

Simulating the Market for Greenhouse Gas Emission Reductions: The CERT Model

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Abstract

The paper presents the structure of the CERT model as well as market projections and scenarios based upon CERT. The relative impact of recent changes in the GHG (greenhouse gas) market including US withdrawal and additional Annex B sinks is discussed. Scenarios are also discussed which quantify the relative impact of an entry of Kazakhstan as Annex B country, a reduced implementation rate of CDM projects, price leadership behavior of the FSU and a banking of emission permits with a reference scenario based upon the market framework conditions after CoP 7. A combined scenario including all different factors is developed to make a "realistic" projection of the GHG market. A market price of USD 15-20 per ton of carbon is considered as most probable under current conditions. This price range is compared with real market deals managed currently.

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Abbreviations

AAUs	Assigned Amount Units
ABARE	Australian Bureau of Agricultural and Resource Economics
BAU	Business As Usual
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CERT	Carbon Emission Reduction Trade Model
CGE	Computable General Equilibrium
CICERO	Center for International Climate and Environmental Research
CO ₂	Carbon Dioxide
CoP	Conference of the Parties
DOE	Department of Energy of the USA
EIT	Economies In Transition
EPPA	Emission Prediction and Policy Assessment Model
ERU	Emission Reduction Unit
EU	European Union
GEF	Global Environmental Facility
GHG	Greenhouse Gas
GTEM	Global Trade and Environment Model
IEA	International Energy Agency
JI	Joint Implementation
KP	Kyoto Protocol
LULUCF	Land Use, Land-use Change and Forestry
MACs	Marginal Abatement Cost Curves
MIT	Massachusetts Institute of Technology
NPV	Net Present Value
NSS	National Strategy Study
OECD	Organization for Economic Co-operation and Development
PCF	Prototype Carbon Fund
RIIA	Royal Institute of International Affairs
SB	Subsidiary Body
Seco	State Secretariat of Economic Affairs
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

This paper presents and discusses simulations of the emerging market for greenhouse gas (GHG) emission reductions under the Kyoto Protocol. The Kyoto Protocol sets legally binding emissions targets for a basket of six GHGs for Annex B countries¹. Together, these countries must reduce their emissions by 5.2% below 1990 levels over the commitment period 2008-2012². The Kyoto Protocol incorporates three flexibility mechanisms through which the costs of abating emissions can be lowered: the Clean Development Mechanism (CDM) for projects jointly implemented between Annex I and Non-Annex I countries (i.e. developing countries), and Joint Implementation (JI) and trading schemes for the transfer and trade of emission reductions among Annex I countries. The term "trade of GHG emission reductions" is used in this paper to cover all three flexibility mechanisms. In providing these mechanisms a new market is established, which not only reduces the costs of meeting the Kyoto commitments but also offers a new source of export earnings for Non-Annex I parties as well as a potential for technology transfer into these countries.

¹ The Kyoto Protocol includes carbon dioxide (CO₂) emissions from fossil fuels, methane, nitrous oxide, perfluorocarbons, hydrofluorocarbons, and sulfur hexafluoride

² Kyoto Protocol to the United Nations Framework Convention on Climate Change, UNFCCC, 1997

The simulations presented and discussed below are calculated with the CERT model, version 1.2. The CERT model (Carbon Emission Reduction Trade) is a partial equilibrium model to simulate the emerging market for the trade of GHG emission reductions. It uses inputs from computable general equilibrium models (CGE models), such as GHG emission projections and marginal abatement cost functions (MACs), and allows for a variety of parameter modifications and specifications of mechanisms stipulated in the Kyoto Protocol. Above all, the CERT model is designed to test the sensitivity of market outcomes with respect to the many uncertainties that characterize this emerging market. The simulations incorporate the decisions of the Conferences of the Parties (CoP), including those of CoP 7 held in Marrakech in November 2001, as well as the decision of the USA in the same year to withdraw from the Kyoto Protocol...

The paper is organized as follows. Chapter 2 summarizes the solution algorithm of the CERT model and the options for parameter modifications and policy assumptions the user can specify. Chapter 3 describes the core variables that affect the GHG market, and different datasets that exist for these variables. Chapter 4 presents and discusses the outcomes of various market scenarios and compares these with current market prices paid.

2. The solution algorithm and options of the CERT model

2.1. Introduction

The CERT model expresses all emissions and reductions of GHGs in tons of carbon.³ Financial data is expressed in US\$ of 2000. The market is cleared for the first commitment period 2008-2012. The year 2010 is taken as a "representative" (average) value for the first commitment period.

The countries and regions included in the CERT model have been taken from the EPPA model (Emission Prediction and Policy Assessment) of the MIT (Yang 1996). The regional structure is given in Table 1.

Table 1: Regional structure of the CERT model⁴

Annex B countries and regions	Non-Annex B countries and regions
USA: United States of America	EEX: Energy Exporting Countries
JPN: Japan	CHN: China
EEC: European Union (EC 15 members)	IND: India
OOE: Other OECD Countries	DAE: Dynamic Asian Economies
EET: Eastern Europe	BRA: Brazil
FSU: Former Soviet Union	ROW: Rest of the World

2.2. Solution algorithm

The solution algorithm of the CERT model is designed to find a minimum-cost solution for the global reduction of GHGs (see also Ellerman and Decaux (1998), Zhang (2000), Grütter et al. (2001)). The required emission reductions of Annex B countries / regions, i.e. the total demand of GHG reductions, are calculated by subtracting the "business as usual" (BAU) emissions 2010 from the so-called "assigned amount" (1990 emissions multiplied by the Kyoto target, i.e. 0.948 for all Annex B countries together). The supply of GHG emission reductions in each country / region is determined by varying the world market price of GHG emission reductions from $P_0 = 0$ US\$ to $P_{kk} = 450$ US\$, by increments of 1 US\$. The interna-

³ To calculate CO₂ you have to multiply by 44/12

⁴ Annex 1 includes the list of countries per region

tional trade of emission reductions can be restricted ("supplementarity") with model options discussed below. The market equilibrium is achieved if global demand equals global supply.⁵

In algebraic terms the required emission reductions for the six Annex B countries / regions are determined as follows:

$$(1) \quad QR_i = BAU_i - (KT_i E_{1990i}) \quad i = 1,6$$

QR = amount of GHG emissions to be reduced
 BAU = business as usual, amount of emissions in 2010
 KT = Kyoto target
 E₁₉₉₀ = emissions 1990

The marginal abatement cost functions for each of the 12 countries / regions of the CERT model are used to calculate the amounts and costs of GHG emission reductions. Given a world market price for GHG emission reductions, and assuming perfect competition, each country / region reduces emissions until marginal costs equal the world market price. The integral of the marginal cost function then gives the total costs of emission reduction.

