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Global economic implications of alternative climate policy strategies

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Abstract

This paper investigates the world economic implications of climate change policy strategies, and particularly evaluates the impacts of an implementation of clean development mechanisms (CDM), joint implementation (JI) and emissions trading with a world integrated assessment model. Of special interest in this context are welfare spill over and competitiveness effects resulting from diverse climate policy strategies. This study elaborates and compares multi-gas policy strategies and explores the impacts of sink inclusion. We furthermore examine the economic impacts on all world regions of the USA's non-cooperative, free rider position resulting from its recent isolated climate policy strategy decision.

It turns out that CDM and JI show evidence of improvement in the economic development in host countries and increase the share of new applied technologies. The decomposition of welfare effects demonstrates that the competitiveness effect (including the spill over effects from trade) have the greatest importance because of the intense trade relations between countries. Climatic effects will have a significant impact within the next 50 years, will cause considerable welfare losses to world regions and will intensify if nations highly responsible for pollution like the USA do not reduce their emissions.

JEL classification: C0; D5; Q0

Keywords: Global impacts of climate change; Integrated assessment modelling

1. Introduction

Recent climate policy negotiations confirm that industrialized countries take the responsibility for climate change as part of the commitment to binding emissions reduction targets. Emissions reduction targets can be reached through either domestic policy measures or more flexible, international mechanisms allowing minimized abatement cost options. Almost all countries committing themselves to reducing greenhouse gas (GHG) emissions project significant emission increases in the absence of measures to tackle their emissions. However, the negotiated emissions reductions obligations do not represent real diminution targets for all countries: economies in transition (EIT) already reached their emissions reduction targets due to poor economic performance in the aftermath of their transition. Because of that, their economies and emissions declined considerably so that their actual emissions lie far below their 1990 baseline emissions. This effect is mostly known as the so called "hot air" effect. EIT representatives however insist on calling it "fair air" because of the negative economic effects these countries must and already have suffered.

Clean development mechanisms (CDM) incorporate the option of transfer investment within specific emissions reduction projects from developed to less developed countries. These investment expansions trigger energy efficiency improvements in the host country and increases the share of new technologies. Joint implementation (JI) projects intend to achieve the same purpose as CDM but concentrate their activities within developed nations. An emission trading instrument can be implemented at the national or international level; both reveal an opportunity to achieve emissions reduction targets at low abatement costs. Woerdman (2000) explains that JI and CDM are both more effective, efficient and politically acceptable than international emissions trading (IET).

A restriction of emission trading and a restriction on the price of permits lower the minimized abatement costs options for the participating countries. McKibbin and Wilcoxen (1999) investigated the impacts of national emissions trading schemes, while Bernstein et al. (1999) studied the restrictions of an emissions trading schemes on a global scale. Most analyses of the impacts of the Kyoto protocol's implementation found that the allowance of international Kyoto mechanisms reduces the global and national costs of abatement significantly; an overview is given by Weyant and Hill (1999) and Edmonds et al. (1999). Kemfert (2000),

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Böhringer and Rutherford (1999) and Babiker et al. (2000) found that the implementation of the Kyoto protocol induces negative impacts to developed and developing countries. The European Commission presented its green paper in 2000 on implementing a European emissions trading scheme. Ellerman (2000) gives an overview of approaches by national emissions trading in Europe, while concrete implementation rules are summarized by Tietenberg et al. (1999) and Zhang (2001). Fullerton and Metcalf (2001) studied cap and trade policies.

The most important indicator of economic impact assessment explains the overall welfare changes measured in real income variations of different world regions. Even more interesting are the different components and influential factors shaping world welfare changes. This paper sheds some light on this issue and dissects the overall economic welfare of different world region changes in (1) pure autarkic domestic effects of the impacts of domestic actions to reduce emissions and (2) competitiveness effects by changes in terms of trade and (3) spill over effects induced by neither domestic action nor competitiveness effects.

If the USA does not participate in the developed country agreement to reduce emissions, economic implications for all other committed nations can only be profitable for the contributing nations if an international emissions trading system is allowed enabling a declining permit price to lead to cost abatement options at a lower price. Furthermore, economic implications can only be beneficial if economic impacts alone are evaluated without the inclusion of climate change impacts. The USA would cover a large share of the total demand of emissions permits. Without their participation, the permit price would drop significantly with the intention that other industrialized countries could reach their emissions reduction targets at much lower costs. A multi-gas investigation reveals that nations have many more options to reduce emissions, resulting in less costly emissions abatement, see Manne and Richels (2000) and Kemfert (2001). The inclusion of sinks in the analysis lowers the abatement costs considerably but increases the impacts of climate change only if the costs of sinks are not integrated.[1] Costs and benefits of climate change are predominantly assessed by integrated assessment models (IAM) incorporating physical relations of climate change and economic effects by damage functions. Examples for IAMs are MERGE (Manne and Richels, 1999), RICE or DICE (Nordhaus and Yang, 1996), CETA (Peck and Teisberg, 1991) or FUND (Tol, 1998). These models do not include sectoral disaggregation of each world region. The inclusion of climatic impacts in our analysis exposes how climatic impacts will have a significant effect within the next 50 years, although other studies cannot confirm this result because of restricted impact assessment (see Deke et al. (2001)).

This article intends to study the world economic implication of climate change policy strategies, with particular attention to joint implementation, clean development mechanisms and emissions trading. The assessment of emissions trading is analysed by the inclusion of different baseline assumptions and restrictions on trade. Of special interest in this context are the spill over effects resulting from diverse climate policy strategies and the assessment as to whether spill over effects can make a significant contribution regarding climate mitigation options. Furthermore, the share of new technologies applied by different sectors is investigated. Climate impact assessment, a multi-gas analysis and a sink enhancement strategy are evaluated interactively. Because of the recent decision of an isolated policy strategy by the United States of America, primary economic impacts are compared against a cooperative strategy.

This paper investigates the above mentioned decomposed economic effects of climate policy instruments by a world integrated assessment general equilibrium model WIAGEM (described briefly in the second part of the paper). The next chapters examine the decomposed economic implications of diverse Kyoto mechanisms, the impacts of applied technologies, a multi-gas strategy, the inclusion of sinks and the isolated climate policy strategy by the USA. The last chapter concludes.

2. The model WIAGAM

The multi-regional model WIAGEM (World Integrated Assessment General Equilibrium Model) is an integrated economy–energy–climate model incorporating economic, energy and climatic modules in an integrated assessment approach. To evaluate market and non-market costs and benefits of climate change, WIAGEM combines an economic approach with a special focus on the international energy market and integrates climate interrelations of temperature changes and sea level variations. The representation of economic relations is based on an intertemporal general equilibrium approach and contains the international markets for oil, coal and natural gas. The model incorporates all greenhouse gases (GHG) influencing potential global temperature, sea level variation and the assessed probable impacts in terms of climate change costs and benefits. Market and non-market damages are evaluated according to the damage costs approaches of Tol (2001). Additionally, this model includes net changes in GHG emissions from sources and removals by sinks resulting from land usage change and forest activities.

Fig. 1 graphically explains WIAGEM interrelations. WIAGEM is an integrated assessment model combining an economy model based on a dynamic intertemporal general equilibrium approach with an energy market model and climatic submodel. The model covers a time period of 50 years

[1] Missfeldt and Haites (2001) conduct a first assessment of sink costs and their potential economic impacts.

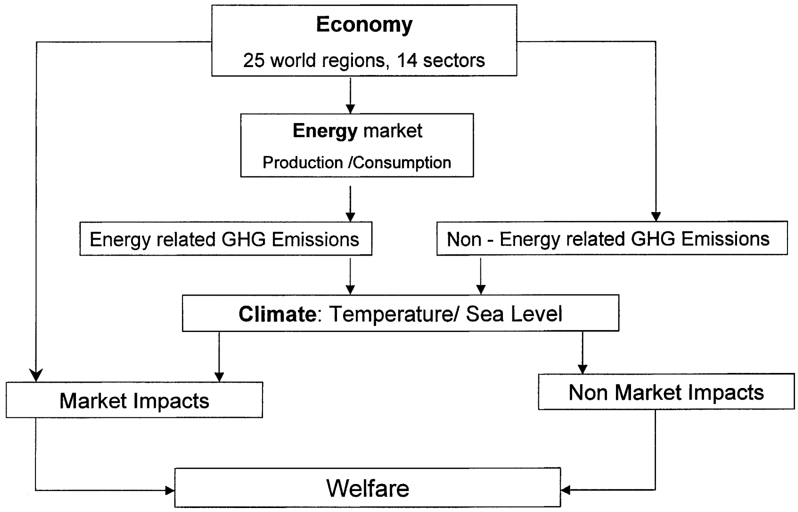

Fig. 1. Interrelations in WIAGEM.

Table 1
World regions

	Regions
ASIA	India and other Asia (Republic of Korea, Indonesia, Malaysia, Philippines, Singapore, Thailand, China, Hong Kong, Taiwan)
CHN	China
CAN	Canada, New Zealand and Australia
EU15	European Union
JPN	Japan
LSA	Latin America (Mexico, Argentina, Brazil, Chile, Rest of Latin America)
MIDE	Middle East and North Africa
REC	Russia, Eastern and Central European Countries
ROW	Other Countries
SSA	Sub Saharan Africa
USA	United States of America

and functions in 5-year increments.[2] The basic idea behind this modelling approach is the evaluation of market and non-market impacts induced by climate change. The economy is represented by 25 world regions aggregated to 11 trading regions (see Table 1). Each region covers 14 sectors.

The sectoral disaggregation contains six energy sectors: coal, natural gas, crude oil, petroleum, coal products and electricity. The dynamic international competitive energy market for oil, coal and natural gas is modelled by global and regional supply and demand, while the oil market is characterized by imperfect competition with the intention that OPEC regions can use their market power to influence market prices. Energy-related greenhouse emissions occur as a result of economic and energy consumption and production activities. A number of gases have been currently identified as having a positive effect on radiative forcing (IPCC (1996)) which are included in the Kyoto protocol as the "basket" of greenhouse gases. The model includes three of these gases: carbon dioxide (CO_2), methane (CH_4) and nitrous dioxide (N_2O) which are evaluated to be the most influential greenhouse gases within the short-term modelling period of 50 years. The exclusion of the other gases is believed to not have substantial impacts on the insights of the analysis. Because of the short-term application of the climate submodel, we consider only the first atmospheric lifetime of the greenhouse gases, assuming that the remaining emissions have an infinite life time. The atmospheric concentrations induced by energy-related and non-energy-related emissions of CO_2, CH_4 and N_2O have impacts on radiative forces influencing potential and actual surface temperature and sea level. Market and non-market damages determine regional and overall welfare development.

[2] Kemfert (2001) gives a more detailed model description.

