Report prepared on behalf of the
NSS program of the World Bank

The GHG Market on the Eve of Kyoto Ratification

Updated Simulations of the Market for Greenhouse Gas Emission Reductions Using the CERT Model Vs. 1.3

December 2002

Abstract

The paper presents market projections and scenarios based upon CERT. CERT is a metamodel which incorporated data of various other models and projections and thus allows for a variety of scenarios. The relative impact of changes in the GHG (greenhouse gas) market including partial US participation, partial supplementarity and differential transaction costs are 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, and different market regimes including price leadership behavior of the FSU (Stackelberg solution), a seller monopoly and a fully competitive market. A combined scenario including all different factors is developed to make a "realistic" projection of the GHG market. Scenarios presented include most recent negotiation agreements and data published till end 2002. Results of CERT are compared with projections of other models and with real market deals managed currently. A market price of USD 7-17 per ton of carbon (equivalent to per 2-5 USD per ton of CO_2) is considered as most probable under current conditions.

Authors:

Dr. Jürg Grütter
Grütter Consulting
j.gruetter@ghgmarket.info

Prof. Dr. Rolf Kappel
NADEL, ETH Zürich
kappel@nadel.ethz.ch

Dr. Peter Staub
ORL Institut, ETH Zürich
staub@orl.arch.ethz.ch

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

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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 countries[1]. Together, these countries must reduce their emissions by 5.2% below 1990 levels over the commitment period 2008-2012[2]. 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.

The simulations presented and discussed below are calculated with the CERT model, version 1.3. 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.

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. Annex A includes a summary of the solution algorithm of the CERT model and the options for parameter modifications and policy assumptions the user can specify.

Table 1: Regional structure of the CERT model[4]

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

The paper is organized as follows. Chapter 2 describes the core variables that affect the GHG market, and different datasets that exist for these variables. Chapter 3 presents and discusses the outcomes of various market scenarios realizing sensitivity analysis and

[1] The Kyoto Protocol includes carbon dioxide (CO_2) emissions from fossil fuels, methane, nitrous oxide, per fluorocarbons, hydro fluorocarbons, and sulfur hexafluoride
[2] Kyoto Protocol to the United Nations Framework Convention on Climate Change, UNFCCC, 1997
[3] To calculate CO_2 you have to multiply by 44/12
[4] Annex 2 includes the list of countries per region

presents a market scenario deemed as "best educated guess" by the authors. It also compares results with other projections and models as well as with current market prices paid.

2. Core Variables of the GHG Market

2.1. 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 supplementarity, treatment of LULUCFs, transaction cost, implementation rate etc.);
- Market behavior of buyers and sellers, e.g. participation of the USA, monopoly, oligopoly, etc.

2.2. Business as Usual Estimates

Required Emission reductions are calculated as projected BAU emissions minus the assigned amount. BAU estimates vary between sources. Table 2 lists the BAU estimates included as standard scenario variables in the CERT model[5]. Differences in the BAU estimates (CO_2 only) are not that large (around 9% difference between high and low projection) - however due to relatively small reduction targets the impact on the reduction requirement is significant leading to differences in the potential demand for GHG offsets of up to 30% with US participation and nearly 50% without US participation (CO_2 only).

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 studies[6], which indicate large emission gaps, and projections based on the compilation of the "national communications"[7], with much smaller differences between the Kyoto target levels and BAU projections.[8]

The amount of “hot air” of the FSU and the EET is a core issue. CERT incorporates “hot air” ranges between 300 and 435 MtC per year (scenarios based upon US DOE, 2002 and Meinshausen, 2002). Other, however older estimates reach 590 MtC (SRES B2, see for a range of projections UNFCCC, 2001).