The CERT model allows for two specifications of the marginal cost functions: a quadratic function and an exponential function.

$$(1a) \quad MC_i = a_i Q_i^2 + b_i Q_i \quad i = 1, 12$$

$$(1b) \quad MC_i = a_i (e^{b_i Q_i} - 1) \quad i = 1, 12$$

MC = marginal costs of emission reduction
 Q = emission reduction

Given a world market price P_k ($0 \leq k \leq 450$), the amount of emissions reduced in each country / region results as:

$$(2a) \quad Q_i = -b_i / 2a_i + ((b_i / 2a_i)^2 + P_k/a_i)^{1/2} \quad i = 1, 12$$

$$(2b) \quad Q_i = \ln(P_k / a_i + 1) / b_i \quad i = 1, 12$$

Q = emissions reduction
 P = world market price of GHG offsets

The costs of emission reductions result from the integration of the marginal cost functions:

$$(3a) \quad C_i = 1/3 a_i Q_i^3 + 1/2 b_i Q_i^2 \quad i = 1, 12$$

$$(3b) \quad C_i = (a_i / b_i) e^{b_i Q_i} - a_i Q_i - (a_i / b_i) \quad i = 1, 12$$

C = costs of emission reduction
 Q = emission reduction

The market equilibrium is achieved if total emissions to be reduced equal total emission reduction. Under the condition of perfect competition the world market equilibrium price of GHG emission reductions results as:

$$(4) \quad TQR = \sum QR_i \quad i = 1,6; QR_i > 0$$

⁵ The exact equilibrium price and quantity is determined by interpolation between the (integer) prices and the quantities just above and below the equilibrium.

$$\begin{aligned} \text{TQR} &= \text{total emissions to be reduced} \\ \text{QR} &= \text{emissions to be reduced} \\ (5) \quad \text{TQ} &= \sum Q_i \quad i = 1, 12 \\ \text{TQ} &= \text{total emission reduction} \\ \text{Q} &= \text{emission reduction} \\ (6) \quad \text{P}^* &= \text{P for TQR} = \text{TQ} \\ \text{P}^* &= \text{equilibrium price for GHG reductions} \\ \text{TQR} &= \text{total emissions to be reduced} \\ \text{TQ} &= \text{total emission reduction} \end{aligned}$$

The worldwide costs of GHG emission reduction are:

$$\begin{aligned} (7) \quad \text{TC} &= \sum C_i \quad i = 1, 12 \\ \text{TC} &= \text{total costs of emission reduction} \\ \text{C} &= \text{costs of emission reduction} \end{aligned}$$

The Kyoto target could also be achieved without trade of emission reductions among countries and regions. In this "autarkic" solution each Annex B country / region would reduce GHG emissions to its "Assigned Amount", i.e. QR_i would equal Q_i for each Annex B country / region with $QR_i > 0$.

Total costs for the autarkic solution are given by:

$$\begin{aligned} (8a) \quad C_{Ai} &= 1/3 a_i Q_{Ai}^3 + 1/2 b_i Q_{Ai}^2 \quad i = 1, 6; QR_i > 0 \\ (8b) \quad C_{Ai} &= (a_i / b_i) e^{b_i Q_{Ai}} - a_i Q_{Ai} - (a_i / b_i) \quad i = 1, 6; QR_i > 0 \\ (9) \quad \text{TC}_A &= \sum C_{Ai} \quad i = 1, 6; QR_i > 0 \\ C_{Ai} &= \text{autarkic costs of emission reduction} \\ Q_{Ai} &= \text{autarkic emission reduction} \\ \text{TC}_A &= \text{total costs of autarkic emission reduction} \end{aligned}$$

Total savings or benefits from international trade of emission reductions (relative to the autarkic solution) then result as:

$$\begin{aligned} (10) \quad \text{TS} &= (\text{TC} - \text{TC}_A) / \text{TC}_A \\ \text{TS} &= \text{total savings from trade of emission reductions in relative terms} \\ \text{TC} &= \text{total costs of emission reduction with trade} \\ \text{TC}_A &= \text{total costs of autarkic emission reduction} \end{aligned}$$

The assumption of perfect competition implies that the Annex B countries capture the savings or benefits from the trade of emission reductions. However, it is theoretically conceivable and, as will be discussed in section 4.3, under certain conditions not unlikely that Non-Annex B countries and suppliers of so-called "hot air"⁶ form some sort of oligopoly with price-setting behavior to capture part of these profits. Suppliers for tradable GHG emission reductions would then be restricted, i.e. suppliers would not expand emission reduction until marginal costs equal the world market price.

⁶ If the "assigned amount" is higher than BAU emissions the respective countries possess "virtual" emission reductions, which are usually called "hot air".

It is well known that the model of an oligopoly requires specific assumptions on the behavior of the actors. Well known analytical solutions exist for the special case of the duopoly: the "Cournot solution", in which the two suppliers act simultaneously by anticipating the other's reaction function, and the "Stackelberg solution", in which one supplier takes the price leadership in anticipating the other's reaction function. Other approaches are n-actor cooperative and non-cooperative games. In all cases solutions depend critically on uncertain information and behavior characteristics that are difficult to determine. None of these approaches has been followed in the CERT model, which, as will be discussed in Section 4, only allows for introducing ad hoc assumptions on oligopolistic behavior.

However, we know that an oligopoly would maximize its profits if it behaved like a monopolist, i.e. if it expands supplies until marginal returns equal marginal costs. In other words, the monopolistic price is the upper price limit that could result from an oligopoly, and any other oligopolistic behavior would result in prices somewhere between the monopolistic price and the price under perfect competition. Therefore the CERT model includes a "monopoly" option, which calculates a solution for the monopolistic equilibrium condition:

$$(11) \quad P_M^* = P \text{ for } \sum Q_i P - \sum C_i = \text{Max} \quad i = 5, 12 \quad QR_i \leq 0$$

P_M^*	=	monopolistic world market price
Q	=	emission reduction
QR	=	emissions to be reduced
C	=	costs of emission reduction

Only Non-Annex B countries / regions plus EET and FSU are included as participants in the monopoly. In extreme cases of BAU projections OOE countries also export GHG emission reductions, albeit small quantities.

2.3. Options of the CERT model

Apart from the "monopoly" solution the CERT model allows for choosing various other market-relevant options. These options can be divided into two groups. The first group includes options that refer to mechanisms of the Kyoto Protocol, and the second group of options includes specifications or modifications of variables and parameters that are of special interest for sensitivity analyses.

The first group of options includes⁷:

- Trade of "hot air": The model user can specify the percentage share of "hot air" that may be traded. Since the conclusion of CoP 7 unlimited trade of "hot air" is allowed. With this option the CERT model can also simulate a voluntary supply restraint of "hot air" suppliers with the goal of increasing revenues through price setting.
- Import ceiling ("supplementarity"): The model user can specify the share of GHG emission reductions that Annex B countries may import, either as percentage of their assigned amount or as percentage of the required emission reduction. CoP 7 decided to not establish a quantitative supplementarity limit, but e.g. the EU as well as Switzerland contemplate to impute import ceilings unilaterally.
- Adaptation fund: The model user can specify a percentage share of proceeds on the CDM project activities that will be allocated to the adaptation fund. At CoP 7 it was decided to finance that fund with a premium of 2% on the proceeds from CER sales.
- "Zero-cost sinks": The user can specify the GHG emission amount reduced through LULUCFs (land use, land-use change and forestry activities) in Annex B countries. These are assumed to incur no additional cost. This quantity is simply added to the

⁷ CERT includes for these options a default value fixed according to most recent decisions taken at CoPs. The user can however change these values.

assigned amount, which leads to a corresponding decline of required emission reductions. The CERT model's default values for "zero-cost sinks" in Annex B countries / regions are those given in the appendix Z of CoP 7 conference document.

The second group of options includes:

- Transaction costs of emission reductions traded through the CDM (CERs): The model user can specify transaction costs in US\$ per ton of carbon, which result in an upward shift of the MACs of Non-Annex B countries.
- Implementation rate of CDM projects: The model user can specify implementation rates (in percent) for Non-Annex B countries. Implementation rates below 100 % assume that Non-Annex B countries do not fully implement all projects as reflected in their MACs. Implementation rates below 100 % increase the gradient of the respective MACs. Implementation rates over 100% allow for early crediting of CERs (prior to the commitment period 2008-12).
- Introduction of MACs as exponential or quadratic functions for "sinks" (LULUCFs) both for Annex B and Non-Annex B countries.
- Calculation of a monopolistic solution (see section 2.2).
- In addition the model user can modify all scenario variables and parameters that are used as inputs for the CERT model (e.g. BAU projections, types and parameters of MAC-functions, etc.). A set of scenarios is stored in a library, and each scenario can be activated by the user. The CERT model always solves for a so-called "reference scenario" and a "new scenario" (in each case including the autarkic solution described before), which allows for easy comparison of results and sensitivity analyses.
- Finally the model user can specify input variables and parameters for a so-called "additional country". If, for instance, MAC parameters are available for Vietnam, the model would calculate the country-specific implications of a scenario solution for this specific country. The additional country option can be activated for individual Annex B and Non-Annex B countries.