3. Economic impacts of international Kyoto mechanisms

3.1. Decomposed economic effects

Although there has been tremendous criticism and opposition against the ratification of the Kyoto protocol, recent climate change negotiations agreed to jointly reduce the global emissions of industrialized countries. Besides the opportunity to reduce emissions domestically, international Kyoto mechanisms allow for low abatement cost options by trading certified emission reductions from investment projects in developed (JI) or developing countries (CDM) or emissions permits (emissions trading). These international mechanisms need to supplement domestic action. Domestic action thus constitutes a "significant element" of the effort made by each Annex I country to meet its emissions reduction obligation. The CDM executive board calls for a prompt start to CDM and JI activities; the latter are already implemented by joint activities (AIJ). The Conference of the Parties (COP)

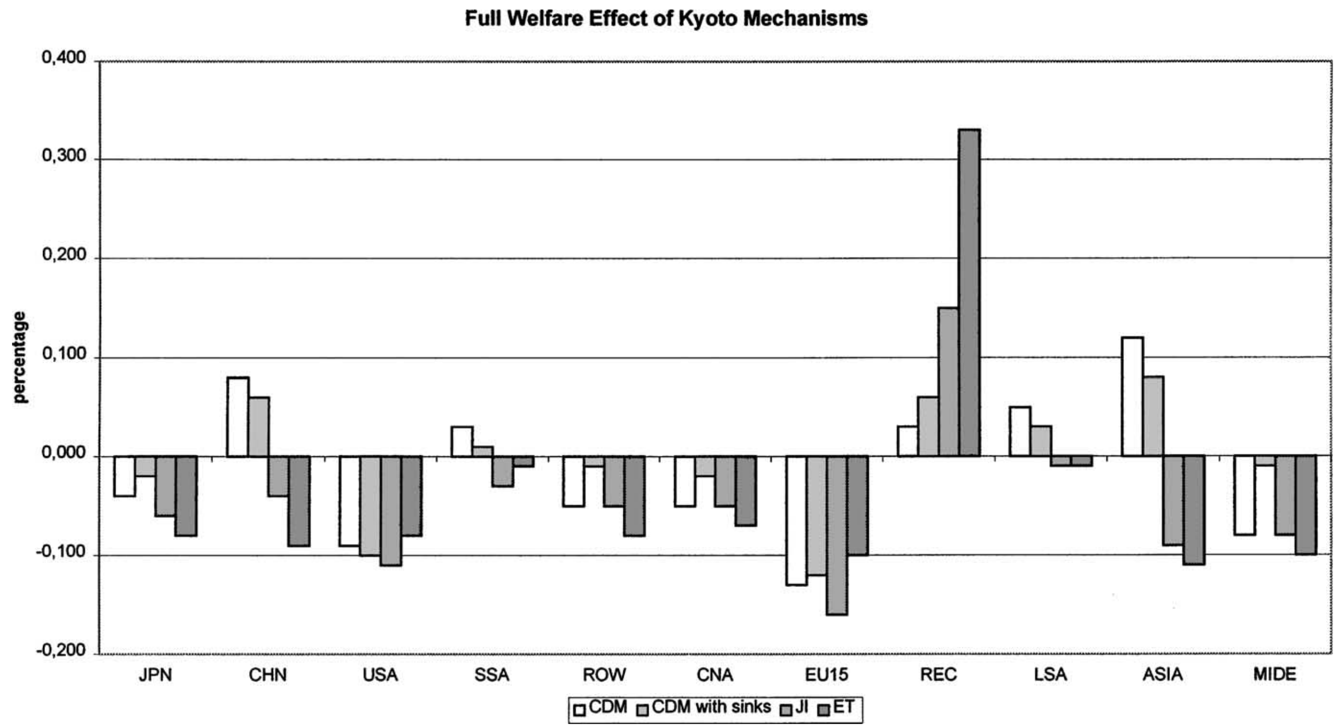

Fig. 2. Full welfare effects of Kyoto mechanisms in percentage to the BAU scenario.

also agreed that all decisions within the CDM/JI project activities assisting in achieving sustainable development must be made by the host countries. Emissions reduction units (ERU) or certified emissions reductions (CER) should not be generated from nuclear facilities to meet their emissions reductions commitments. Because of this, we only include in our analysis CDM technologies excluding nuclear power and including new, carbon-free technologies.

The economic implications of the quantified emissions reductions targets accomplished in the Kyoto protocol by Kyoto mechanism implementation are assessed by the previously described WIAGEM model simulating world economic relations until 2050. It is assumed that the Kyoto mechanisms are initiated in the first commitment period 2008–2012 and last until the end of the projection period. We evaluate the economic impacts of the implementation of the Kyoto mechanisms by a comparison of full welfare effects measured in real income variations (Hicksian equivalent variation) against a so-called "Business as Usual" (BAU) scenario where no policy measures take place. The economic assessment of all climate policy instruments critically depends on the assumptions model calculations are based upon, especially sensitivity parameter and emissions baseline development conjecture. Emissions baseline projections are of particular importance when the economic impacts of climate policies are evaluated after the first commitment period of 2012, and the second commitment periods 2012–2017 and 2013–2025.[3]

[3] See Kemfert (2001) for detailed information.

- The *CDM* scenario simulates the investment projects as additional investment decisions by Annex I countries increasing energy efficiencies in host countries.
- The *CDM* with sinks scenario includes additional sinks projects such as afforestation and reforestation within the first commitment period 2008–2012.
- The *JI* scenario represents the investment projects from industrialized countries to countries in transition (here the REC region).
- The *ET* scenario demonstrates the Annex I emissions trading options.

Fig. 2 summarizes the results by revealing the full welfare effects in terms of the Hicksian equivalent in comparison to the BAU scenario. The first conclusion drawn from this analysis is that the achievement of the Kyoto reduction targets is costly for the developed regions that must commit to the quantified emissions reduction targets. However, economic costs are much higher if reached by domestic policy measures without any flexibility (as proposed by the Kyoto mechanisms). Because of the high abatement costs of developed nations like Japan, Europe and the USA, negative overall economic welfare effects occur in the range of 0.05 for Japan, 0.12 for the USA and 0.27 for the EU as the percentage of real income losses in comparison to a base case scenario. However, the CDM project transfer to developing nations like China, Asia, Latin South America and Sub Saharan Africa stimulate self-enforcing investment processes that additionally augment energy efficiency by an application of new, carbon-free technologies. Both aspects improve the economic situation drastically so that developing regions may benefit considerably, manifested through welfare increases. It must be stressed that we disregard transaction costs such as search, negotiation, approval, and monitoring costs for both JI, CDM and emissions trading. The exclusion of transaction costs is assumed to not distort this analysis, as the volume of transaction costs would not significantly change the results.

If sink options are included in CDM projects, negative economic implications in developed regions do not reach the extent described earlier and cannot stipulate self-enforcing investment activities triggering growth in developing regions. Economies in transition represented in this context by the REC region can benefit by the joint implementation program which exhibits large welfare gains when compared to the BAU case. Both scenarios demonstrate that welfare gains can be achieved by host countries benefiting from self-enforcing investment activities. This improves economic development along with the effect of increasing energy efficiencies, enhancing distinct production processes. Moreover, this effect augments the competitiveness of developing regions so that all world nations benefit by advanced terms of trade conditions. The share of new and less carbon-intensive technologies is increased, as Fig. 4 illustrates. For example, in China the share of hydro power plants can be increased, intensifying energy efficiency and therefore abating or even reducing emissions. The positive economic effects of self-enforcing investment growths by CDM projects succeed in an increasing share of carbon-free technologies, the positive spill over effects support the rise of carbon-free technologies in developing countries. Positive production effects in fast growing regions like Asia and China occur mainly in industrial sectors that can benefit from new technologies. CDM projects focusing on forestration induce positive economic effects on agricultural sectors in regions like Sub Saharan Africa and Latin South America, as Fig. 5 demonstrates.

A positive welfare effect (as previously described) with CDM projects active in developing countries appear in economies in transition because of JI projects inducing self-initiated investment processes additional to strong economic growth. Emissions trading enables developed regions to minimize abatement costs. Countries in transition benefit from Annex I permit trading because of the above described “hot air” effect allowing a large purchase of permits, drastically improving effects on welfare.

The Kyoto protocol has been criticized by many scientists. Particularly after the USA’s decision to withdraw from their commitment, a huge debate has developed regarding the strength and weaknesses of Kyoto mechanisms. Alternative proposals to the Kyoto mechanisms encompass national permit trading systems or the implementation of a globally uniform carbon tax that would force developing regions predicted to quickly reach growth standards to reduce emissions as well. From an “equity” point of view, and considering that a uniform emissions tax is neither economically efficient nor

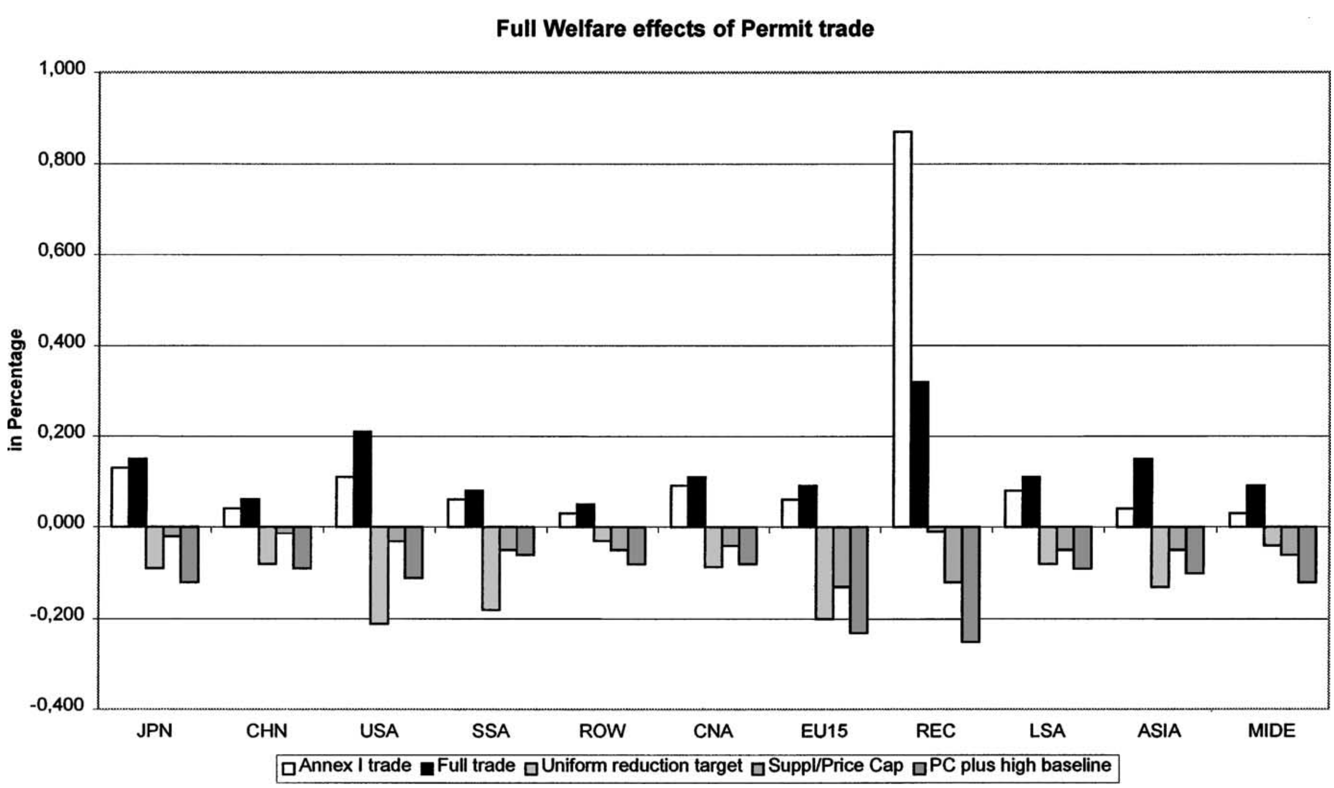

Fig. 3. Full welfare gains of permit trading in comparison to a no trade/BAU/full trade scenario.