Table 2 shows clearly the magnitude on the GHG market of the US withdrawal with reduction requirements falling by 60 to 70% thus leading to a sharp decline in the demand for GHG offsets and therefore also the GHG market price. For the remaining Annex B countries

[5] Sources: US DOE, 2002; Polidano, 2000; UNFCCC, 2002; calculation for regions by Grütter
[6] like the ones realized by US DOE (2001), EPPA (Ellermann et al, 1998 and Reilly et al, 2000) or GTEM (Polidano, 2000)
[7] e.g. realized by RIIA (Vrolijk, 2000), Cicero (1998) and Zhang (1999)
[8] 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.

compliance with Kyoto has become much more economical due to this fact while on the other hand the CDM income will also be reduced.

2.3. 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. Currently four sets of MACs are available: one set from the EPPA model of MIT for CO_2 only; two sets from the GTEM model for CO_2 only and for all GHGs; and one set of "quasi bottom-up" MACs (see below) generated with the GTEM model. The EPPA model and the GTEM model are multi-sector and multi-region CGE models that simulate the development of global production, trade, energy use, and GHG emissions[9].

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.[10] The MACs available to the moment do not include LULUCFs.

Bottom-up estimates of MACs are used by e.g. the MERGE or POLES model[11]. 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.[12]

2.4. 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.

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[9] See for more information on the generation of MACs in EPPA: Ellermann et al, 1998
[10] Ellerman et al. 1998
[11] OECD, 1998
[12] Polidano, 2000

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

BAU projections	**USA**	**JPN**	**ECE**	**OOE**	**EET**	**FSU**	**Total with USA**	**Total without USA**
CO_2 only US DOE low	1795	312	964	311	207	540	4129	2334
CO_2 only US DOE medium	1835	343	1013	331	226	587	4335	2500
CO_2 only US DOE high	1887	359	1066	347	243	641	4543	2656
All GHG (Meinshausen)	2060	385	1161	428	296	810	5140	3080
Assigned Amount								
CO_2 only	*1246*	*289*	*835*	*231*	*279*	*864*	*3744*	*2498*
All GHG	*1535*	*311*	*1057*	*330*	*349*	*1112*	*4694*	*3159*
Reduction requirement incl. domestic sink allowances[13]								
CO_2 only	*521-613*	*10-57*	*123-225*	*67-103*	*-40 to -76*	*-258 to -359*	*721 to 998*	*200 to 385*
All GHG	*498*	*61*	*99*	*85*	*-57*	*-336*	*743*	*245*

[13] 100% of domestic sink allowances negotiated at CoP 7 according to Art. 3.3. and 3.4.

3. Scenarios and Simulation Results

3.1. 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 CO_2 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 (see Annex 1). Regarding market rules all scenarios reflect decisions taken at the Conferences of the Parties up to October 2002.

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. The comparison is made to a "reference case" based upon unfettered full-competition with a 50% participation of the USA (except for the first scenario analysis)[14]. Following factors are analyzed for their sensitivity on market prices:

- (partial) participation of the US
- variation of implementation rates CDM
- variation of transaction costs
- impact of different supplementarity levels / countries with supplementarity rules
- competition vs. Stackelberg solution vs. seller monopoly

3.2. Impact of a (partial) US Participation

Table 3 shows expected world market prices for 100%, 50% and 0% participation of the USA. A partial participation is calculated as percentage of reduction requirements (BAU minus Kyoto target).

Table 3: Impact of US participation on GHG prices (USD 2000 per tC)[15]

	100% participation	50% participation	0% participation
Low BAU	4-10	1	0
Medium BAU	8-23	2-8	0
High BAU	15-31	7-15	1-3

Without US participation the "hot air" of the FSU is sufficient to cover reduction requirements and under competition the GHG market price collapses. However even with a 50% participation expected prices are 50% lower than compared to a full US participation. This also explains to a considerable extent the much higher GHG market prices projected before 2001 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; see also the special issue of the Energy Journal, 1999). Additionally the inclusion of significant domestic sinks allowances in Annex B countries assigned during CoP7 reduces reduction requirements considerably.