The model version CERT 1.2 is available as version with or without participation of the USA in the Kyoto Protocol.

3. Core variables of the GHG market

3.1. Introduction

Four core factors determine the market for GHG emission reductions:

- BAU projections of GHG emissions of Annex B countries / regions;
- Marginal Abatement Costs (MACs) of GHG emission reductions of all countries / regions;
- Rules governing the market (e.g. on complementarity, treatment of LULUCFs, etc.);
- Market behavior of buyers and sellers, e.g. participation of the USA, monopoly, oligopoly, etc.

3.2. Business as Usual Estimates

Required Emission reductions are calculated as projected BAU emissions minus the assigned amount. BAU estimates vary considerably between sources. Table 2 lists the BAU estimates included as standard scenario variables in the CERT model⁸. The aggregate levels of projected emissions in 2010 are dramatically smaller than figures estimated pre CoP 7 (see e.g. Zhang, 2000 or Ellermann 1998). This is mainly due to the withdrawal of the USA

⁸ Additionally all GHG BAU projections including all GHG assigned amounts based upon GTEM data are also included in CERT

from the Kyoto Protocol. Moreover, particularly the lowest BAU projection recognizes the possibility that economic growth up to 2010 might be significantly lower than expected in previous projections.

Table 2: BAU projections and assigned amounts for Annex B countries / regions (year 2010, MtC)⁹

BAU projections	USA	JPN	ECE	OOE	EET	FSU	Total with USA	Total without USA
US DOE low	1750	309	964	307	206	542	4078	2328
US DOE medium	1809	330	1011	324	227	575	4276	2467
US DOE high	1883	353	1062	343	236	672	4549	2666
<i>Assigned Amount</i>	<i>1259</i>	<i>274</i>	<i>822</i>	<i>218</i>	<i>282</i>	<i>816</i>	<i>3671</i>	<i>2411</i>

BAU projections depend on a complex interaction of the development of GDP per capita, population growth, overall structural and technical change, and energy and carbon elasticity. The latter depend on interdependent changes in the energy sector, such as technical progress, development of energy prices and energy mix, as well as energy and environment policies implemented by governments. These policies also include the future use of nuclear energy. It goes without saying that each of these changes is burdened with uncertainties, and it is these uncertainties – and their interactions – that account for the differences in the projections. Especially for the EU there is a large difference between BAU projections from economic modeling studies¹⁰, which indicate large emission gaps, and projections based on the compilation of the "national communications"¹¹, with much smaller differences between the Kyoto target levels and BAU projections.¹²

The amount of "hot air" of the FSU and the EET is a core issue. CERT incorporates "hot air" ranges between 190 and 370 MtC per year (scenarios based upon US DOE, 2001 and GTEM, 2000). Other estimates even reach 590 MtC (SRES B2, see for a range of projection UNFCCC, 2001). Estimates have been increased recently due basically to lower growth estimates for Russia. However the wide range of estimates shows also that considerable insecurity is attached to these projections.

3.3. Marginal Abatement Costs

The world supply for GHG emission reductions is determined by marginal abatement cost functions (MACs). MACs can be estimated either with a top-down approach (i.e. estimates from modeling studies) or a bottom-up approach (i.e. engineering estimates based on project data). The MACs used in the CERT model belong to the group of top-down approaches. At the time being, four sets of MACs are available: one set from the EPPA (Emission Prediction and Policy Analysis) model of MIT for CO₂ only; two sets from the GTEM model (Global Trade and Environment Model) for CO₂ only and for all GHGs of ABARE (Australian Bureau of Agricultural and Resource Economics); and one set of "quasi bottom-up" MACs (see below) generated with the GTEM model. The EPPA model and the GTEM model are multi-

⁹ Annex B countries without the USA; US DOE estimates are for CO₂ only

¹⁰ like the ones realized by US DOE (2001), EPPA (Ellermann et al, 1998 and Reilly et al, 2000) or GTEM (Polidano, 2000)

¹¹ e.g. realized by RIIA (Vrolijk, 2000), Cicero (1998) and Zhang (1999)

¹² Reasons for the low EU BAU projections used in the National Communications are basically the internal burden sharing of the Kyoto commitments among the member countries and impacts of energy policies that are currently being either implemented or negotiated in response to climate change. These are incorporated in the National Communications but not in the economic models. Examples for such policies are the change to an environmental tax system based on energy instead of labor, the introduction of carbon taxes or voluntary but binding agreements such as the ones made between the EU and the European Automobile Manufacturers Association (ACEA) or between the Swiss Agency for Environment and industrial sectors in Switzerland.

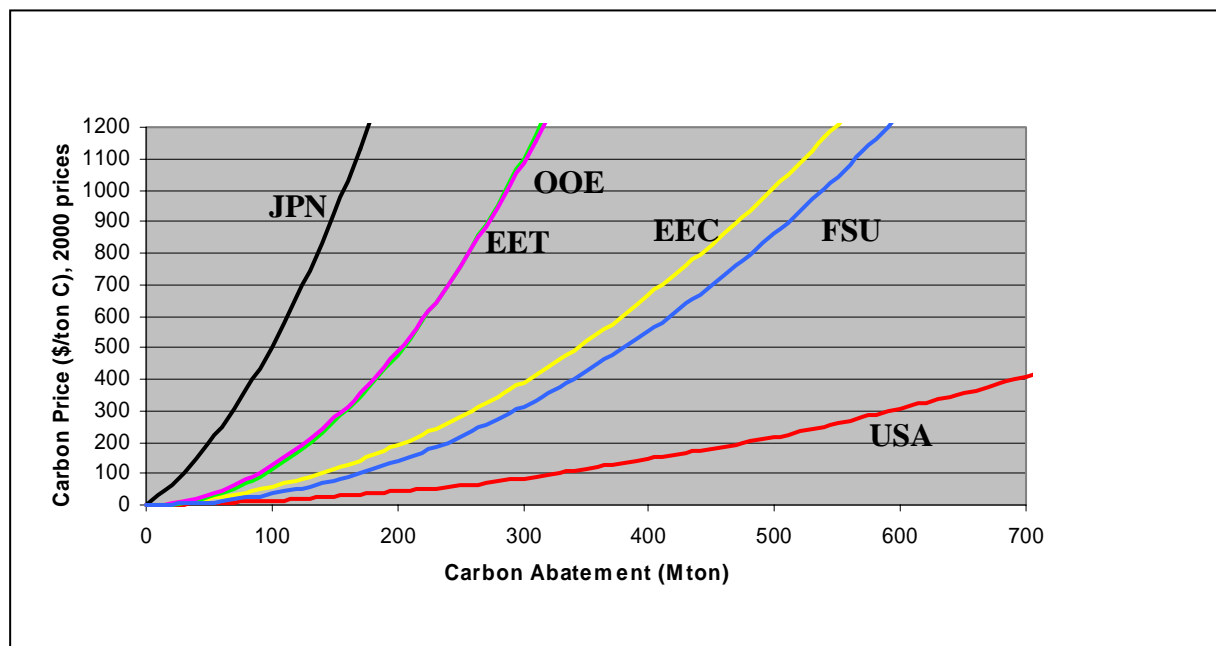
sector and multi-region CGE models that simulate the development of global production, trade, energy use, and GHG emissions¹³.