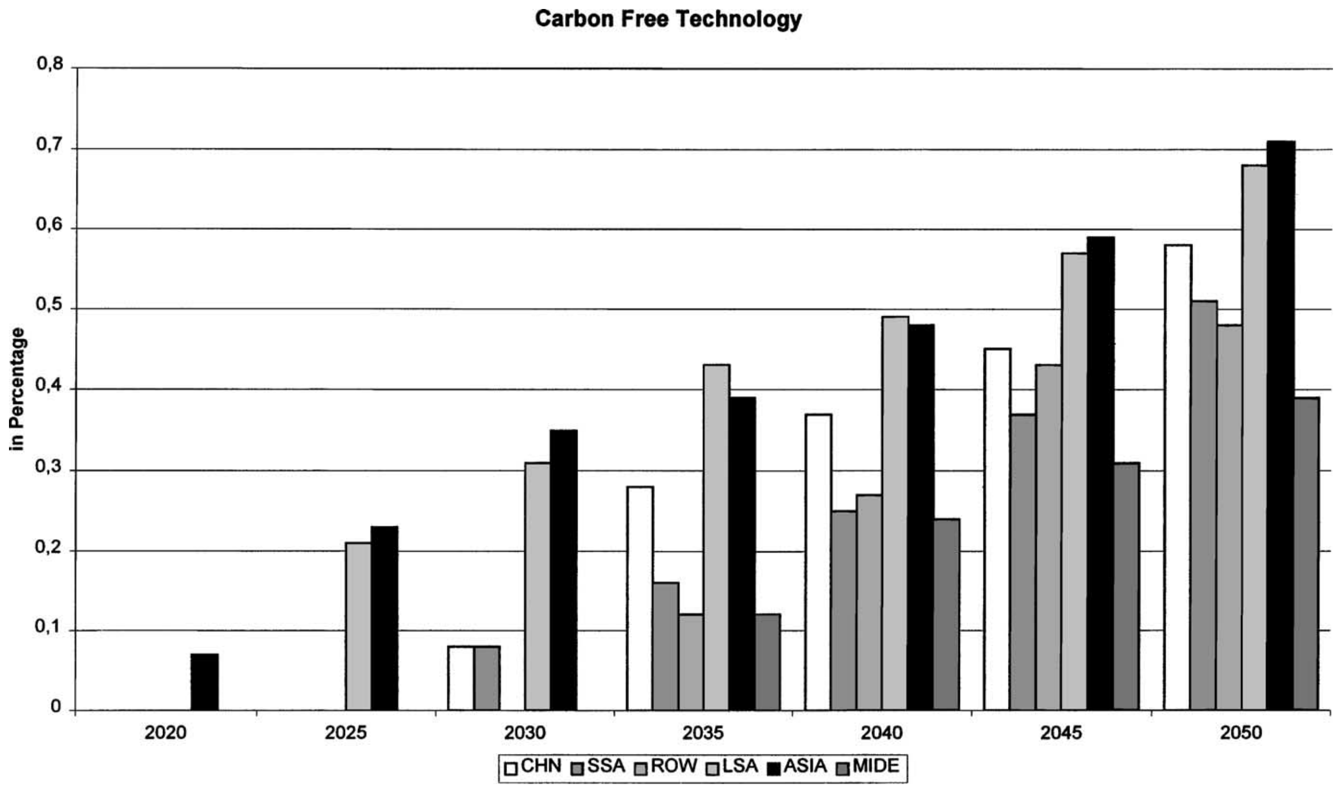

Fig. 4. Share of regional applied carbon-free technologies in the CDM scenario.

effective, the nations most responsible for climate change should take the lead in drastically cutting their emissions. However, the best initiative for covering both equity and responsibility viewpoints is opening emissions permit trading to all world regions. The following simulations confirm this hypothesis:

- *Annex I permit trade* scenario versus no trade.
- *Full global trade* scenario versus no trade.
- *Uniform reduction target* in comparison to the BAU scenario.
- *Supplementarity/price cap* in comparison to the full trade scenario.
- *Supplementarity/price cap and high baseline* in comparison to a full trade scenario.

The first simulations exhibit how both Annex I permit trade and a full global trade scenario can increase regional welfare effects drastically in comparison to a scenario where no trade is allowed and predefined emissions reduction targets must be reached. Full global trade also expands the welfare impacts of developed regions with high abatement costs like the USA, EU and Japan because the permit price decreases due to a larger supply of permits. This, on the other hand, allows limited welfare upsurges to the selling regions like China or Russia due to less revenue, but opens lower cost emissions reductions opportunities to developed regions. Mainly, positive welfare effects in developing regions occur due to positive terms of trade and spill over effects whereas full global trade raises revenue gains from the trade of permits (see Fig. 3). A uniform reduction target of 5% (or a uniform carbon tax) for all world regions leads to welfare losses in all world regions.

The supplementarity criteria initiates the same effect as a price cap: due to restricted trade of permits (90% of full trade) their price is lowered, which is the same effect of a price cap introduction. This price cap represents a uniform price ceiling so that no varying regional permit prices occur that could trigger mass selling of permits in regions with high price limits. A restriction on permit trade also has negative welfare implications on developed and developing regions in comparison to a full trade scenario. Economic regions with high abatement costs like the USA and Europe could benefit from a reduced carbon price because of lower abatement options. However, because of a lower permit price due to restrictions on trade, less revenue can be earned, resulting in Russia suffering welfare losses in comparison to the full permit trade case where it would have sold a larger amount of permits. The model results crucially depend on the assumption and predefinitions of parameters. If a higher baseline development for the first (2008–2012) and second (2013–2017) commitment period is assumed, regional welfare losses are higher if the supplementary criteria leads to a price cap of permits (see Fig. 3). From an equity point of view, permit allocation should be ruled by either emissions per capita or purely per capita rules; model results confirm that this leads to a positive growth and welfare trend for all

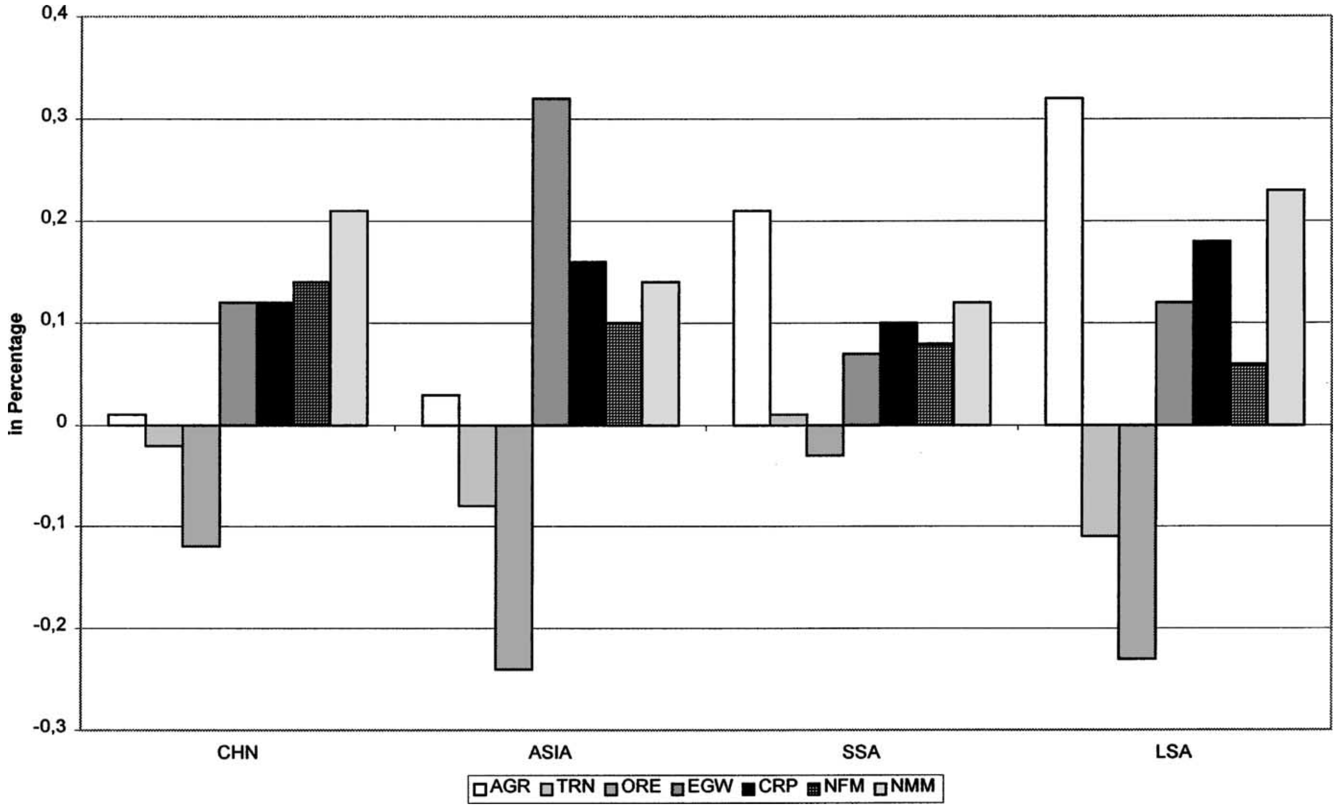

Fig. 5. Sectoral production effects in 2040 in percentage from the baseline in the CDM scenario.

developing nations, see Kemfert (2001). The price of permits declines because of the advanced supply of permits. Because CDM and JI investors focus almost solely on cost effective opportunities, CDM and JI credits will be cheaper than emissions permits. Because of the lower and more cost effective opportunities through JI projects, JI credits are estimated to be cheaper than CDM credits (Table 2).