[14] base scenarios have the following characteristics: competition, no supplementarity, 0 USD transaction costs, 100% implementation rate CDM, 50% participation USA, 2% adaptation fund CERs

[15] see footnote 14 for scenario specifications

A reduced US participation has especially severe consequences for the expected CDM export revenues declining from an average expected[16] 3 600 to 400 million USD annually - a fall of 90%.

3.3. Implementation Rate CDM

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 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. The implementation rate CDM can be technically more than 100% (implementation of projects before the commitment period). In practice however to assume even 100% implementation rate, taking into account projects realized before 2008, is rather optimistic. Also not all countries might be willing to participate in GHG trading as the recent example of Thailand shows, where the government refused to engage in the CDM. Table 4 shows the impact of various implementation rates. As in all following parts a 50% participation of the USA is included in the base scenario.

Table 4: Implementation rates CDM and GHG prices (USD 2000 per tC)[17]

	100% implementation	50% implementation	0% implementation
Low BAU	1	1	1-2
Medium BAU	2-8	4-11	9-23
High BAU	7-15	13-25	37-69

Table 4 clearly shows that the lower the implementation rate the higher prices. A 50% implementation rate would increase prices by around 50%. Price increases offset in general the demand reduction leading to similar export revenues and slightly higher profits. This trend increases with higher BAU estimates. However the improvement is not very strong: with medium BAU estimates CDM export revenues would remain stable on average and profits would increase by less than 10% with a 50% participation rate compared to a 100% rate. This shows clearly the limited market power to improve prices of CDM countries under the current conditions.

3.4. Transaction Costs

Transaction costs are based on USD per ton of carbon traded. They are differentiated between such for CERs and such for JI as transaction costs for CERs tend to be higher due to stricter requirements. Table 5 shows the impact of various levels of transaction costs compared to the reference case of 0 costs.

[16] medium BAU estimates
[17] see footnote 14 for scenario specifications

Table 5: Transaction costs and GHG prices (USD 2000 per tC)[18]

	CDM transaction cost			*JI transaction cost*		
	0 USD	2 USD	5 USD	*0 USD*	*2 USD*	*5 USD*
Low BAU	1	1-2	1-2	1	*1-2*	*1-2*
Medium BAU	2-8	4-9	6-10	2-8	*3-9*	*3-11*
High BAU	7-15	9-17	11-19	7-15	*8-16*	*9-17*

Levels of transaction costs have only a slight influence on prices but therefore of course a relatively large influence on profits. JI or CDM transaction costs work in the same direction and magnitude. “Hot air” is assumed to be without transaction costs (no project required as “hot air” are in fact AAUs).

3.5. Supplementarity Levels

CoP 7 decided on no compulsory supplementarity levels. However various countries are individually contemplating to introduce voluntary supplementarity levels, especially in the EU. Table 6 shows the impact of a general 50% supplementarity level of all Annex B countries and of 50% supplementarity only introduced in the EU, while other countries introduce no restrictions to import of GHG reduction offsets.

Table 6: Supplementarity levels and GHG prices (USD 2000 per tC)[19]

	Supplementarity all Annex B		Supplementarity only EU	
	0%	50%	0%	50%
Low BAU	1	0	1	0
Medium BAU	2-8	0	2-8	2-4
High BAU	7-15	1-2	7-15	5-10

Table 6 shows clearly that a 50% supplementarity would reduce the GHG offset price internationally in a very significant manner, even assuming high BAU growth. The impact of a supplementarity restriction of the EU only on the other hand would not have such a massive effect, but would increase with higher BAU estimates.

3.6. Market Order

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 it is likely that the suppliers of "hot air" will act as price leaders by restraining their supplies. Table 7 shows the results of a monopolistic solution, a Stackelberg solution (see e.g. Varian, 1984) with the FSU as price leader and other suppliers are price followers and a competitive solution.