The teams of MIT and ABARE have generated the MACs by running their models with a set of varying exogenous and policy assumptions. Econometric estimates of quadratic functions (EPPA model) or exponential functions (GTEM model) give a good approximation of the generated marginal cost data. Moreover, sensitivity tests have shown that the MACs are robust to different levels of abatement within regions, and to the amount of international trade of GHG emission reductions.¹⁴ The MACs, presented below, do not include LULUCFs.

Bottom-up estimates of MACs are used by e.g. the MERGE or POLES model¹⁵. These MACs are usually based on engineering estimates of reduction potentials (technical projects), leading often to a large amount of so-called "no-regret" options, i.e. emission reductions with negative or zero abatement costs. The CERT model also includes GTEM "quasi bottom-up" MACs, which have been derived from samples of projects in a few countries. The samples indicate that "bottom-up" estimates of MACs are about 30 % above "top-down" estimates, and that factor of proportionality was applied for the MACs of each country / region.¹⁶

Figures 1a to 1b show the MACs for Annex B countries/regions derived from the EPPA model and the GTEM model for CO₂ only¹⁷. Generally speaking, the GTEM MACs have a steeper gradient than the EPPA MACs. Note that the ranking of countries / regions is the same in all sets of MACs. Nonetheless, the differences of the estimates indicate considerable uncertainties of expected costs of emission reductions.

Figure 1a: MACs for Annex B countries / regions (EPPA, CO₂ only)



Source: Ellermann et al, 1998

¹³ See for more information on the generation of MACs in EPPA: Ellermann et al, 1998

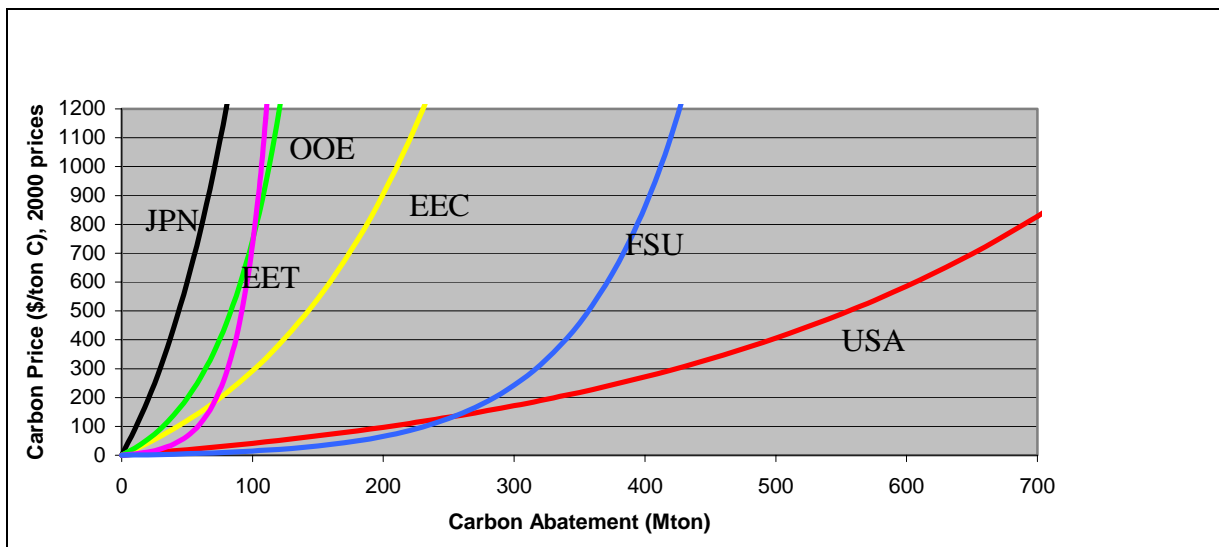
¹⁴ Ellerman et al. 1998

¹⁵ OECD, 1998

¹⁶ Polidano, 2000

¹⁷ CERT also includes all GHG MACs from GTEM

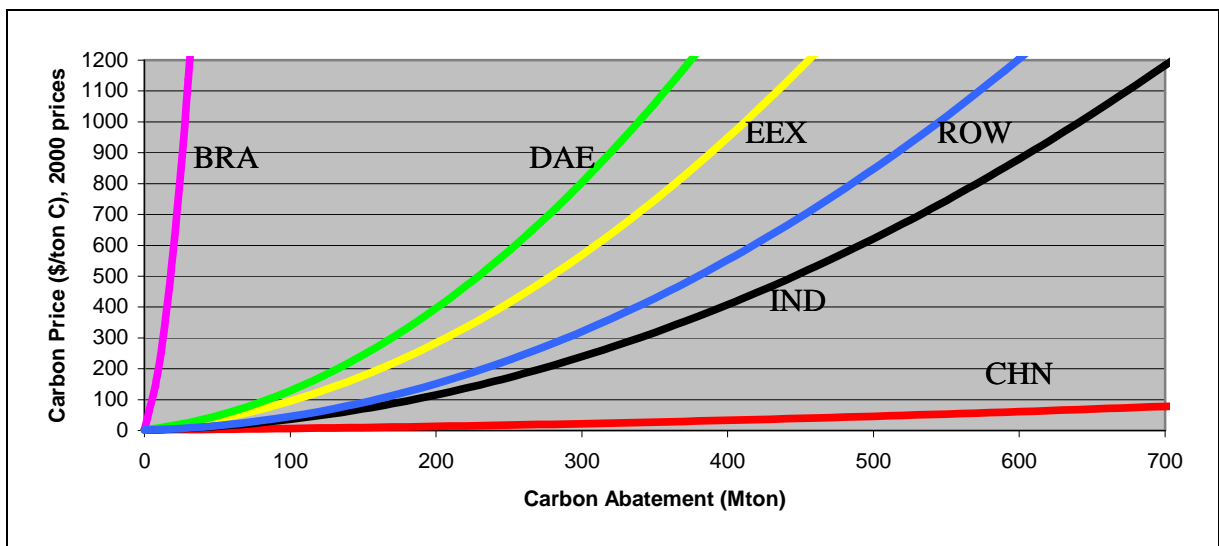
Figure 1b: MACs for Annex B countries / regions (GTEM, CO₂ only)



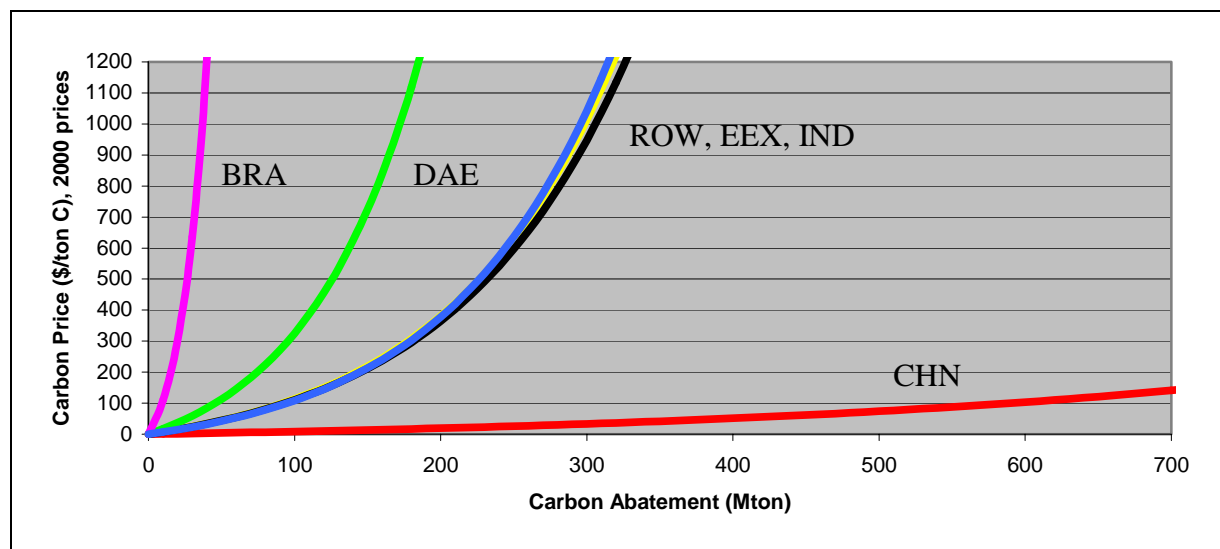
Source: Polidano, 2000

For Non-Annex B countries the differences between MACs of the EPPA model and the GTEM model give a similar picture. Again, the gradients of the GTEM MACs are generally steeper than those of the EPPA MACs, and the ranking of countries / regions is the same in both sets of curves (Figure 2a to 2b). The figures show very low MACs for China, with a very flat gradient. India also shows a large potential of low-cost CERs, while other countries and regions have significantly higher MACs and smaller supply potentials.