The decomposition of welfare effects exhibit that the domestic emissions abatement effect is determined by the reduction target that Annex I nations must accomplish. Because of high emissions abatement costs Japan, Europe and the USA suffer welfare losses by domestic action; the only regions which could benefit are the countries in transition (see Table 3). Domestically, the effort needed from Annex I regions remains the same independent of whether further flexible abatement measures are implemented. The competitiveness effect demonstrates the composed welfare effect resulting from terms of trade changes; the spill over

Table 2
Permit prices in US$ per tons of carbon

Year	Scenario					
	Annex I trade	Full trade	CDM	JI	Supplementarity/ price cap	PA/cap
2015	52	35	25	20	14	6

effect shows the welfare effect that is neither influenced by domestic actions nor by terms of trade variations. The clean development mechanism stipulates positive competitiveness effects in the host countries China, Sub Saharan Africa and Asia. The CDM increases investment activities in the host countries so that not only energy efficiency growth but also increased overall economic activities induce an improvement in trade balance. On the other hand, supporting countries needing to reach their intended emissions reduction target endure export losses resulting from an increased economic effort and a competitive disadvantage. Considering CDM projects with sink opportunities, neither economic advantages nor disadvantages for host and funding countries reach the extent they would have if sinks would not have been included. This is because sink projects are not modelled as additional investment projects but as existing sinks in the host country that could be accounted for by the emissions baseline level. Due to this, investment activities are lower than those in a purely CDM case. A decrease in favourable effects on the overall economy and energy efficiency is the result. In comparison to the case where emissions reductions must be reached but no emissions trading is allowed, beneficial welfare effects in terms of pure competitiveness effects occur to all world regions without exception if permit trading is endorsed. The main beneficiaries are the regions in transition also profiting from the implementation of joint implementation projects. The spill over effects represent

Table 3
Decomposed welfare effects of diverse climate policy strategies

	Domestic				Competitiveness				Spill over			
	CDM	CDM with sinks	JI	ET	CDM	CDM with sinks	JI	ET	CDM	CDM with sinks	JI	ET
JPN	−0.016	−0.016	−0.016	−0.016	−0.021	−0.002	−0.007	0.085	−0.002	−0.001	−0.037	0.062
CHN	0.000	0.000	0.000	0.000	0.051	0.039	−0.026	0.024	0.029	0.021	−0.014	0.016
USA	−0.041	−0.041	−0.041	−0.041	−0.031	−0.074	−0.081	0.064	−0.018	0.015	0.013	0.087
SSA	0.000	0.000	0.000	0.000	0.020	0.009	−0.027	0.059	0.010	0.001	−0.003	0.001
ROW	0.000	0.000	0.000	0.000	−0.024	−0.005	−0.026	0.025	−0.026	−0.005	−0.025	0.005
CAN	−0.013	−0.013	−0.013	−0.013	−0.020	−0.011	−0.029	0.011	−0.017	0.005	−0.008	0.092
EU15	−0.045	−0.045	−0.045	−0.045	−0.042	−0.074	−0.099	0.054	−0.044	−0.001	−0.016	0.050
REC	0.020	0.020	0.020	0.020	0.009	0.035	0.087	0.714	0.001	0.005	0.043	0.136
LSA	0.000	0.000	0.000	0.000	0.029	0.018	−0.006	0.018	0.021	0.012	−0.004	0.062
ASIA	0.000	0.000	0.000	0.000	0.075	0.043	−0.049	0.040	0.045	0.037	−0.041	0.000
MIDE	0.000	0.000	0.000	0.000	−0.076	−0.010	−0.076	0.030	−0.004	−0.001	−0.004	0.000

only a small fraction of the overall welfare effect. Positive spill over effects mainly occur in host countries of CDM projects and in the emissions trading simulation because of the beneficiary situation in the participating regions, which induces competitive advantages and profitable spill over effects. The decomposition of welfare effects reveals that the domestic effort to reduce emission competitiveness effects plays the dominant role whereas the spill over effects represent only a small fraction of this process. This can be explained by the strong trade relations of world economies significantly influencing the terms of trade variations.

4. Climatic impacts

Impacts of climate change cover market and non-market damages, the former comprise all sectoral damages, production impacts, loss of welfare etc. while the latter contain ecological effects like biodiversity losses, migration, natural disasters etc. To assess impacts by climate change we follow the approach of Tol (2001) to include impacts on forestry, agriculture, water resources and ecosystem changes as an approximation of a linear relationship between temperature changes, per capita income or GDP and protection costs due to rising sea level. Tol (2001) estimates climate change vulnerability, covering a comprehensive evaluation of diverse climate change impacts. Besides sectoral impacts on agriculture, forestry, water resources and energy consumption, Tol covers impacts on ecosystems and mortality due to vector borne diseases as well as cardiovascular and respiratory disorders. We use the assessed protection costs and an approximation of potential impacts, i.e. additional costs to the economy lowering other investments (the "crowding out" effect). Kemfert (2001) gives a detailed description of this model, the Appendix A shows the main interrelations.

In contrast to many other climate impact assessment studies detecting only insignificant economic impacts of climate change, we find considerable climate change impacts in the next 50 years. Model results demonstrate that primarily developing countries must accept high welfare losses and GDP reductions in comparison to a scenario where no climate change impacts are included. The climate change (CC) scenario is one where no climate impacts are evaluated (Table 4).

Table 4
Welfare in HEV, GDP in % and impacts in % of the CC scenario in comparison to no impact assessment

	Welfare	GDP	Impact (%)
JPN	−0.08	−0.02	0.12
CHN	−1.14	−0.57	3.44
USA	−0.28	−0.05	0.30
SSA	−0.82	−0.24	1.45
ROW	−1.29	−0.31	1.87
CAN	−0.23	−0.09	0.54
EU15	−0.24	−0.06	0.36
REC	−0.44	−0.08	0.48
LSA	−0.29	−0.12	0.72
ASIA	−0.30	−0.18	1.09
MIDE	−0.04	−0.10	0.60

Developing regions suffer economic deficits if climate impacts are included because of their vulnerability and higher percentage of economic values impacts. Relatively poor countries must spend a significant percentage of their income on protection costs. As a consequence, production losses due to low economic investment are much higher. Affluent countries like the USA or Europe suffer from economic losses in terms of welfare as real income losses and in terms of GDP reductions, but percentage decreases are not as significant as those in developing regions. As these results demonstrate, climate change impacts are significant within the next 50 years. Primarily developing regions are those affected negatively.

5. Multi-gas/sinks

Regional greenhouse gas emissions differ substantially. The inclusion of the other greenhouse gases CH_4 and N_2O

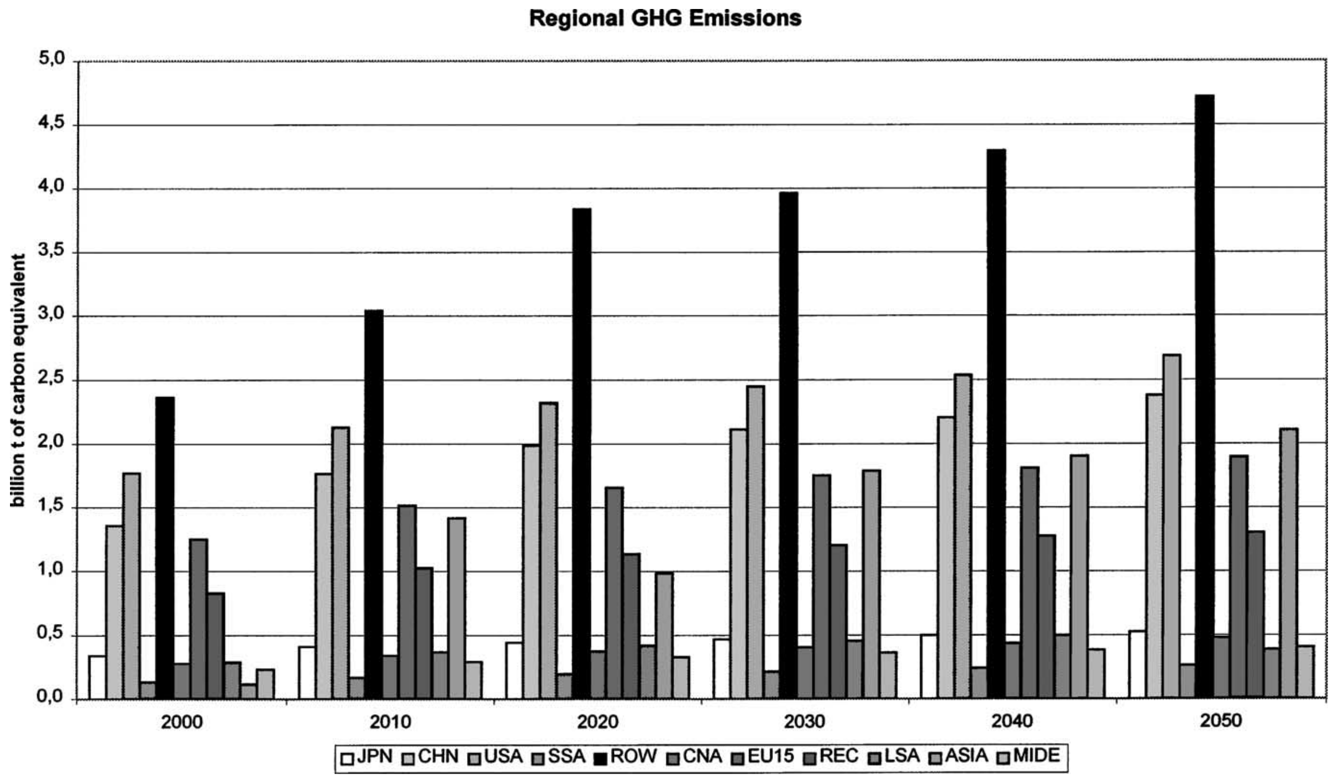

Fig. 6. Regional greenhouse (GHG) emissions.

raises reference emissions for the European Union from 1.517 billion tons of carbon in 2010 to 1.894 billion tons. For the US, the inclusion of sinks lowers the greenhouse gas emissions from 2.133 to 2.030 in 2010 and 2.686 to 2.496 billion tons of carbon in 2050. Japan has no significant net emissions changes resulting from sinks inclusion. The global CO_2 emissions baseline pathway is assumed to increase from 6 to 12.7 billion tons of carbon in 2050 which is roughly consistent with the carbon emissions projections of the IPCC reference case of medium economic growth (Figs. 6 and 7). By including all greenhouse gases, total GHG emissions increase from roughly 9 to 17 billion tons carbon equivalent emissions in 2050 that are in line with recent IPCC emissions scenarios (IPCC (2001a)), see Fig. 8.

The inclusion of sinks lowers total net GHG emissions to roughly 15.5 billion tons of carbon equivalent in 2050 (see Fig. 8). Sinks are assumed to be available at no cost which can be explained by the fact that only existing sinks potentials are included without accounting for new investment projects in carbon sinks. Because of the time deceleration of response impacts by potential and actual temperature changes ranging from 0.15 to 0.25 °C from 2030 to 2050, the inclusion of sinks causes comparatively marginal declines in actual temperature after 2030 (see Fig. 9).

Because of the assumed linearity between temperature changes and rise in sea level, the potential sea level increases by 1 cm in 2025 to roughly 1.8 cm in 2050. As seen before, the incorporation of sinks by land use change and forestry tends to lower this increase marginally after 2030. These changes are low in comparison to other projected studies (IPCC (2001a,b)) and can be explained mainly by the short-term time horizon considered and because of the time deceleration of response impacts (Fig. 10).

Potential impacts by climate change are measured in percentage of global GDP covering impacts on forestry, agriculture, water resources and ecosystem changes as an approximation of a linear relationship between temperature changes, per capita income or GDP and protection costs due to a rise in sea level. Emissions upsurge augments climate change impacts through warming and rising sea levels. Fig. 11 compares the impacts of climate change through the emissions reductions induced by the Kyoto protocol. The emissions reductions attempt prescribed by the Kyoto protocol necessitates enormous economic efforts due to drastic GHG emissions reductions inducing lower economic impacts of climate change measured in percentage of GDP. In terms of economic effects, this means that with the inclusion of sinks, global impacts increase because of fewer economic welfare losses. Because of the major economic efforts needed to reach the emissions targets of the Kyoto protocol, regional welfare declines, especially for those regions having high emissions reduction targets (Table 5). Through the inclusion of sinks, net emissions and therefore emissions reduction targets are reduced, causing impact increases due to less GHG emissions reduction needs and hence less income and GDP losses.