Table 7: Market structure and GHG prices (USD 2000 per tC)[20]

	Competition	Stackelberg	Monopoly[21]
Low BAU	1	4-9	NA
Medium BAU	2-8	6-18	12-96
High BAU	7-15	7-15	63-248

[18] see footnote 14 for scenario specifications
[19] see footnote 14 for scenario specifications; Supplementarity levels are defined as percentage of reduction requirements.
[20] see footnote 14 for scenario specifications; Supplementarity levels are defined as percentage of reduction requirements.
[21] Excludes “hot air” in the monopoly solution

With low and medium BAU estimates a non-competitive solution would be able to achieve significantly higher prices. Also with the reference growth scenario the Stackelberg solution (and of course even more the monopolistic seller solution) increases the price range significantly. With high BAU estimates the Stackelberg solution is equal to the competitive solution as the market power of FSU as price leader diminishes considerably.

3.7. Comparative Impact

Graph 1 gives us an overview of the relative impact of the market changes analyzed, based only upon medium BAU estimates of the different parameters discussed in this chapter. It shows clearly that supplementarity levels of 50% for all Annex B countries as well as no participation at all of the USA would lead to a virtual collapse of the world market. The strongest factors leading to high prices are the unrealistic monopoly and the fairly realistic Stackelberg solution. All other factors are of minor importance.

3.8. Other Factors with Price Potential

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 year[22].

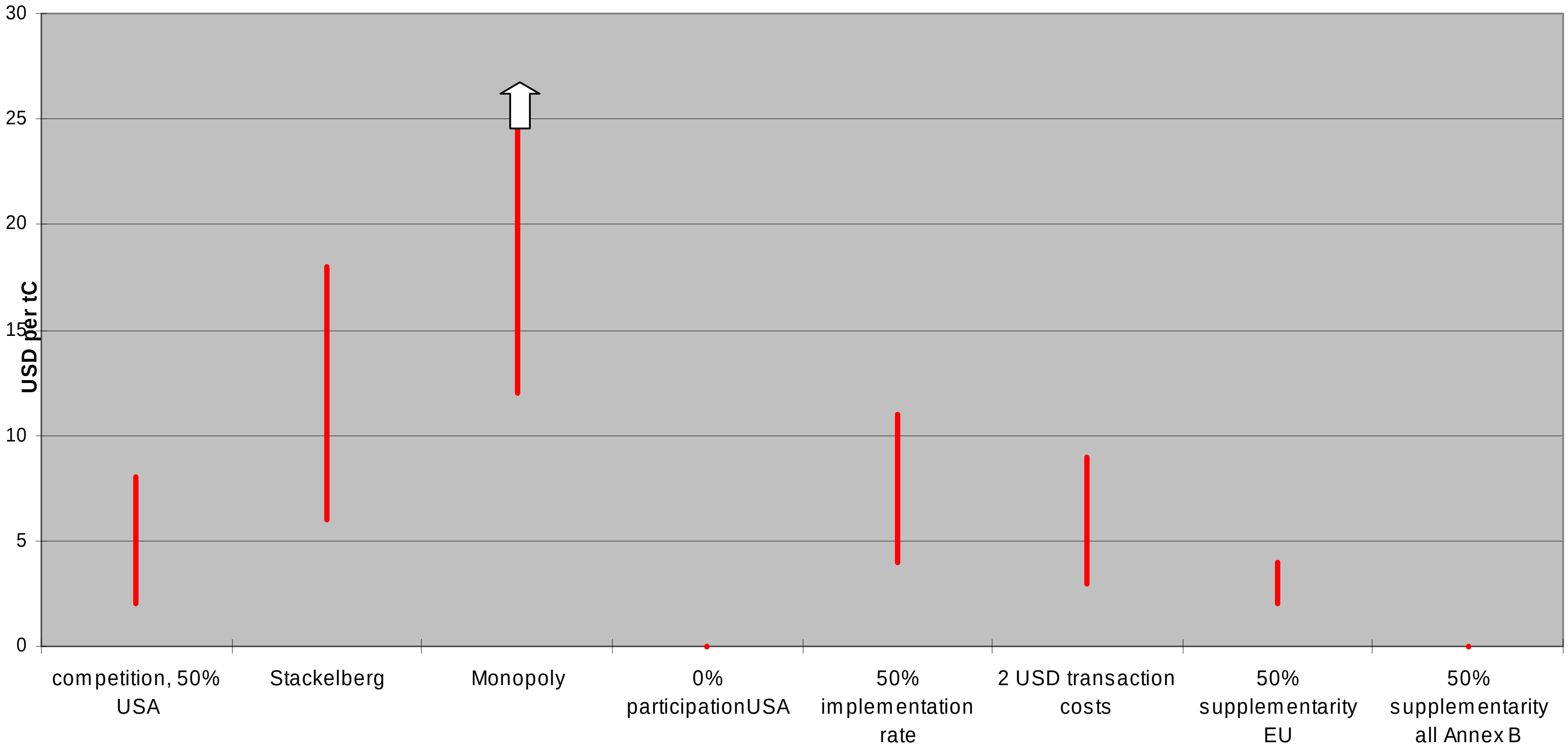
A non participation of Australia and eventually Canada would also have a downward impact on prices. Australia as well s Canada represent each without US participation nearly 15% of projected reduction requirements (with USA less than 5%) thus summing up more than a third of total world GHG reduction demand without the USA. Non-ratification of both countries would lead to a significant price reduction, while non-ratification of Australia alone leads to price changes in the order of 10%.