Figure 2a: MACs for Non-Annex B countries / regions (EPPA, CO₂ only)



Source: Ellermann et al, 1998

Figure 2b: MACs for Non-Annex B countries / regions (GTEM, CO₂ only)

Source: Polidano, 2000

3.4. Market rules and market behavior

For scenario construction the current rules and regulations are taken and various probable market behavior scenarios are run. CERT allows for changing these variables as described in chapter 2.3.

4. Scenarios and simulation results

4.1. Introduction

The scenarios and simulation results presented and discussed below are based on the four BAU projections presented in Table 2. The three DOE BAU scenarios are each calculated with the two sets of MACs for CO₂ only of the EPPA model and the GTEM model. The GTEM BAU scenario for all GHGs is combined with the GTEM MACs for all GHGs. In addition a medium BAU scenario of GTEM is calculated with the "quasi bottom-up" MACs mentioned before (these combinations of scenario assumptions are summarized in Appendix 2). Regarding market rules all scenarios reflect decisions taken at the Conferences of the Parties, including those reached at CoP 7 including no quantitative supplementarity rules, no restrictions on "hot air" trading and a 2% levy on the share of proceeds from CDM projects for the Adaptation Fund.

The first set of scenarios compares the GHG market before the retirement of the USA and before agreements reached at Bonn and Marrakech 2001 (called "reference scenario old") with the situation currently. The impact on the GHG market of the US retirement and of the inclusion of sinks for Annex B countries is estimated. Also a partial participation of the USA is discussed.

The second set of scenarios compares the situation after CoP 7 with factors which influence the market. A "reference scenario new" is created against which alternative market scenarios are compared. Comparisons are made with a possible entrance of Kazakhstan as Annex B country, a price-leadership behavior of FSU, a reduced implementation rate of CDM projects and a banking of emission permits.

In the final section a combination of factors is assumed to make a projection of the GHG market price based upon currently available information and trends. This projection is compared with other recent modeling estimates and also with prices of real deals and auctions in the GHG market.

The following presentation and discussion is structured along the assumptions on market forms and market participation, as well as the level of the BAU estimates (low, medium, high). Lower and upper boundaries of prices and quantities for each scenario reflect the variance of simulation results caused by differences in the four sets of MACs.

4.2. Impact of the CoP 7 agreement and retirement of the USA

Table 3 shows the price ranges, volumes of worldwide trade of GHG emission reductions, and export revenues of Non-Annex B countries from CDM proceeds for the year 2010 before retirement of the USA and before CoP 6+¹⁸.

Table 3: "Reference Scenario old": GHG market as estimated start 2001 (US\$ 2000)¹⁹

Scenario	world market price per tC	Traded volumes in MtC (imports Annex B)	export revenues non-Annex B in millions
Low BAU estimates	7-15	640-700	1'500-3'300
medium BAU estimates	12-31	730-900	4'200-9'700
high BAU estimates	22-43	830-920	11'000-12'300

Estimates of other models published in 1999 or 2000 come to similar results with price ranges from 10 US\$ to 40 US\$ per ton of carbon (Bernstein, 1999 (MS-MRT model); CICERO 1998, Ellermann, 1998 (EPPA model); Jotze (GTEM model); Zhang, 1999).

Figure 3 shows the impacts of a complete and partial US retirement as well as of sinks for Annex B countries agreed upon at CoP 7. In Annex 3 the price ranges, volumes of worldwide trade of GHG emission reductions, and export revenues of Non-Annex B countries from CDM proceeds for the year 2010 are presented for the three scenarios. The expected GHG world market price is also compared to the reference scenario.

The US withdrawal leads to an average estimated price reduction in the order of 90%. On the other hand this increases the negotiation potential as well as the market power of Russia as participation of latter is required for the Kyoto Protocol ratification (it can thus negotiate a certain price for its "hot air") and Russia is now by far the dominant market supplier for GHG reductions. A partial participation of the USA in the global market is a realistic possibility. This might take the form of agreeing on the Kyoto Protocol with a reduced target, or participating in the GHG market under national or state regulations with similar criteria as those used in the flexibility mechanisms of the Protocol²⁰. Partial participation might even come through the voluntary participation of individual US-firms. While the latter would lead to two market mechanisms the product price would be fairly homogeneous if similar restrictions apply, e.g., on sinks. Calculations based upon a realization of 30% of calculated emission reductions required to fulfill the KP in 2010 lead to an average price reduction of more than 70% compared to the reference case.

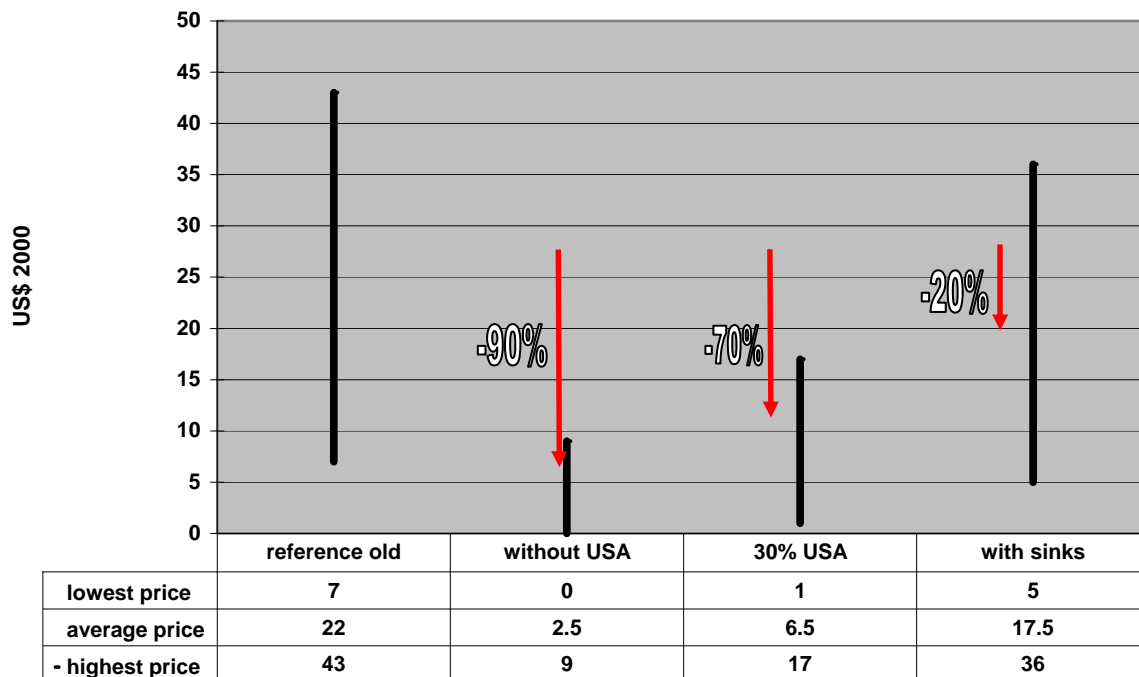
¹⁸ with exception of the non-significant 2% of proceeds for the adaptation fund