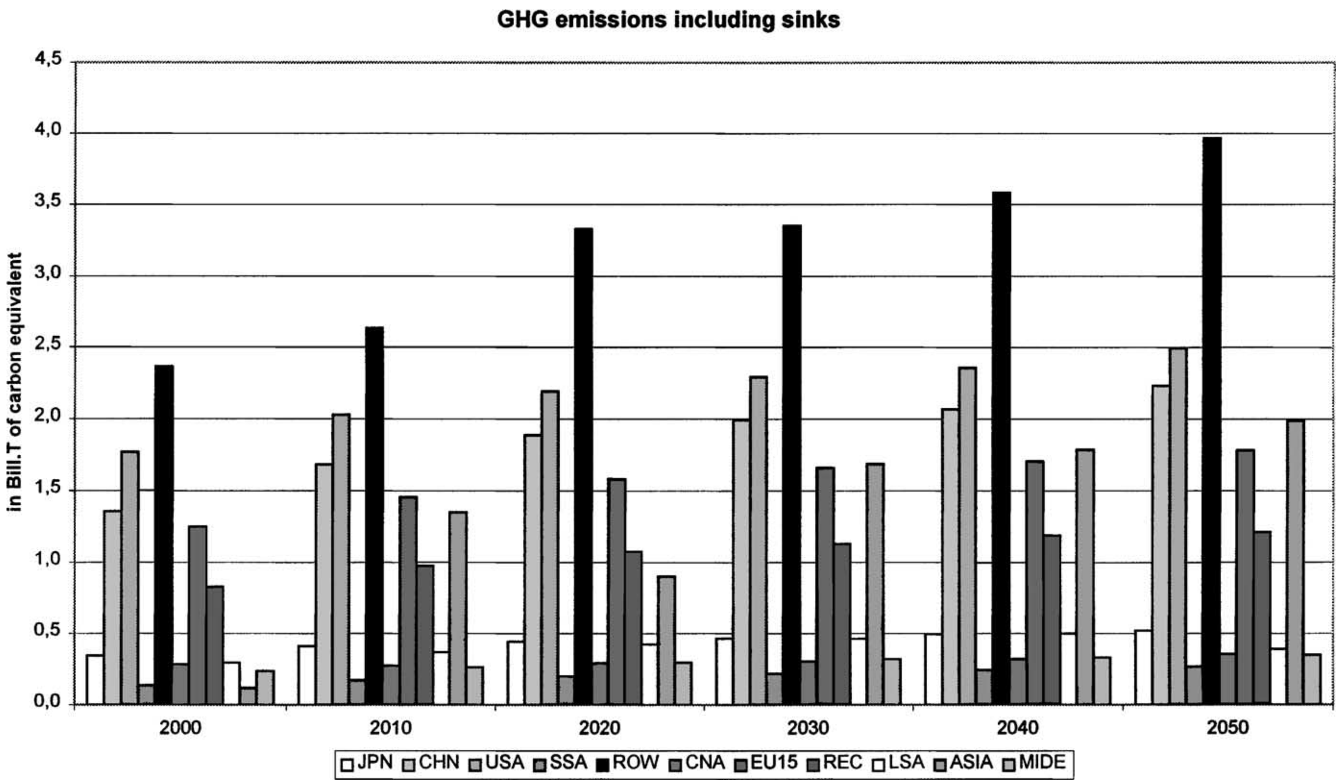

Fig. 7. Regional GHG emissions including sinks.

Developing regions suffer from the implementation of the Kyoto protocol and emissions reduction targets mainly because of negative international trade spill over effects due to the loss of competitiveness (as described before in this paper). Although international emissions permits trading is allowed, economic welfare in terms of the Hicksian equivalent (which explains the real income variation) decreases in developed and developing regions in comparison to the base

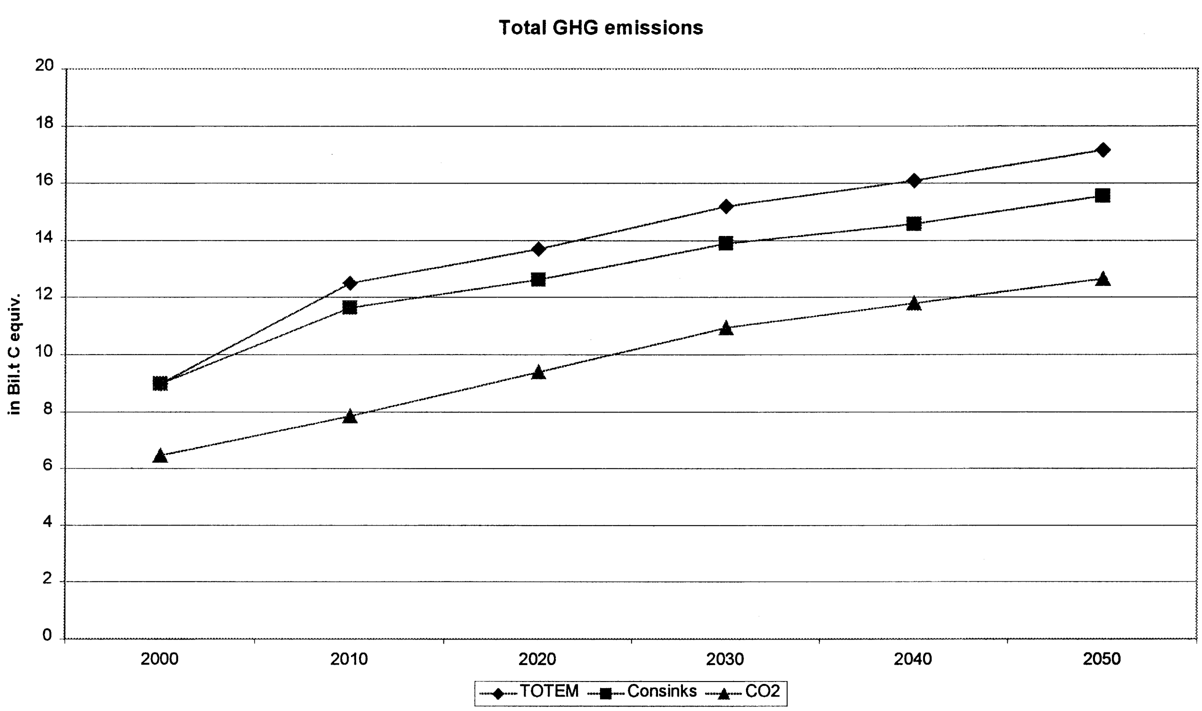

Fig. 8. Total CO_2 and greenhouse gas emissions with and without the inclusion of sinks.

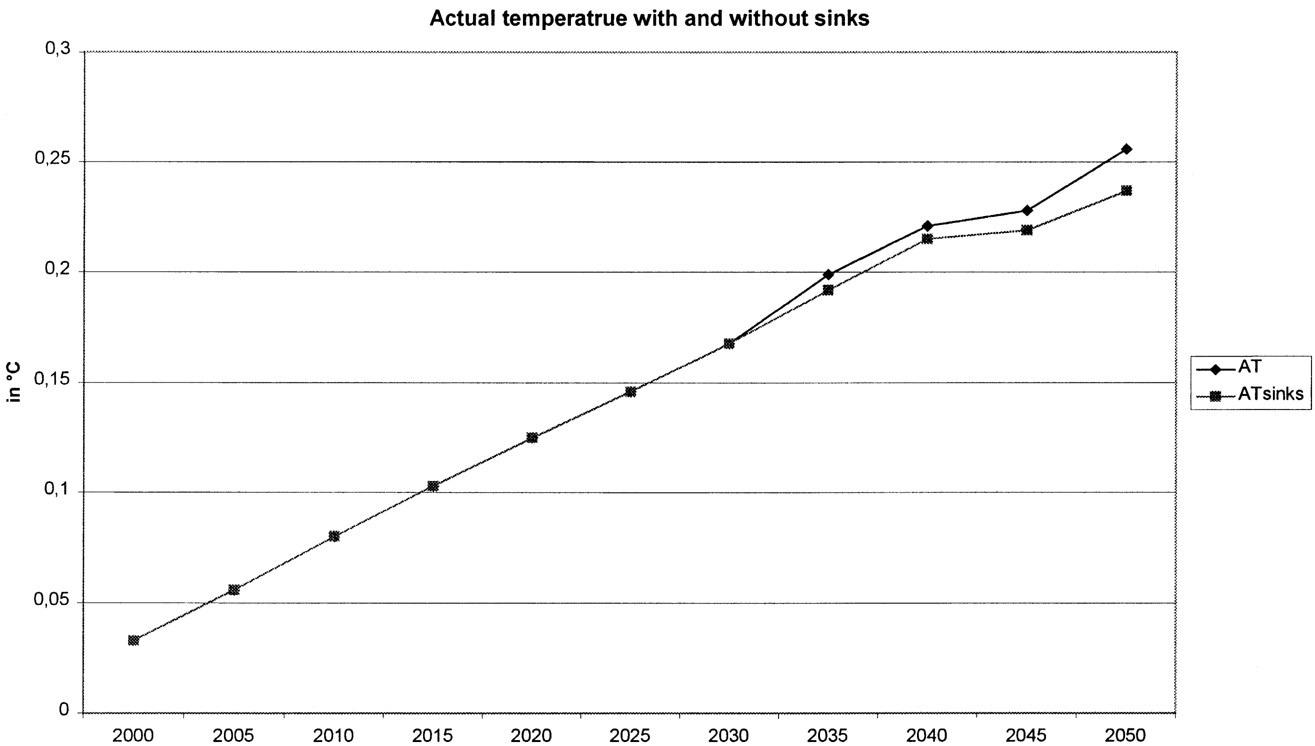

Fig. 9. Actual temperature changes with and without including sinks.

case. A drastic emissions reduction lowers the demand for energy, inducing a decrease in energy prices. Regions with high energy import shares could benefit from this development, but countries facing a high share of energy exports will suffer, e.g. the coal exporting region China.

If no emissions permit trading is allowed, a main seller of emissions permits such as Russia will suffer due to high economic deficits. This negative welfare effect for Russia and Eastern Europe can be explained as follows: because of poor economic performances, the Russian economy endured

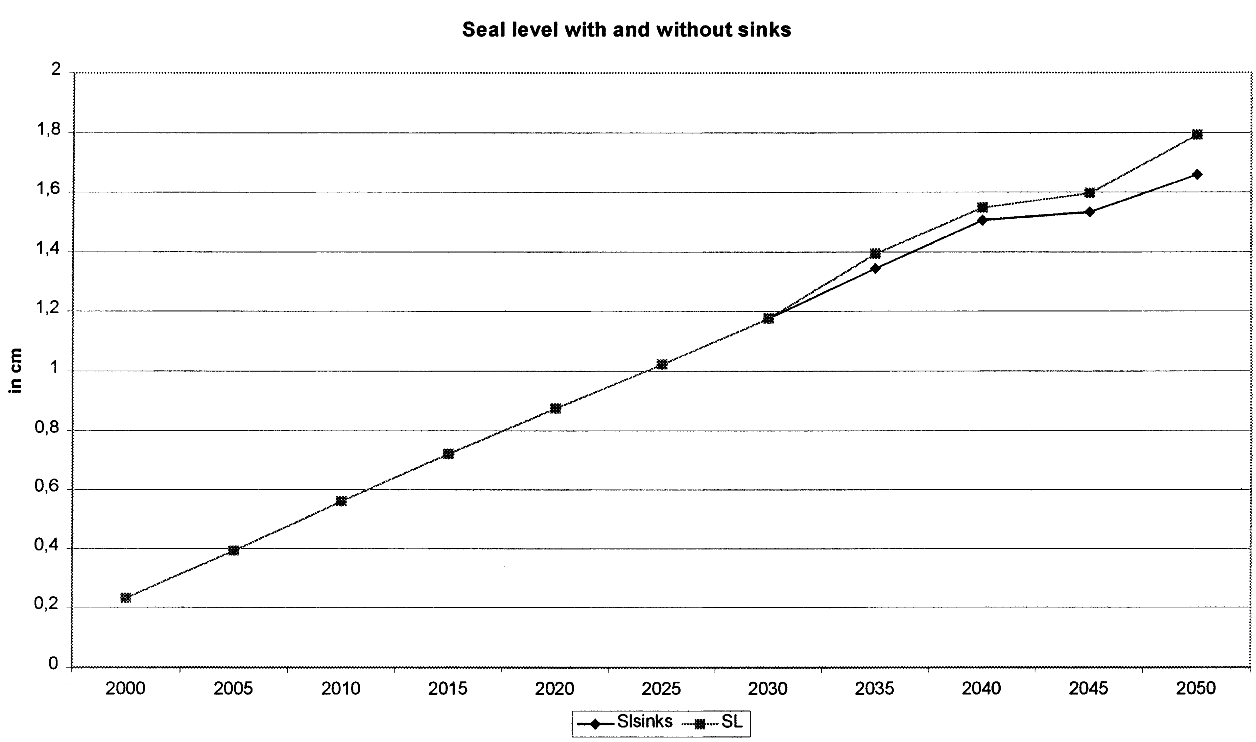

Fig. 10. Sea level changes with and without the inclusion of sinks expressed in centimeters.