Future negotiation agreements including targets fixed, type of targets (relative or absolute), countries involved (e.g. extended Annex B group) and renewed participation of the USA have a strong potential impact on prices, due to rising marginal abatement cost curves and increasing demand for offsets. Currently a proposal is being made to realize a CERT 2.0 as an advanced version of a multi-period metamodel to analyze the impact of future commitments.

LULUCFs from Non-Annex B countries have been restricted by type and by amount (art 12) to 1% of allowances of Annex B countries. The restriction to certain types of sinks leads by trend to price increase while the limited amount sinks can be used by Annex B countries reduces their value and creates an additional competition among suppliers of sinks leading to a price reduction of sinks and therefore in total of the GHG market.

[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

Graph 1: Impact of Parameters on GHG Prices



3.9. Combined Scenario

The scenario presented in table 8 combines different factors. It includes a partial participation of the USA (30% of emission reductions required[23]), a Stackelberg solution for the FSU, a 50% implementation rate[24], 2 USD transaction costs of CERs and 1 USD for JI/IET[25], 2% of CERs for the adaptation fund and 50% supplementarity for EU[26]. Various other combinations are of course possible, but the authors consider this option to be a fairly interesting one.

Table 8: Combined scenario (US$ 2000)

Scenario	world market price per tC	traded volumes in MtC (imports Annex B)	export revenues non-Annex B in million USD
low BAU estimates	3-8	260-290	60-410
medium BAU estimates	7-17	330-370	620-1’240
high BAU estimates	10-20	400-430	1’260-2’620

A price range of USD 7 to 17 per ton of carbon equivalent (equals 2 to 5 USD per ton of CO_2) can be projected from this scenario.

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), 33 USD per ton of carbon (based on interviews of market participants, Natsource 2002) and 48 USD (Jakeman, ABARE, 2001) per ton of carbon.

3.10. 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 where disclosed and which have been sealed after CoP7 November 2001[27]. This section expresses all deals in tons CO_2eq as this is more used for deals than tons carbon.