¹⁹ scenarios based upon no supplementarity, no LULUCFs from Non-Annex B, 100% implementation rate CERs, 100% trade hot air, no banking, 2% adaptation fund CERs, perfect competition, participation of the USA; Using scenarios of CERT 1.2 based upon scenarios 1-8 described in Annex 2; the ranges inside low-medium-high BAU estimates are due to different MACs

²⁰ various states have already passed such legislation or are in the process of passing. For a review of US state and private sector involvement see EcoSecurities Carbon Market Intelligence Reports 1-3, 2001/2

Annex B sinks as determined in Marrakech are introduced in the maximum quantities as fixed in Appendix Z. These sinks are modeled as 0-cost sinks and thus reduce the remaining emission reductions required. The impact of the agreed-upon sinks using US sinks on the same calculation base as those agreed upon at Bonn (see appendix Z, CoP 7) is an average relative price reduction of more than 20%.

Figure 3: Impact of a US participation and sinks on the GHG market price



4.3. Impact of other key market factors

Table 4 shows the price ranges, volumes of worldwide trade of GHG emission reductions, and export revenues of Non-Annex B countries from CDM proceeds for the year 2010 based upon the "reference scenario new". This be reference scenario incorporates the agreed upon sinks at CoP7 and assumes a 30% participation of the USA primarily due to voluntary reductions of companies and state led initiatives.

Table 4: "Reference Scenario New": GHG market after CoP 7²¹

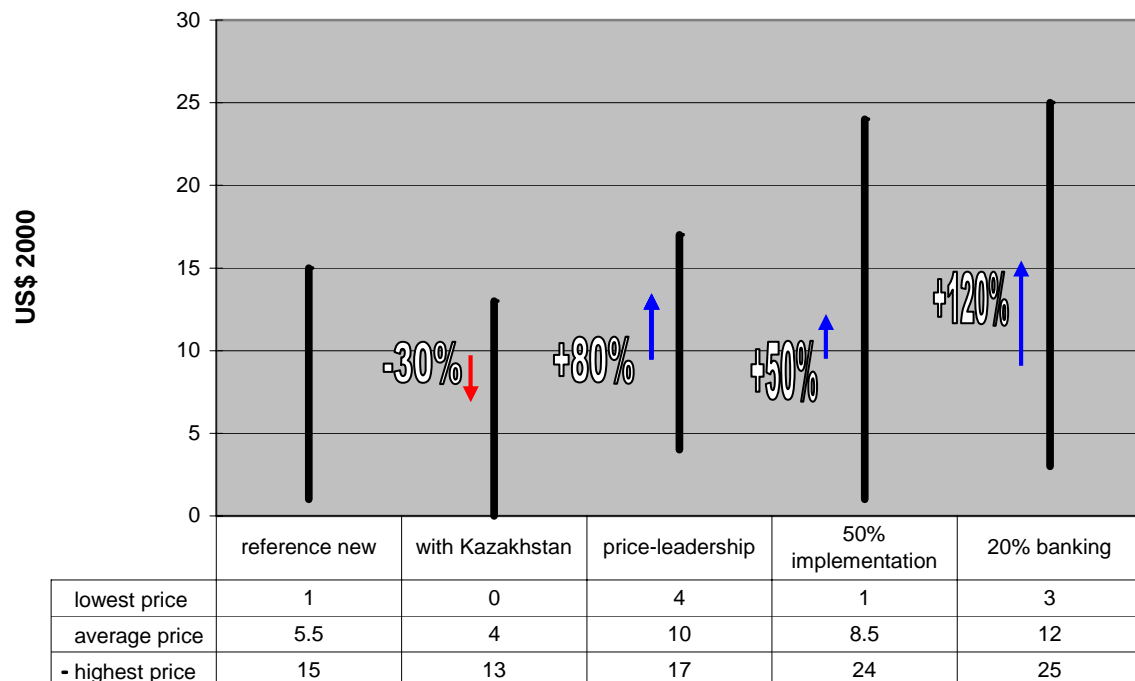
Scenario	world market price per tC	Traded volumes in MtC (imports Annex B)	export revenues non-Annex B in millions
Low BAU estimates	1	390-420	20-40
Medium BAU estimates	2-7	460-530	220-840
high BAU estimates	7-15	520-580	1'500-3'400

Figure 4 shows the impacts of a participation of Kazakhstan, of a price leadership behavior of FSU, of a reduced implementation rate of the CDM (50%) and of a possible banking of permits (20% additional reductions than required). In Annex 4 the price ranges, volumes of worldwide trade of GHG emission reductions, and export revenues of Non-Annex B countries

²¹ scenarios based upon no supplementarity, no LULUCFs from Non-Annex B, 100% implementation rate CERs, 100% trade hot air, no banking, 2% adaptation fund CERs, perfect competition, 30% participation of the USA, sinks Annex B according to Appendix Z CoP 7; Using scenarios of CERT 1.2 based upon scenarios 1-8 described in Annex 2; the ranges inside low-medium-high BAU estimates are due to different MACs

from CDM proceeds for the year 2010 are presented for the four scenarios. The expected GHG world market price is also compared to the new reference scenario.

Figure 4: Impact of key market factors on the GHG market price



The data clearly shows that banking and price-leadership behavior influence in a very strong manner GHG market prices.

Kazakhstan has reconfirmed its intention at CoP7 to join the Kyoto Protocol as Annex B country. Assuming similar reduction agreements as those of Russia (stabilization at 1990 levels) Kazakhstan would be a supplier of "hot air". The level of hot air of Kazakhstan is estimated at 50 MtC per year²². The impact of a participation of Kazakhstan is on average a reduction of 30% of the world GHG market price.

It is very unlikely that the suppliers of "hot air" and all Non-Annex B countries would be able to form a "perfect" cartel with monopolistic price setting. The sheer number of countries is so large, and partial interests are probably so diverse, that it would be extremely difficult to establish and maintain strict cartel discipline. However, as argued before, it is rather likely that the suppliers of "hot air" will act as price leaders by restraining their supplies. The solution modeled is that the FSU and EET ("hot air" suppliers) behave as Stackelberg leaders (see e.g. Varian, 1984) and other suppliers are price followers. This assumption is also based upon a restricted amount of trading entities in Russia and Ukraine as major suppliers of "hot air". Depending on the BAU emission development the optimal solution for the FSU would be to restrain between 0% and 65% of their potential "hot air" offer²³.

The implementation rate of projects, especially concerning projects in the CDM is an open issue. The question is not only of absorption capacity but also of how quickly a large number of projects could be implemented if trading only picks up very slowly. Using the CERT model the implementation rate can be changed for all Non-Annex B countries simultaneously or for

²² based upon 1990 data, 1998 data CDIAC and authors projections based upon similar relative development of Kazakhstan as Russia 1998-2010: Elzen (RIVM), 2001 estimate the additional "hot air" between 35 and 81 MtC

²³ high restraint with low BAU emissions and no restraint necessary with high BAU emissions

individual Non-Annex B countries. The implementation rate is defined as a proportional shift downward in the supply curve; e.g. a rate of 50% means that at each price, only 50% of the potential supply would actually be realized. With implementation rates of 50% we receive on average a 50% price increase relative to the new reference case.