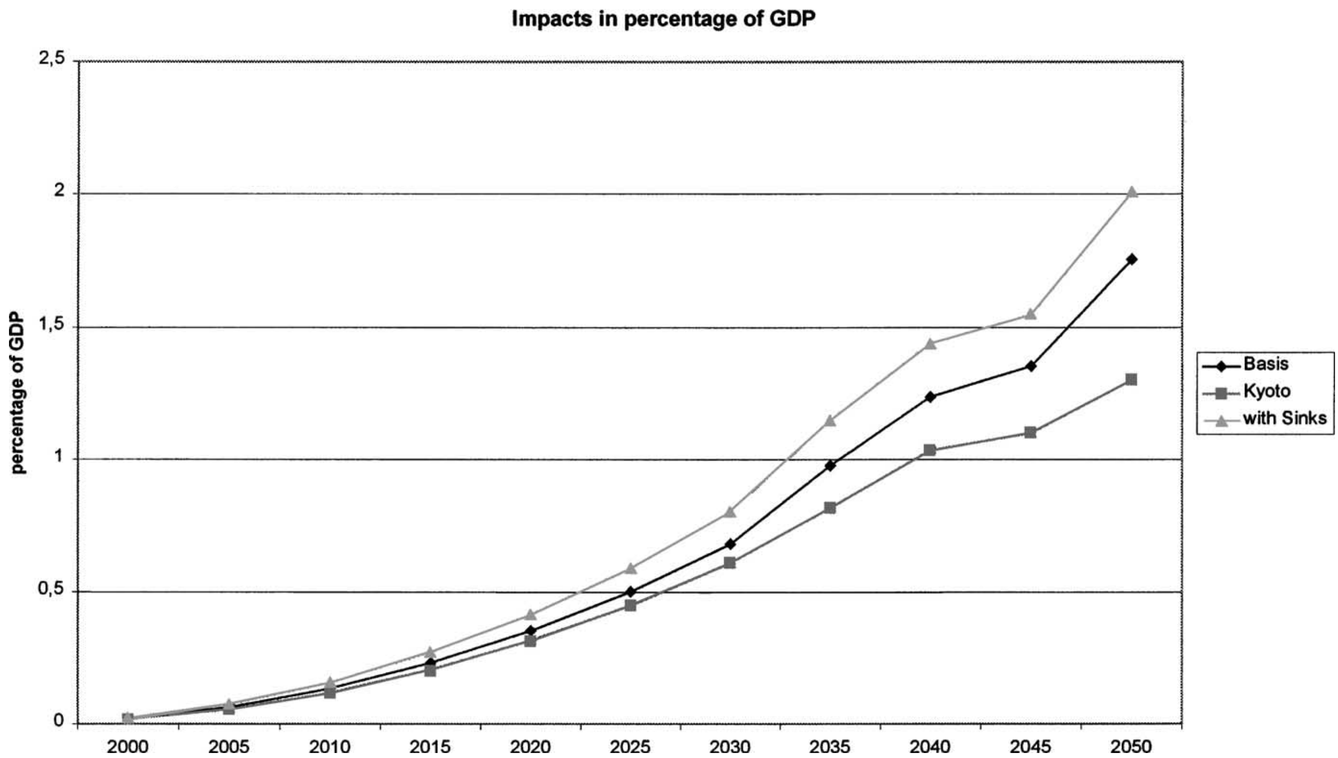

Fig. 11. Impacts of climate change in percentage of global GDP.

a substantial economic recession. Substantial production and trade efforts are necessary to regain economic potential. If the Kyoto protocol is implemented, substantial welfare losses occur to Annex I regions resulting in terms of trade deterioration. In comparison to the BAU case where no emissions reduction measures are active, Russia's positive export trends of e.g. selling more gas than before cannot overcompensate negative trade spill over effects coming from the economic declines of other robust Annex I countries. Developed regions like EU15 or Japan face significant abatement costs, leading to higher economic losses by meeting the Kyoto emissions reduction target. If all GHG are included, the number of low costs abatement options are increased, improving the economic situation for OECD regions. Without the allowance of permit trade, regional welfare impacts are much higher if only CO_2 emissions are considered.

A comparison of a trade versus no trade scenario demonstrates that all countries can benefit from Annex B permit trading, mostly for countries in transition such as REC because of the "hot air" effect. Emissions permit trading is better off in all Annex B countries as well as non Annex B or developing countries owing to an improvement in competitiveness. Annex B countries facing high emissions reduction targets and high domestic marginal abatement costs like Japan and the USA will certainly benefit from Annex B emissions permit trading. Essentially, the USA and EU 15 will trade permits within a full trade scenario because of their high share of total carbon emissions. The option of

Table 5
Welfare effects measured in Hicksian equivalent in comparison to the base case

	Kyoto all GHG	Kyoto CO_2	Kyoto GHG trade	Kyoto CO_2 trade	Sinks
JPN	−0.09	−0.15	−0.05	−0.08	−0.01
CHN	−0.08	−0.14	−0.04	−0.09	−0.06
USA	−0.35	−0.42	−0.12	−0.19	−0.10
SSA	−0.02	−0.01	−0.03	−0.01	−0.05
ROW	−0.14	−0.18	−0.05	−0.08	−0.01
CAN	−0.08	−0.10	−0.05	−0.07	−0.02
EU15	−0.28	−0.39	−0.18	−0.24	−0.12
REC	−0.08	−0.12	0.24	0.33	0.11
LSA	−0.02	−0.01	−0.01	−0.01	−0.03
ASIA	−0.12	−0.18	−0.09	−0.11	−0.08
MIDE	−0.13	−0.19	−0.08	−0.10	−0.01

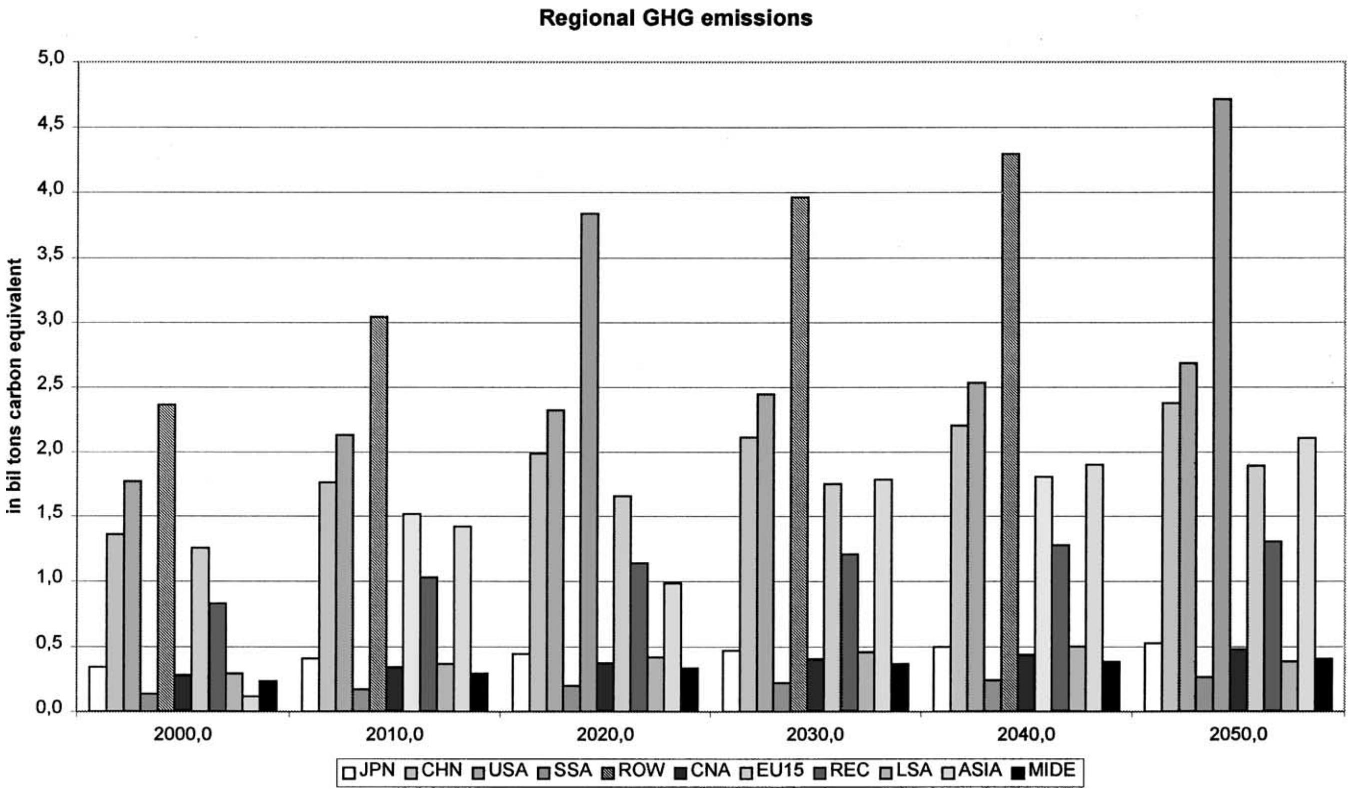

Fig. 12. Regional GHG emissions reaching the Kyoto emissions reduction target.

permit trade lowers negative welfare impacts, the inclusion of all GHG brings about a decreasing international permit price which also leads to more benefits for OECD regions by making imports more attractive relative to domestic emissions abatement.

The inclusion of sinks and the parallel GHG emissions reduction target forced by the Kyoto protocol improves the welfare effects in comparison to the Kyoto emissions reduction scenario without the inclusion of sinks. The USA and Canada particularly benefit from the inclusion of sinks because of their high sinks potential. The oil exporting region OPEC also benefits due to less severe emissions reductions targets. Furthermore, economic welfare impacts are improved in comparison to the cases where trade is allowed (see Fig. 12).