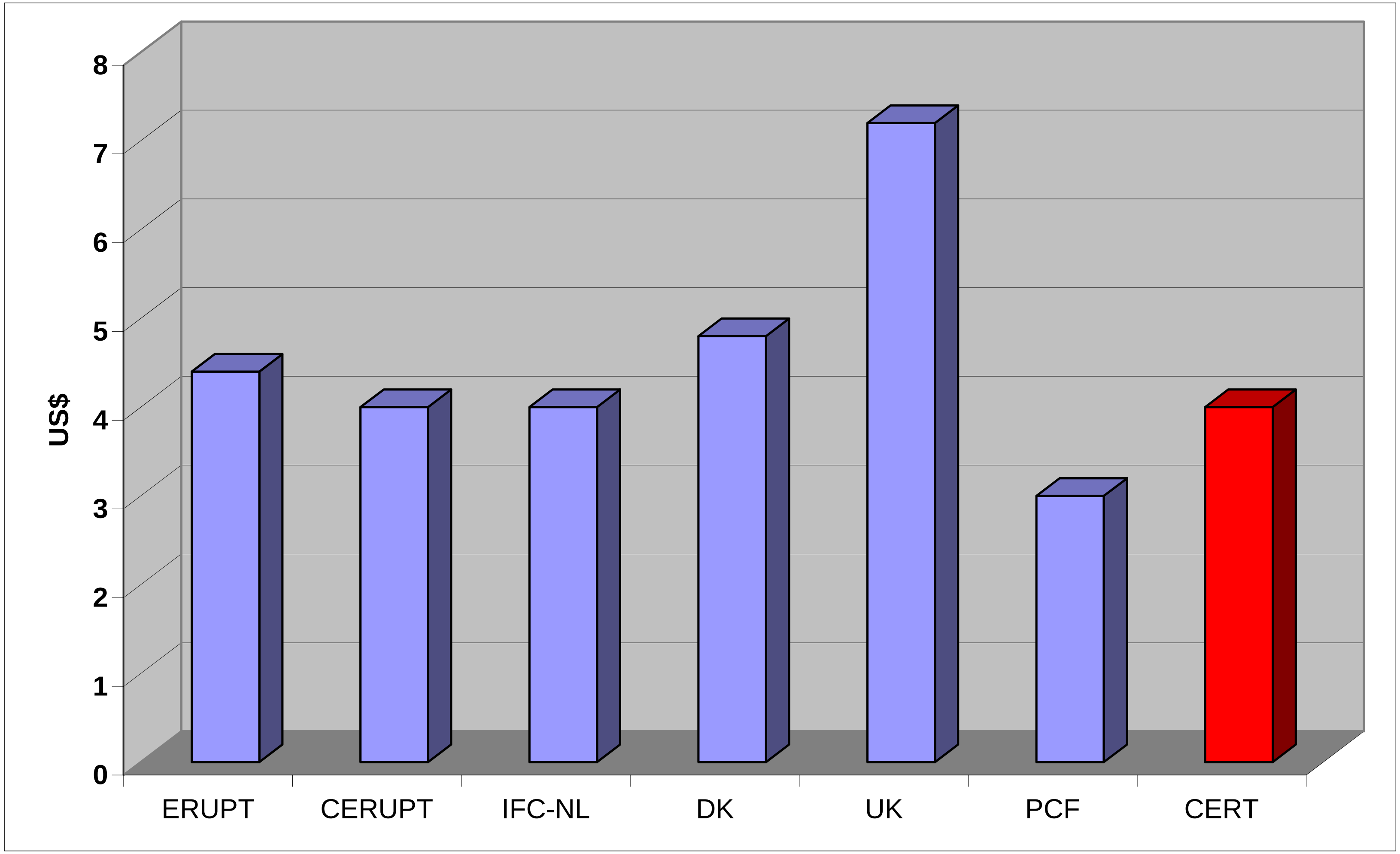
- The CERUPT tender of the Netherlands has pre-selected in June 26 CDM projects in 13 countries (13 Latin America, 10 Asia, 3 Africa) worth 32 million tons of CO_2 at an average price of 4.5 US$ per ton CO_2. The ERUPT tender has pre-selected in June 6 ERU projects in 5 countries including New Zealand worth 5 million tons of CO_2 at an average price of 4.6 US$ per ton CO_2. This price is downward from the first ERUPT tender of 2000 in which an average price of 7.5 US$ per ton of CO_2 was paid.