The negotiations at Marrakech permits in practice nearly unrestricted banking. This tends to increase current prices as future reduction offsets are expected to be more expensive. However the impact is still limited due to insecurity over future climate change scope including amount of countries involved (e.g. China, India), insecurity over future reduction obligations of Annex B countries as well as those of large developing country emitters (new "hot air" of China...), and insecurity over inclusion of the USA or the regime of future climate change agreements (e.g. absolute or relative reductions). While marginal abatement costs rise strongly the energy and carbon intensity of the economy tends to decline depending not least on technological development and prices of carbon based fuels. Together with the impact of a (high) discount value on current prices of future offsets this can reduce the attractiveness of banking.

4.4. Combined scenario

The scenario presented in table 5 combines the different factors described above. It includes a partial participation of the USA (30% of emission reductions required), price leadership behavior of the FSU and EET, a 50% implementation rate of China, 2 USD transaction costs of CERs, 20% banking of permits (120% reduction requirements with exception of the USA) and a participation of Kazakhstan. Various other combinations are of course possible, but the authors consider this option to be a fairly interesting one.

Table 5: Combined scenario (US\$ 2000)²⁴

Scenario	world market price per tC	traded volumes in MtC (imports Annex B)	export revenues non-Annex B in millions
low BAU estimates	7-18	330-390	700-2'100
medium BAU estimates	11-32	410-520	1'500-4'100
high BAU estimates	16-34	500-590	3'000-7'100

A price range of 15-20 USD per ton of carbon equivalent (equals 4-5 USD per ton of CO₂) can be projected from this scenario. A factor which might reduce this price CoP is that various European countries have mentioned that they will only buy a limited amount from the international market and that they are willing to pay a higher internal price. The Dutch government e.g. limits currently external buys to 100 MtC (about 40-50% of projected total reduction requirements), the Portuguese government when ratifying in December the KP announced that it did not expect to use the flexibility mechanisms to fulfill its obligations, other European countries are awaiting the termination of rules governing the flexibility mechanisms to decide on participating or not and the Swiss CO₂ law reduces implicitly trading to firms or groups of firms which realize voluntary CO₂ reduction agreements with government thus reducing the potential scope of trading basically to industry. These are clear signs that supplementarity on a voluntary base will be the predominant case in Europe thus increasing domestic abatement costs while reducing international permit prices.

²⁴ scenarios based upon no supplementarity, no LULUCFs from Non-Annex B, 50% implementation rate, price-leadership behavior FSU and EET, 2 USD per ton carbon transaction cost CERs, 2% adaptation fund CERs, 30% participation of the USA (50% of required emission reduction with Kyoto target), 20% banking (120% reduction requirement all Annex B except USA), participation of Kazakhstan with 50 MtC hot air per year, zero-cost sinks according to Appendix Z; Using scenarios of CERT 1.2 based upon scenarios 1-8 described in Annex 2; the ranges inside low-medium-high BAU estimates are based upon different MACs

Other recent modeling estimates come to prices of 4 USD (Jotzo, HWWA, 2001), 5 USD (Babiker, EPPA, 2002), 15 to 20 USD (Elzen, RIVM, 2001) up to 48 USD (Jakeman, ABARE, 2001) per ton of carbon.

4.5. Current market prices

Current market prices are volatile and depend to a considerable extent on the quality of the certificates. However in the last 12 months a certain price trend can be observed. The deals and auctions listed include such where prices and trading quantities were disclosed and which have been sealed after CoP7 November 2001²⁵.

- New ERUPT and CERUPT (NL) tenders were closed in the first quarter of 2002. Prices to be paid in CERUPT (CERs) are between 3 and 5 US\$ per ton of CO₂. The average offer price for the second JI round (ERUPT) was around 4.4 US\$ per ton CO₂. The offer size was between 0.5 and 3.8 million tons CO₂. Projects presented are mainly energy efficiency and renewable energy. The Dutch government plans to buy 100 million tons CO₂²⁶. This price is downward from the first ERUPT tender of 2000 in which an average price of 7.5 US\$ per ton of CO₂ was paid.
- The Dutch government closed in January 2002 a deal with the IFC investing 40 million US\$. It will receive for this investment 10 million tons CO₂, i.e. the price fixed is 4 US\$ per ton of CO₂.
- 2 Danish power companies sold in December 2001 150 000 tons CO₂ to E.ON (Germany) and 10 000 tons to Entergy (USA). E.ON has participation in a Danish power plant also included in the system. The non-disclosed price is assumed to be definitely less than 4.8 US\$ per ton of CO₂ as this is the fine Danish companies would need to pay as fine when exceeding their cap. Denmark has established a cap and trade system for power-sector CO₂ emissions.
- In March 2002 34 companies participated in the bidding under the UK emissions trading scheme. Their commitment is to reduce emissions by 4 million tons CO₂. The implied allowance price paid as financial incentive by the government is maximum 25 US\$ per ton CO₂ before and 17.5 after tax. However supply is expected to be larger than demand for allowances with resulting allowance prices being significantly lower. The current trading level in the UK is at prices lower than 7 US\$ per ton CO₂. The first spot deal on the market was reported April 10th by BP selling and buying 1 000 carbon credits at 7.2 US\$ per ton CO₂. In the UK all industrial sectors are included, while the electricity sector is excluded.
- The PCF is in the process of closing 6 more deals worth 20-25 million US\$ in Chile, Costa Rica, Brazil and Uganda paying a maximum of 3 US\$ per ton of CO₂.

Figure 5 shows market prices paid or agreed upon in the last quarter for CO₂ reductions.

A lower offset price can be expected if following changes occur:

- Non-ratification of the KP.
- Definitely no and not even a partial participation of the USA.
- Economic recession especially in the FSU and large Annex B countries reducing their GHG offset demand while increasing the "hot air" supply.
- Expansion of domestic abatement programs in Annex B countries and inclusion of supplementarity rules in many countries.

²⁵ see: GHG Market Trend 1/2002

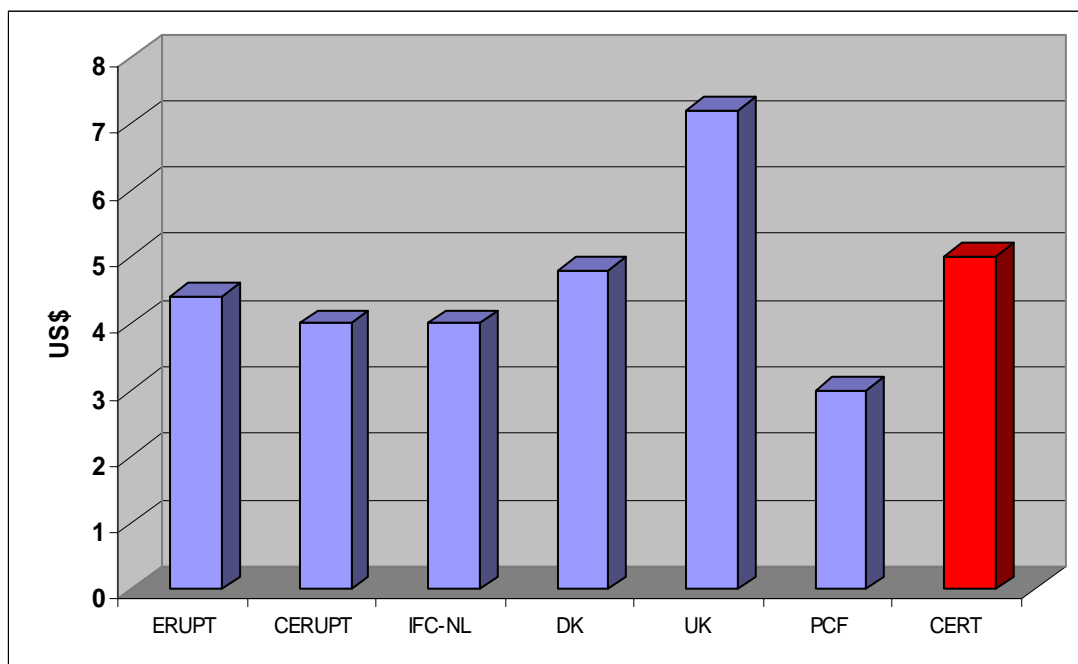
²⁶ NL had 1990 emissions of 218 million tons CO₂e and a Kyoto target of minus 8 %. For 2010 emissions of all GHG are expected to be 250-260 million tons CO₂ which leads to a required emission reduction of 50-60 million tons per year or 250-300 million tons over the commitment period. Inside the EU bubble the NL would need to reduce minus 6 % which reduces the reduction requirement to 225 to 275 million tons CO₂.

