents)[26]. The maximum recovery efficiency for the whole landfill life cycle is 55% (Oonk, 1994). The closer the drainage pipes, the higher the efficiency, but the higher the costs. Total potential in the EU: 150 PJ (70 Mt CO_2 equivalents) (Scheepers, 1995).

Agriculture

Agricultural emissions represent one-third to two-thirds of the CH_4 emissions in the individual countries. Ruminants and manure storage are main emission sources. A split of the emissions over both categories is not available. Worldwide, the ratio of the emissions from ruminants and manure storage is 8:1.5. In the Netherlands, the ratio is 4:1 (VROM, 1997). This ratio is probably also valid for Western Europe.

Methane emissions associated with enteric fermentation of ruminants range from 3-8% of gross feed intake. For the vast majority of the world's domestic ruminants consuming a wide range of diets under common production circumstances, CH_4 emissions are equivalent to 6% of the gross energy fodder intake. Opportunities for reducing CH_4 emissions from intensively managed cattle are generally aimed at higher product yields per unit of food intake (IPCC, 1995):

- genetic improvement (-10%),
- use of bovine growth hormones (-10%),
- improved feed formulation (-10%),
- a higher protein gain/fat gain ratio (-20%).

Together, these measures are thought to decrease CH_4 emissions from ruminants by 30%. Most of these measures will have limited costs once they are developed. However, genetic improvements and growth hormones face major consumer opposition in Europe. As a consequence, the potential for Europe is thought to be limited to a 10% improvement (3% of total CH_4 emissions) at zero cost. One must add that this is a fairly optimistic estimate for 2010.

Concerning manure storage, covered lagoons pose a major reduction option. Approximately 40% emission reduction is possible. However, the potential for total CH_4 emissions is limited to 2-3%. Centralised biogas plants exclusively based on the digestion of animal manure are not profitable under the present technological and economic conditions (DEA, 1989). If 10-25% easily convertible organic matter is added, the plants can achieve break-even conditions, as examples in Denmark show. However, the profitability depends critically on the electricity revenues. In other countries with lower electricity prices the situation is less favourable (DEA, 1994).

[26] From: Gielen and Kram (1988).

Mining
Fossil fuel related emissions are mainly accounted for by deep coal mining. The emissions are in the range of 5-15 kg CO_2/GJ coal, depending on the mine depth (higher for deeper mines). Mine closures in Germany and the UK are considered in the emission estimates. The remaining (relatively insignificant) emissions from deep mines can be reduced by 80-90% before, during, or after the mining of the coal.

N_2O
Industrial N_2O emissions are related to the production of nitric acid (HNO_3) and the production of adipic acid, an intermediate in the nylon 6.6 production. Emissions can be reduced by catalytic conversion of N_2O. Emission reduction costs are in the range of 1-3 ECU/t CO_2 equivalent.

PFCs
PFC emissions are predominantly related to primary aluminium production. These emissions arise during periods when the alumina concentration in the smelter bath is too low. This causes short-circuiting of the cell, the so-called 'anode effect'. Improved control of the alumina concentration can reduce the anode effect by one order of magnitude. Modern smelters use so-called point feeders for improved alumina concentration control. Autonomous replacement of existing aluminium smelters or upgrading the existing smelters will result in a considerable reduction of these emissions. On the long run, the development of inert anodes can reduce PFC emission to zero. However, successful development of inert anodes before 2010 seems unlikely. The average life of an aluminium smelter is between 25 and 30 years. An autonomous reduction by 75-90% in the next two decades seems likely in the countries with existing smelters.

HFCs
HFC emissions can be split into emissions in production (the bulk of HFC-23 emissions) and emissions during use (from refrigerators, air conditioning equipment etc.). These emissions can be reduced significantly through reduction of leakages and through substitution of cooling agents. For example the high HFC emission for the Netherlands is accounted for by HFC-23, by-product from HCFC-22 production. The emission can be reduced by 90% through installation of cracking installations and after-burners (Ros, 1994).

SF_6
The bulk of SF_6 is used for high voltage equipment. The emissions are caused by leakages and waste handling of old equipment. The introduction of new sealing materials, the chemical and mechanical treatment of flanges and the improvement of shield welding techniques should help to decrease this leakage rate. Moreover, it is possible to install SF_6 leakage detection cameras. Integrated chain management strategies can be developed for old equipment. The potential for emission reduction is 20-40%. However, cost data have not been encountered. These options have not been considered in the analysis.