[23] this assumption is based upon various US states (e.g. California, New Hampshire, Massachusetts, North East/East Canada, New Jersey, Oregon, NY/Suffolk and Wisconsin) realizing domestic regulations
[24] based on limited capacity to develop a large amount of projects in the short time available
[25] based upon PCF transaction cost experience for current CDM projects and lower requirements for JI and IET trades
[26] based upon declarations of the EU and various Member States (e.g. Portugal, Netherlands, Germany)
[27] see: GHG Market Trend 1/2002, 2/2002, 3/2002

- The Dutch government closed in January 2002 a deal with the IFC investing 40 million US$. It will receive for this investment 10 million tons CO_2, i.e. the price fixed is 4 US$ per ton of CO_2. A similar agreement was reached with the CAF (Corporacion Andino de Fomento) for Andean countries and the World Bank.
- 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 CO_2. The implied allowance price paid as financial incentive by the government is maximum 25 US$ per ton CO_2 before and 17.5 after tax. In April BP made the first spot deal on the UK's GHG emission trading system selling and buying at US$ 7.2 per ton of CO_2. Prices since then picked up to 9 US$ and end June 10.5 US$.
- The PCF pays a price of 3-4 US$ per ton of CO_2 while the investor receives the certificates for around 5.5 USD per ton. The World Bank is in the process of launching two new carbon funds (community development carbon fund) with a contract price range of around 3-8 US$ and a investor delivery price of 7-7.5 US$ per ton of CO_2, while the BioCarbon fund would be targeted towards sequestration projects, with prices similar to the PCF (contract price range 3-4 US$ and delivery 5.5 US$ per ton of CO_2).

Figure 2 shows market prices paid or agreed upon in the last 12 months.

Figure 2: Real market prices 2002 (US$ per ton CO_2e)



Annex 1: Solution algorithm and options of the CERT model

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 at 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 international trade of emission reductions can be restricted ("supplementarity") with model options discussed below. The market equilibrium is achieved if global demand equals global supply.[28]

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

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

QR	=	amount of GHG emissions to be reduced
BAU	=	business as usual, amount of emissions in 2010
KT	=	Kyoto target
E_{1990}	=	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) $MC_i = a_i Q_i^2 + b_i Q_i$ $\quad i = 1, 12$

(1b) $MC_i = a_i \, (e^{biQi} – 1)$ $\quad i = 1, 12$

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

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

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

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) $C_i = 1/3\, a_i\, Q_i^{\,3} + 1/2\, b_i\, Q_i^{\,2}$ $i = 1, 12$

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

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

TQR = total emissions to be reduced
QR = emissions to be reduced

(5) $TQ = \sum Q_i$ $i = 1,12$

TQ = total emission reduction
Q = emission reduction

(6) $P^* = P$ for $TQR = TQ$

P* = equilibrium price for GHG reductions
TQR = total emissions to be reduced
TQ = total emission reduction

The worldwide costs of GHG emission reduction are:

(7) $TC = \sum C_i$ $i = 1, 12$

TC = total costs of emission reduction
C = costs of emission reduction

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:

(8a) $C_{Ai} = 1/3\, a_i\, Q_{Ai}^{\,3} + 1/2\, b_i\, Q_{Ai}^{\,2}$ $i = 1, 6;\ QR_i > 0$

(8b) $C_{Ai} = (a_i / b_i)\, e^{b_i Q_{Ai}} - a_i Q_{Ai} - (a_i / b_i)$ $i = 1, 6;\ QR_i > 0$

(9) $TC_A = \sum C_{Ai}$ $i = 1,6; QR_i > 0$

C_{Ai} = autarkic costs of emission reduction
Q_{Ai} = autarkic emission reduction
TC_A = total costs of autarkic emission reduction

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

(10) $TS = (TC - TC_A) / TC_A$

TS = total savings from trade of emission reductions in relative terms
TC = total costs of emission reduction with trade
TC_A = total costs of autarkic emission reduction

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"[29] form some sort of oligopoly with price-setting behavior to capture part of these profits. Supplies 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.