6. Non-cooperative climate policies

The process towards an establishment of international environmental agreements such as the implementation of the Kyoto protocol requires an enormous effort of international negotiation and bargaining policies and strategies. International cooperative negotiation solutions can be reached if all negotiation partners and players expect improved results in comparison to a non-cooperative approach and independent initiatives controlled by self interests. More precisely, individual nations will not cooperate in reaching a common target if the difference in net benefits of non-cooperative and cooperative strategies is very high. Whether an agreement can be reached depends on the opportunities to reduce interest conflicts towards a minimum agreement; a bargaining situation contains opportunities to collaborate for mutual benefits. As real negotiation processes demonstrate, a full agreement from all players is unlikely. More realistic would be that some players may act independently or unilaterally to maximise their own welfare and self interests, other players join small and stable coalitions (Carraro and Siniscalo (1992), Carraro and Siniscalco (1993) and Hoel et al. (1994)), while others act as free riders, i.e. they stay outside instead of participating. The encouragement of countries to join a partial coalition can be enforced by capital or technology transfer (Tol et al. (2000)) that can be considered as side payments. Kemfert and Tol (2001) investigate and assess partial coalition games. Applied model results demonstrate that the partial coalition of Japan and the USA is the only internally and externally stable coalition.

However, although the USA is the greatest emitter of greenhouse gases, recent statements by the US confirm that it will not ratify the Kyoto protocol in its current state. Their main argument against the emissions reductions commitment agreed upon in Kyoto is that it is ineffective and unfair to the US due to the lack of meaningful participation by key developing nations, i.e. any agreement should also include significant commitments from these countries. However, no developing country is projected to surpass total USA carbon emissions in the next 20 years.

Offering no concrete alternative to drastically decrease emissions, the USA seems to act as a free rider. Other countries, however, stick to their previous commitment of greenhouse gas reduction targets, leading to the question of what economic impacts will result for all other Annex I countries and especially to what extent the US economy will be affected. If the USA does not participate in the developed country agreement to shrink emissions, economic implications for all other commitment nations can only be profitable for the contributing nations if an international emissions trading system is allowed so that a declining permit price will lead to more low-cost abatement options. The USA would comprise a large share of the total demand for emissions permits so that without their participation the permit price would drop significantly with the intention that other industrialized countries could reach their emissions reduction targets at lower costs. If Annex I emissions trading is allowed without any supplementarity and banking options the permit price would drop to US$ 8 per ton of carbon. However, economic implications can only be beneficial if economic impacts alone are evaluated without the inclusion of climate change impacts. The loss of welfare in other Annex I countries can be explained by the higher climatic change impacts.

If the US withdraw its support of the Kyoto protocol, all other countries must support the proposal of GHG emissions reduction declared by the Kyoto protocol to reach the required 55% of Annex I emissions. Model simulations demonstrate that the US could benefit substantially if the other countries reduce their emissions as declared within the Kyoto protocol; the economic benefits are higher if the other countries have additionally diminished the US emissions as declared by the global reduction target of roughly 5.2% (see Fig. 13). We compare our model results against a scenario where the Americans act cooperatively and meet their greenhouse gas reduction target. For Russia, the US withdrawal induces fewer economic benefits because of the reduced emissions permits demand leading to less economic revenues and earnings for Russia. A smaller demand for emission permits induces a significant decline in the permit price, thus creating fewer economic revenues for selling regions like Russia. By including all greenhouse gases in our analysis, global GHG rise from 13.7 billion tons in 2020 to 17.1 billion tons of carbon equivalent in 2050. If the USA does not reduce GHG emissions and the other Annex I regions nevertheless reach the Kyoto target, all while developing countries do not reduce their GHG emissions, all other Annex regions must reduce emissions by 30%, inducing substantial welfare losses (Table 6).

If the USA does not reach its GHG emissions reduction target, it could increase welfare development significantly whereas other regions would have to accept welfare losses, especially high if other regions must diminish emissions by 30% to reach the global target negotiated in Kyoto. Welfare losses, especially for the EU, result from higher climatic

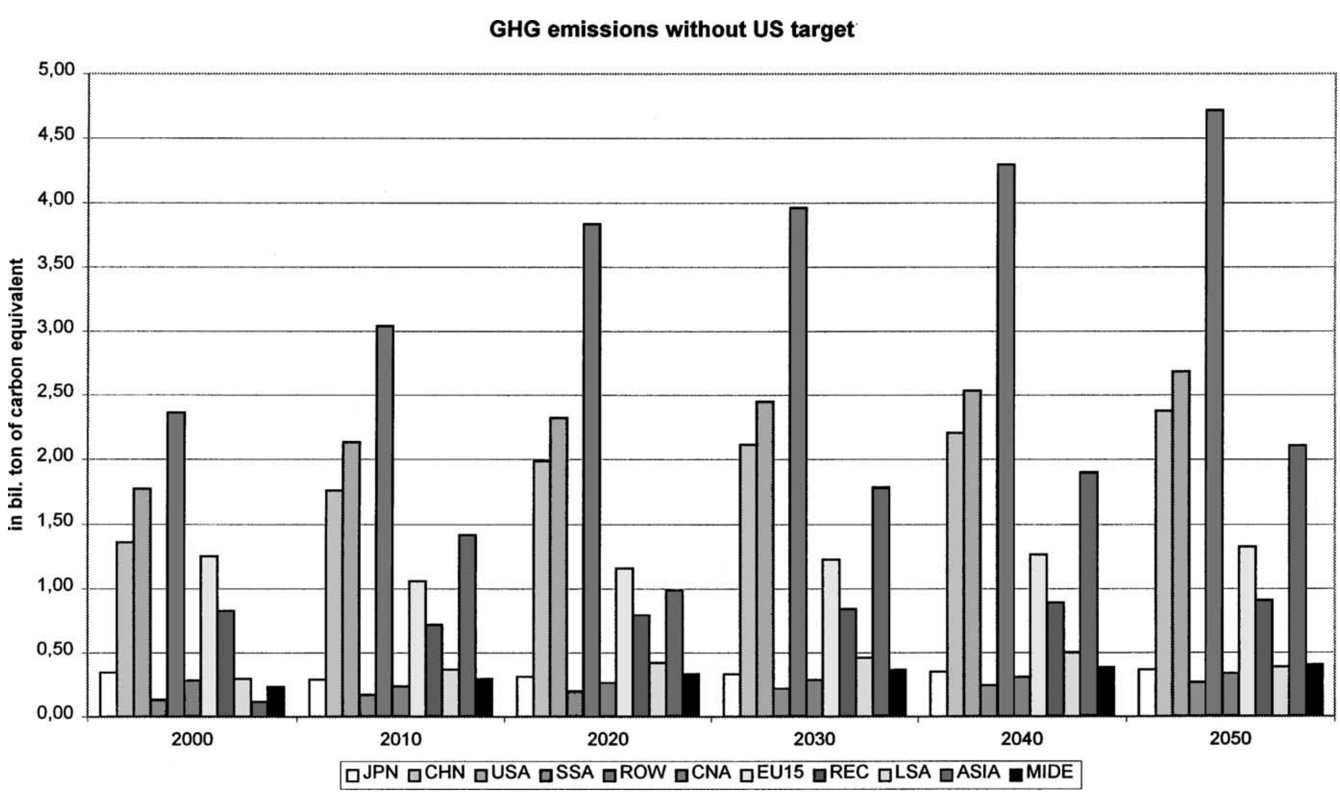

Fig. 13. GHG emissions with global emissions reductions target of 5.2 without US reduction.

Table 6
Welfare effects measured in Hicksian equivalent

	US no reduction less global target	US no reduction global target 5.2
JPN	0.00	−0.30
CHN	0.05	−0.15
USA	0.08	0.08
SSA	0.04	−0.26
ROW	0.00	−0.06
CAN	0.02	−0.74
EU15	−0.18	−0.41
REC	−0.21	+0.12
LSA	−0.07	−0.10
ASIA	−0.03	−0.01
MIDE	0.12	−0.62

impacts caused by emissions reduction below those expected. The demand of permits drastically decreases due to the US withdrawal. As a result, mainly Russia must accept welfare losses. But, if all nations must meet the global reduction target negotiated in Kyoto, permit demand increases considerably so that Russia could sell its excess supply of permits. Even if it must accept higher emissions reduction targets, it will not meet its 1990 baseline emissions because of poor economic performances. Because of this, Russia is the only region that could benefit by a higher emissions reduction target if the US does not ratify the Kyoto protocol. All other Annex I regions suffer by higher emissions reduction targets compared to the previously mentioned scenario because of the additional climate change impacts inducing welfare losses.

7. Conclusion

Several conclusions can be drawn from this analysis. The attainment of specific emissions reductions targets is costly for those countries having to meet their obligations. Clean development mechanisms and joint implementation show evidence that these measures can improve economic development in host countries mainly by self-enforcing investment processes inducing positive production effects and the application of new and carbon-free technologies in industrial sectors. The decomposition of welfare effects demonstrates that the competitiveness effect including the spill over effects from trade have a more significant impact than other spill over effects because of the large trade relations between world nations. Climatic effects will have a significant impact within the next 50 years causing substantial welfare losses to world regions, and will be even higher if nations highly responsible for pollution like the USA do not reduce their emissions. The additional inclusion of sinks improves the welfare impacts in comparison to all other scenarios, which leads to higher economic impacts and damages. The conclusion from this analysis is that on the one hand, pure economic effects demonstrate positive impacts regarding the inclusion of sinks, but on the other hand, positive income effects also lead to higher non-market impacts according to temperature and sea level variations.

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Appendix A. Interrelations of WIAGEM

The model comprises three of the most important anthropogenic greenhouse gases: carbon dioxide (CO_2), covering over 80% of total forced radiation by anthropogenic greenhouse gases, methane (CH_4) and nitrous oxide (N_2O). Primarily due to human activities, the concentration of these gases in the earth's atmosphere have been increasing since the industrial revolution.

In WIAGEM, we consider the relationship between man-made emissions and atmospheric concentrations and their resulting impact on temperature and sea level. Because of the 50-year short-term analysis up to 2050, we neglect classes of atmospheric greenhouse gas stocks with different atmospheric lifetimes (usually modelled by the impulse response function) and reduced forms of the carbon cycle model developed by Maier-Reimer and Hasselmann (1987). Energy and non-energy-related atmospheric concentrations of CO_2, CH_4 and N_2O have an impact on forced radiation relative to their base year levels. Energy-related emissions are calculated according to the energy development of each period. Energy-related CO_2 emissions are considered according to the emissions coefficients of the EMF group (Table 7).

Energy-related CH_4 emissions are determined by the CH_4 emissions coefficients of gas and coal production in billions of tons of CH_4 per exajoule gas and coal production; the coefficients are taken from the MERGE model 4.0 (Manne and Richels, 1999; Tables 8 and 9).

Non-energy-related emissions cover parts of the CH_4 emissions and N_2O emissions. The global carbon dioxide emissions baseline pathway is assumed to start from 6 to 11 billion tons of carbon in 2030 which is roughly consistent with the carbon emissions projections of the IPCC reference case of medium economic growth (IPCC, 1996; Table 10).