Land use change
Land use change refers to the carbon storage in soil and trees. The costs are accounted for by land costs, plantation costs and carbon storage potentials. Costs and potentials will depend on the future land use (production forests or sec carbon storage). The carbon storage option seems more likely, if the surplus wood situation in Europe is considered. Assuming 50 years of carbon storage, 5-10 tonne CO_2 storage per ha per year, 1000 ECU/ha/year, costs are 100-200 ECU/tonne CO_2. This measure does not seem cost-effective within the framework of the Kyoto agreement. However, one must emphasise that new forests can provide major secondary benefits. Wood production, recreation and erosion control are examples of secondary benefits. The distribution of forestry costs between these categories can significantly reduce emission reduction costs.

Reduction of industrial N_2O emissions

The countries of the European Union (excluding Italy, Spain, Portugal) reported for 1990 an industrial N_2O emission of 306 Gigagrams (UNFCCC, 1997). This emission equals 95 Mt CO_2 equivalents (compared to a total emission of approximately 4500 Mt CO_2 equivalents). Two industrial processes account for the bulk of these process emissions. The first one is the production of nitric acid. The second one is the production of adipic acid.

Nitric acid production

Western European nitric acid (HNO_3) production amounted to 18.3 Mt in 1989. The process emission is approximately 3 tonne CO_2 equivalents per tonne HNO_3. The total Western European emission from this source is approximately 60 Mt CO_2 equivalents per year (Gielen, 1997).

The N_2O concentration in the off-gases is in the range of 500-3000 ppm. Emissions can be reduced by more than 90% through end-of-pipe equipment, based on catalytic conversion. The concentration of N_2O in the off-gases is so low that special ovens must be installed to heat the off-gases to the minimum temperature of 300°C.

Emission abatement costs can be calculated on the basis of a case study for a specific plant. A nitric acid plant produces 80.000 m^3 off-gases per hour, containing 500 ppm of N_2O. This equals a total emission of 0.68 Kt N_2O per year. Based on a GWP of 310, this equals 210 Kt CO_2 equivalents per year. The investment for an installation that achieves 90% emission reduction amounts to 1-2 million ECU. Annual costs for catalysts, labour, etc. amount to 200-350 thousand ECU. Assuming a plant life of 25 years and an interest rate of 10%, total costs amount to 310-570 thousand ECU per year. Emission abatement costs amount to 1.5-2.7 ECU per tonne CO_2 equivalent.

Current research at ECN focuses on the optimisation of the N_2O conversion efficiency through improved selection of catalysts and temperature optimisation.

Adipic acid production

Western European adipic acid production amounted in 1992 to 650 Kt (Weissermel, 1994). Adipic acid is produced in 10-20 industrial plants. Adipic acid is an intermediate in the production of nylon 6.6. Its chemical structure is $COOH(CH_2)_4COOH$. It is produced from cyclohexane that is converted into a mixture of cyclohexanol and cyclohexenone by catalytic oxidation. The mixture is catalytically converted into adipic acid. Two catalyst systems are applied. One uses HNO_3, the other one uses oxygen. In the system that uses HNO_3, significant amounts of N_2O are generated as by-product. The N_2O- concentration in the off-gases is 20 volume percent. The N_2O emission amounts to 180 kg/t adipic acid (Ayres and Ayres, 1996). This equals a CO_2 emission of 60 t/t adipic acid. For the whole of Western Europe, the emission equals 40 Mt CO_2. If oxygen is used, no N_2O is produced. However, this new process is not yet widely applied. Other new process routes start from butadiene. In conclusion, alternative process routes can on the long term easily reduce the N_2O emissions in adipic acid production.

On the mid-term (the next 10 years), catalytic reduction of N_2O in exhaust gases poses the most attractive alternative. The catalysts are available, the main technological problem is the heat that is produced. Cooling is required to prevent overheating of the equipment.

The annual costs of catalytic conversion equipment are estimated to be lower than for nitric acid plants, because the oven costs can be saved. Assuming costs of 1 million ECU per plant and assuming an emission of 1 Mt per plant, emission reduction costs are 1 ECU/t CO_2 equivalents.

Conclusions

The total of N_2O emissions for HNO_3 production and for adipic acid production, based on bottom-up estimates, is 100 Mt per year, N_2O abatement constitutes for both processes a cost-effective option for greenhouse gas emission reduction. Emission reduction costs are between 1 and 2.7 ECU/t CO_2 equivalents. The catalysts are available, retrofit of existing production plants is feasible before 2010. Retrofit can reduce the emissions by more than 90%. Additional research focuses currently on the optimisation of the N_2O conversion efficiency.

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