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", implmented in the CERT model (vs. 1.3), in which one supplier takes the price leadership in anticipating the other's reaction function. He offers thereafter a maximum profit supply quantity. Based on market projections on the supply side the FSU was identified as potential "Stackelberg" actor. Technically the FSU reduces its quantity of "hot air" to achieve maximum profits. Other oligopolistic 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.

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. The CERT model therefore also includes a "monopoly" option, which calculates a solution for the monopolistic equilibrium condition:

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

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

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

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.

CERT includes 100% domestic sink allowances (Art. 3.3. and 3.4) of Annex B countries as defined at CoP 7. These allowances are assumed at zero cost and are automatically deducted from the BAU projections made.

Options of the CERT model

Apart from the "monopoly" and the Stackelberg 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 includes[30]:

- Trade of "hot air": The model user can specify the percentage share of "hot air" that is traded. Legally unlimited trade of "hot air" is allowed. The default parameter is thus 100% trade.
- Import ceiling ("supplementarity"): The model user can specify the share of GHG emission reductions that Annex B countries may import either as total Annex B countries or as individual country (group). Supplementarity is defined as percentage of the required emission reductions that is made domestically. CoP 7 decided to not establish a quantitative supplementarity limit. The default parameter is thus 0% supplementarity. However some Annex B countries are contemplating 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. This value is thus set as default parameter in CERT 1.3.
- Participation of the USA. CERT allows the user to specify a percentage participation of the USA. The idea behind this option is that various US states as well as large US companies are realizing GHG reduction commitments resulting also in GHG offset demand. The percentage is defined as BAU-Kyoto target. The MAC parameter is thereafter adjusted to the percentage rate chosen.[31] The default parameter set is 0%.

The second group of options includes:

- Transaction costs of emission reductions traded: The model user can specify transaction costs in US$ per ton of carbon, which result in an upward shift of the MACs. Transaction costs can be set individually for all countries/regions thus allowing e.g. also to differentiate CDM from JI transaction costs. The default value set is 0 US$.
- 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 %

[30] CERT includes for these options a default value fixed according to most recent decisions taken at CoPs. The user can however change these values.
[31] If no adjustment would take place we would assume that all adjustments would take place in the place with least costs. This is however not commensurate with an approach based upon GHG reduction targets of specific states.

increase the gradient of the respective MACs. Implementation rates over 100% allow for early crediting of CERs (prior to the commitment period 2008-12. The default value set is 100% implementation.

- 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 above).
- Calculation of a Stackelberg solution (see above).
- 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.

Annex 2: 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 3: BAU and MAC scenarios of CERT 1.3

No	Scenario	1990 data source	BAU data source	MAC data source
1	medium growth, EPPA MACs, CO_2 only	UNFCCC, 2002	US DOE, 2002	Ellermann, 1998 (MIT/EPPA)
2	low growth, EPPA MACs, CO_2 only	UNFCCC, 2002	US DOE, 2002	Ellermann, 1998 (MIT/EPPA)
3	high growth, EPPA MACs, CO_2 only	UNFCCC, 2002	US DOE, 2002	Ellermann, 1998 (MIT/EPPA)
4	medium growth, GTEM MACs, CO_2 only	UNFCCC, 2002	US DOE, 2002	Polidano, 2000 (ABARE/GTEM)
5	low growth, GTEM MACs, CO_2 only	UNFCCC, 2002	US DOE, 2002	Polidano, 2000 (ABARE/GTEM)
6	high growth, GTEM MACs, CO_2 only	UNFCCC, 2002	US DOE, 2002	Polidano, 2000 (ABARE/GTEM)
7	GTEM all GHG	UNFCCC, 2002	Polidano, 2000 (ABARE/GTEM)	Polidano, 2000 (ABARE/GTEM)
8	medium growth, GTEM MACs bottom-up, CO_2 only	UNFCCC, 2002	US DOE, 2002	Polidano, 2000 (ABARE/GTEM)

Adjustments and calculations for country groups made by Grütter

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