Table 7
CO_2 coefficients

	Coal	Oil	Gas
CO_2 coefficients in billions of metric tons/exajoule	0.2412	0.1374	0.1994

Table 8
Emissions coefficients in billions of tons of CH_4 per exajoule gas production; source: MERGE 4.0

	USA	EU15	JPN	CAN	FSU	CHN	MIDE	ASIA	ROW
2000	0.187	0.493	0.000	0.225	1.005	1.170	1.377	0.468	0.982
2010	0.168	0.413	0.000	0.222	0.823	0.955	1.121	1.121	0.805
2020	0.149	0.333	0.000	0.190	0.641	0.740	0.864	0.864	0.627
2030	0.131	0.253	0.000	0.158	0.458	0.524	0.607	0.607	0.449
2040	0.112	0.173	0.000	0.126	0.276	0.309	0.350	0.350	0.271
2050	0.094	0.094	0.000	0.094	0.094	0.094	0.094	0.094	0.094

Table 9
Emissions coefficients in billions of tons of CH_4 per exajoule coal production; source: MERGE 4.0

	USA	EU15	JPN	CAN	FSU	CHN	MIDE	ASIA	ROW
2000	0.354	0.196	0.000	0.371	0.512	0.963	0.000	0.117	0.356
2010	0.354	0.196	0.000	0.371	0.512	0.963	0.000	0.117	0.356
2020	0.354	0.196	0.000	0.371	0.512	0.963	0.000	0.117	0.356
2030	0.354	0.196	0.000	0.371	0.512	0.963	0.000	0.117	0.356
2040	0.354	0.196	0.000	0.371	0.512	0.963	0.000	0.117	0.356
2050	0.354	0.196	0.000	0.371	0.512	0.963	0.000	0.117	0.356

Table 10
Non-energy-related emissions in millions of tons-1990; source: MERGE 4.0, IPCC (1996) and IEA (1998)

	USA	EU15	JPN	CAN	FSU	CHN	MIDE	ASIA	ROW
CH_4	25.8	15	1	5	7	43.2	0	46	132
N_2O	1.1	0.8	0.1	0.3	0.3	0.7	0.2	0.5	1.7

Table 11
Potential sinks enhancement in 2010 in millions of tons of carbon; source: MERGE 4.0[5]

	USA	EU15	JPN	CAN	FSU	CHN	MIDE	ASIA	ROW
Sinks 2010	50	17	0	50	34	25	25	13	250

Additionally, net changes in greenhouse gas emissions are covered from sources and removal by sinks resulting from human-induced land use change and forest activities such as aforestration, reforestration and deforestration. We use potential sinks enhancements as measured by the IPCC (1996) and used in MERGE 4.0 (Table 11).[4]

Atmospheric concentrations of CO_2, CH_4 and N_2O have impacts on the forced radiation relative to the base level:

$$\Delta F_{CO_2} = 6.3 \ln\left(\frac{CO_2}{(CO_2)_0}\right) \tag{A.1}$$

$$\Delta F_{CH_4} = 0.036((CH_4)^{0.5} - (CH_4)_0^{0.5}) - f(CH_4, N_2O) + f((CH_4)_0, (N_2O)_0) \tag{A.2}$$

$$\Delta F_{N_2O} = 0.14((N_2O)^{0.5} - (N_2O)_0^{0.5}) - f((CH_4)_0, N_2O) + f((CH_4)_0, (N_2O)_0) \tag{A.3}$$

where ΔF measured in $W\,m^{-2}$ as changes in radiative forcing of each greenhouse gas corresponding to a volumetric concentration change for each greenhouse gas relative to the base level. The CH_4–N_2O interaction term is determined by:

$$f(CH_4, N_2O) = 0.47 \ln[1 + 2.01 \times 10^{-5}(CH_4, N_2O)^{0.75} + 5.31 \times 10^{-15} CH_4(CH_4, N_2O)^{1.52}] \tag{A.4}$$

Total chances of radiative forcing F is obtained by adding each greenhouse gas radiative forcing effect. The potential temperature PT is influenced by radiative forcing with d as parameter ($d = 0.455$):

$$\Delta PT = d\Delta F \tag{A.5}$$

Actual temperature is reached by a time lag resulting from the lag of potential climate change impacts due to temper-

[4] We follow the approach of Manne and Richels (2000) and MacCracken et al. (1999) that additional sinks enhancement activities are costless. An assessment of different sink options analyses are provided by Missfeldt and Haites (2001).

[5] See Manne and Richels (2000).

Table 12
Protection costs of 1 m sea level rise in 109 US$; source: Tol (2001)

USA	EU15	JPA	CAN	FSU	CHN	ASIA	MIDE
71.38	136	63	10.79	53	171	305	5

tature changes:

$$\Delta \mathrm{AT}_{t-1} - \Delta \mathrm{AT} = t_{\mathrm{lag}}(\Delta \mathrm{PT}_t - \Delta \mathrm{AT}_t) \quad \text{(A.6)}$$

where t_{lag} is the time lag, $\Delta \mathrm{AT}_t$ measures the actual change in temperature in year t relative to the base year.

Because of the short-term 50-year analysis, sea level will change insignificantly during this time period. However, newest calculations estimate a rough linear relationship between temperature changes and sea level variations. Assuming that sea level will vary by 7 cm of 1 °C temperature change ($s = 7$), we calculate small sea level changes due to actual temperature changes: sea level variations are determined by the very rough estimates of a linear relationship between actual temperature:

$$\Delta \mathrm{SL} = s\Delta \mathrm{AT} \quad \text{(A.7)}$$

Impacts of climate change cover market and non-market damages; the former comprise all sectoral damages, production impacts, loss of welfare etc. while the latter contain ecological effects such as biodiversity losses, migration, and natural disasters. To assess impacts by climate change, we follow Tol's approach (2001) to cover impacts on forestry, agriculture, water resources and ecosystem changes as an approximation of a linear relationship between temperature changes, per capita income or GDP and protection costs due to sea level increase. Tol (2001) estimates climate change vulnerability covering a comprehensive evaluation of diverse climate change impacts. Along with sectoral impacts on agriculture, forestry, water resources and energy consumption, he covers impacts on ecosystems and mortality due to vector-borne diseases and cardiovascular and respiratory disorders. We use the assessed protection costs and an approximation of potential impacts, i.e. additional costs to the economy lowering other investments (crowding out effect). Protection costs due to sea level rise are shown in Table 12.

Aggregated impacts of climate change are evaluated by:

$$\Delta \mathrm{DAM}_t^r = \alpha_t^r \left(\Delta \mathrm{PT}_t^\beta \frac{y_t^r}{y_0^r} \right) + \mathrm{PC}_t^r \quad \text{(A.8)}$$

where DAM is the total impacts (damages), α and β are parameters, PC represents the sectoral protection costs due to sea level rise.

References

Babiker, M., et al., 2000. The Kyoto protocol and developing countries. Energy Policy 28, 525–536.

Bernstein, P.M., et al., 1999. Global impacts of the Kyoto agreement: results from the MS-MRT model. Resour. Energy Econ. 21, 375–413.

Böhringer, C., Rutherford, T., 1999. In: Hillebrand, R., Ulph, A., Welfens, P.J. (Eds.), World Economic Impacts of the Kyoto Protocol. Internalization of Economy, Environmental Problems and New Policy Options. Heidelberg, New York.

Carraro, C., Siniscalo, D., 1992. The international dimension of environmental policy. Eur. Econ. Rev. 26, 379–387.

Carraro, C., Siniscalco, D., 1993. Strategies for the international protection of the environment. J. Public Econ. 52, 309–328.

Deke, O., et al., 2001. Economic Impact of Climate Change: Simulations with a Regionalized Climate-Economy Model. Kiel Institute of World Economics, Kiel.

Edmonds, J., et al., 1999. International emissions trading and global climate change—impacts of the costs of greenhouse gas mitigation. In: Clausser, E., et al. (Eds.), Climate Change: Science, Strategies and Solutions. pp. 209–227.

Ellerman, D., 2000. Tradable Permits for Greenhouse Gas Emissions: A Primer with Particular Reference to Europe. MIT Press, Cambridge, MA.

Fullerton, D., Metcalf, G.E., 2001. Cap and Trade Policies in the Presence of Monopoly and Distortionary Taxation, MIT Joint Program on the Science and Policy of Global Change. NBER Working Paper No. w8901.

Hoel, M., et al., 1994. Efficient climate policy in the presence of free riders. J. Environ. Econ. Manage. 27, 259–274.

IPCC, 1996. Climate Change 1995: Economic and Social Dimensions. Cambridge University Press, Cambridge.

IPCC, 2001a. Special Report on Emissions Scenarios.

IPCC, 2001b. WG II Climate Change 2001: Impacts, Adaptation and Vulnerability.

Kemfert, C., 2000. Emissions Trading and its Impacts on World Economies-Contemplation of Baseline Emissions Paths and a Ceiling on Emissions Trading. Nota di Lavoro 1/2000 and Environmental Economics 15/2000.

Kemfert, C., 2001. Economy, Energy–Climate Interaction—The Model WIAGEM. Oldenburg discussion paper V226-01. Integr. Assess. Modell., submitted for publication.

Kemfert, C., Tol, R., 2001. Equity, international trade and climate policy. Int. Environ. Agreements, Politics, Law Econ. 2, 23–48.

Manne, A., Richels, R., 1999. The Kyoto Protocol: a cost-effective strategy for meeting environmental objectives? The Energy Journal, a Special Issue: The Costs of the Kyoto Protocol: a Multi-Model Evaluation, pp. 1–24.

Manne, A.S., Richels, R.G., 2000. In: Proceedings of the EMF-19 Workshop on A Multi-Gas Approach to Climate Policy—With and Without GWPs. Washington, DC.

MacCracken, C.N. et al., 1999. The Economics of the Kyoto Protocol. The Energy Journal, Special Issue of the Costs of the Kyoto Protocol: A Multi-Model Evaluation, pp. 25–71.

McKibbin, W., Wilcoxen, P., 1999. Permit Trading under the Kyoto Protocol and Beyond. EMF/IEA/IEW Workshop, International Energy Agency, Paris, The Brookings Institutions.

Maier-Reimer, E., Hasselmann, K., 1987. Transport and storage of CO_2 in the ocean—an inorganic ocean-circulation carbon cycle model. Clim. Dynam. 2, 63–90.

Missfeldt, F., Haites, E., 2001. The potential contribution of sinks to meeting Kyoto protocol commitments. Environ. Sci. Policy 4, 269–292.

Nordhaus, W.D., Yang, Z., 1996. RICE: a regional dynamic general equilibrium model of optimal climate change policy. Am. Econ. Rev. 86, 741–765.

Peck, S.C., Teisberg, T.J., 1991. CETA: a model for carbon emissions trajectory assessment. Energy J. 13, 55–77.

Tietenberg, T., et al., 1999. International Rules for Greenhouse Gas Emissions Trading Defining the Principles, Modalities, Rules and Guidelines for Verification, Reporting and Accountability, UN.

Tol, R.S.J., 1998. Short-term decisions under long-term uncertainty. Energy Econ. 20, 557–569.

Tol, R.S.J., et al., 2000. Technology diffusion and the stability of climate coalitions. FEEM working paper 20, 2000.

Tol, R.S.J., 2001. New estimates of the damage costs of climate change. Part II. dynamic estimates, environmental. Environ. Resour. Econ. 1, 22–43.

Weyant, J.P., Hill, J.N., 1999. The Costs of the Kyoto Protocol: A Multi-Model Evaluation—Introduction and Overview. The Energy Journal, A Special Issue: The Costs of the Kyoto Protocol: A Multi-Model Evaluation, pp. vii–xiiv.

Woerdman, E., 2000. Implementing the Kyoto protocol: why JI and CDM show more promise than international emissions trading. Energy Policy 28, 29–38.

Zhang, Z., 2001. The liability rules under international GHG emissions trading. Energy Policy 29, 501–508.

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