- Perception of a second commitment period with "weak" reduction targets and/or including significant quantities of "hot air" as a "ticket" for Non-Annex B countries to agree upon emission reduction targets.

A higher price would result by reversing above listed arguments.

The projected market price is basically sensitive to some key assumptions or projections such as autarchic GHG development in European countries, the development of Russia and Ukraine, the development of some form of cartelistic behavior, the eventual partial participation of the USA and perceptions of the second commitment period. Second period commitments, banking potentials and regulations concerning LULUCFs will play an important role in the future GHG market. The CERT modeling team is thus preparing an advanced CERT version to incorporate 2nd period commitments as well as introducing new data on MACs for sinks in Non-Annex B countries.

Figure 5: Real market prices 1st quarter 2002 (US\$ per ton CO₂e)



Annex 1: Country groups of CERT

Annex B Countries

USA: United States of America

JPN: Japan

EEC: 15 members; Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, UK

OOE: Rest OECD; Australia, Canada, Iceland, New Zealand, Norway, Switzerland

EET: Economies in Transition of Eastern Europe; Bulgaria, Croatia, Czech Rep., Hungary, Poland, Romania, Slovakia, Slovenia

FSU: Former Soviet Union; Estonia, Latvia, Lithuania, Russia, Ukraine

NOTE: FSU only contains Annex B component of FSU

Non-Annex B Countries

EEX: Energy Exporting Countries; Algeria, Bahrain, Botswana, Egypt, Indonesia, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Lesotho, Libya, Namibia, Oman, Qatar, Saudi Arabia, Syria, South Africa, Swaziland, Tunisia, United Arab Emirates, Venezuela, Yemen

In GTEM the following countries are not included in EEX but in ROW: Bolivia, Colombia, Ecuador, Mexico, Peru

In GTEM following countries are included in EEX instead of ROW: Botswana, Lesotho, Namibia, Swaziland

CHN: China and Chinese Taipei

BRA: Brazil

DAE: Dynamic Asian Economies; Philippines, Singapore, South Korea, Thailand
in GTEM additionally Malaysia

ROW: Rest of the World; all other Non-Annex B countries

Annex 2: BAU and MAC scenarios of CERT 1.2

No	scenario	1990 data source	BAU data source	MAC data source
1	medium growth, EPPA MACs, CO ₂ only	Vrolijk, 2000 (RIIA)	US DOE, 2001	Ellermann, 1998 (MIT/EPPA)
2	low growth, EPPA MACs, CO ₂ only	Vrolijk, 2000 (RIIA)	US DOE, 2001	Ellermann, 1998 (MIT/EPPA)
3	high growth, EPPA MACs, CO ₂ only	Vrolijk, 2000 (RIIA)	US DOE, 2001	Ellermann, 1998 (MIT/EPPA)
4	medium growth, GTEM MACs, CO ₂ only	Vrolijk, 2000 (RIIA)	US DOE, 2001	Polidano, 2000 (ABARE/GTEM)
5	low growth, GTEM MACs, CO ₂ only	Vrolijk, 2000 (RIIA)	US DOE, 2001	Polidano, 2000 (ABARE/GTEM)
6	high growth, GTEM MACs, CO ₂ only	Vrolijk, 2000 (RIIA)	US DOE, 2001	Polidano, 2000 (ABARE/GTEM)
7	GTEM all GHG	Vrolijk, 2000 (RIIA)	Polidano, 2000 (ABARE/GTEM)	Polidano, 2000 (ABARE/GTEM)
8	medium growth, GTEM MACs bottom-up, CO ₂ only	Vrolijk, 2000 (RIIA)	US DOE, 2001	Polidano, 2000 (ABARE/GTEM)

Annex 3: Datasets of scenarios with "reference case old"

Table A3.1: GHG market without the USA (US\$ 2000)²⁷

scenario	world market price per tC	% change to reference case	Traded volumes in MtC	export revenues non-Annex B in millions
Low BAU estimates	0	-100%	260-270	0
medium BAU estimates	1-2	-93%	330-350	40-70
high BAU estimates	4-9	-79%	400-440	700-1'400

Table A3.2: GHG market with partial US participation (US\$ 2000)²⁸

Scenario	world market price per tC	% change to reference case	Traded volumes in MtC	export revenues non-Annex B in millions
Low BAU estimates	1-2	-86%	380-410	40-70
medium BAU estimates	3-8	-73%	450-510	300-1'000
high BAU estimates	8-17	-63%	510-570	1'900-4'100

Table A3.3: GHG market with additional sinks (US\$ 2000)²⁹

scenario	world market price per tC	% change to reference case	Traded volumes in MtC	export revenues non-Annex B in millions
Low BAU estimates	5-11	-31%	610-660	700-1'700
medium BAU estimates	9-24	-21%	700-860	2'600-7'000
high BAU estimates	18-36	-16%	790-890	8'100-16'300

Annex 4: Datasets of scenarios with "reference case new"

Table A4.1: GHG market with Kazakhstan (US\$ 2000)³⁰

Scenario	world market price per tC	% change to reference case	Traded volumes in MtC	export revenues non-Annex B in millions
Low BAU estimates	0	-100%	410-420	0
medium BAU estimates	2-5	-24%	470-540	160-510
high BAU estimates	6-13	-24%	530-590	1'100-2'500

Table A4.2: GHG market with price-leadership behavior FSU (US\$ 2000)³¹

Scenario	world market price per tC	% change to reference case	Traded volumes in MtC	export revenues non-Annex B in millions
Low BAU estimates	4-9	+575%	340-390	610-1'390
medium BAU estimates	5-17	+108%	430-510	900-2'900
high BAU estimates	7-15	+2%	520-580	1'600-1800

Table A4.3: GHG market with 50% implementation rate (US\$ 2000)³²

Scenario	world market price per tC	% change to reference case	Traded volumes in MtC	export revenues non-Annex B in millions
Low BAU estimates	1	+20%	390-420	20
medium BAU estimates	4-9	+46%	450-510	230-1'000
high BAU estimates	11-24	+60%	480-560	1'800-3'800

²⁷ reference scenario plus no participation of the USA

²⁸ reference scenario plus 30% participation of the USA (30% of Bau-Kyoto target)

²⁹ reference scenario plus Annex B sinks according to Annex Z CoP 7 agreement

³⁰ reference scenario plus 50MtC hot air from Kazakhstan per year

³¹ reference scenario plus price leadership FSU and EET

³² reference scenario plus 50% implementation CERs

Table A4.4: GHG market with banking (US\$ 2000)³³

Scenario	world market price per tC	% change to reference case	Traded volumes in MtC	export revenues non-Annex B in millions
Low BAU estimates	3-7	+380%	460-500	310-720
medium BAU estimates	6-16	+140%	550-640	1'300-3'300
high BAU estimates	12-25	+70%	640-720	4'000-8'400

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³³ reference scenario plus price leadership FSU and EET

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