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Emissions trading beyond Europe: Linking schemes in a post-Kyoto world

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Abstract

This paper assesses the economic impacts of linking the EU emissions trading scheme (ETS) to emerging schemes beyond Europe in the presence of a post-Kyoto agreement in 2020. Numerical simulations with a multi-country equilibrium model of the global carbon market show that linking the European ETS induces only minor economic benefits. As trading is restricted to energy-intensive companies that are assigned high initial emissions, the major compliance burden is carried by the non-trading industries excluded from the linked ETS. In the presence of parallel government trading under a post-Kyoto Protocol, the burden of the excluded sectors can be substantially alleviated by international permit trade at the country level. However, the parallel carbon markets of linked ETS companies and post-Kyoto governments are still separated here. From an efficiency perspective, the most desirable future climate policy regime is thus represented by a joint trading system facilitating international emissions trading between ETS companies and post-Kyoto governments. While the Clean Development Mechanism is not able to attenuate the inefficiencies within linked ETS, in a parallel or joint trading regime the economy-wide access to project-based abatement options in developing countries induces large additional cost-savings.
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1. Introduction

By the initiation of the European greenhouse gas emissions trading scheme in January 2005, for the first time international trading of carbon emissions allowances became feasible for energy-intensive companies at the installation level. Introducing the largest multi-country emissions trading

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scheme (ETS) world-wide, the EU aims at cost-efficient compliance with the reduction commitments of its Member States under the Kyoto Protocol (UNFCCC, 1997). In the future, carbon trading will however not be limited to Europe: The EU ETS directive proposes that "agreements should be concluded with third countries listed in Annex-B to the Kyoto Protocol which have ratified the Protocol to provide for the mutual recognition of allowances between the Community scheme and other greenhouse gas emissions trading schemes" (EU, 2003). At the same time, countries beyond the EU are contemplating the set up of domestic ETS with the intention of linking up to the European scheme — which would enable companies outside the EU to trade emissions with European firms. From 2008 on, company trading among linked schemes would however occur in parallel with trading among countries, as the Kyoto Protocol facilitates international government trading of emissions between Annex-B parties at the country level. To quantify the economic implications of these overlapping future climate policies is the goal of this paper.

Developments of domestic ETS outside the EU have already made substantial progress in Norway and Switzerland who are designing schemes similarly to the European system. Since discussions on linking are already underway, chances are high that these countries will already be linked to the EU ETS until 2010 (Sterk, 2005). In the medium-term perspective up to 2020, further candidates for linking to the EU ETS appear on the stage: Canada has promoted the Large Final Emitter System to cover energy-intensive companies which account for almost 50% of total Canadian greenhouse gas emissions (CEPA Environmental Registry, 2005). The scheme aims to be based on intensity targets and to include a "Price Assurance Mechanism" capping allowance costs at 15 Canadian dollars. Japan has started the Pilot Project of Domestic emissions trading scheme on a voluntary basis, with about 30 private companies participating in the program (Japanese Ministry of the Environment, 2004). Russia – having ratified the Kyoto Protocol – could have incentives to develop a domestic emissions trading system in order to be linked to the European scheme and exploit a larger market for the sale of excess emissions permits – so-called "Hot Air" – due to lower *Business-as-Usual* (BAU) than target emissions committed to.

Although the United States and Australia have not ratified the Kyoto Protocol, individual states in both countries are promoting emissions trading schemes: In the U.S. the Regional Greenhouse Gas Initiative, aiming at a regional ETS, is pushed by several Northeast and Mid-Atlantic states (RGGI, 2006). In Australia the New South Wales Greenhouse Gas Abatement Scheme is already operating at the state level (NSW government, 2006) and more recently, Australian state premiers have released early proposals for a national cap and trade system starting in 2010 (Point Carbon, 2006). Also these schemes could quickly arouse interest in EU-ETS decision makers, as "the Commission should examine whether it could be possible to conclude agreements with countries listed in Annex-B to the Kyoto Protocol which have yet to ratify the Protocol" (EU, 2004). In summary: There are strong signs for future ETS to be established in non-EU countries and potentially linked with the European scheme by 2020.

At the same time, three flexible mechanisms proposed by the Kyoto Protocol will facilitate various emissions market operations by Annex-B parties from 2008 on: International emissions trading makes government trading of *Assigned Amount Units* (AAUs) possible at the country level; the Clean Development Mechanism (CDM) enables project-based emissions reductions in developing countries in order to generate *Certified Emission Reductions* (CERs), and Joint Implementation (JI) facilitates project-based abatement in other Annex-B regions, generating *Emission Reduction Units* (ERUs).

However, the use of the project-based mechanisms will not be restricted to governments: The amending directive linking the European ETS with the Kyoto Protocol's project-based mechanisms (EU, 2004) allows European companies to generate emissions reductions by means of the CDM or JI.

Imports of CDM and JI credits may serve as substitutes for ETS allowances since they are interchangeable with the European allowances. Moreover, EU ETS allowances are simultaneously labeled as Kyoto units (AAUs). Consequently, four types of emissions reduction credits – ETS allowances, Kyoto units, CDM and JI credits – may be used by countries to comply with their reduction commitments under the Kyoto Protocol. This paper analyzes these parallel climate policies due to regulation at the country and installation level by both emissions trading and project-based crediting.

Previous studies have assessed the economic aspects of international emissions trading schemes both in theoretical and applied model frameworks. Rehdanz and Tol (2005) consider the coordination of domestic carbon permit markets in which countries determine their own emissions reduction targets. Using a theoretical two-country model they find that linking such schemes benefits both countries but may cause the exporting country to decrease its emissions reduction target and increase permit exports. Quantitative studies have on the one hand focused on efficiency aspects of segmented carbon markets under the current European ETS in partial or general equilibrium frameworks (see Böhringer et al., 2005 or Peterson, 2006), and on interactions between the European ETS and the project-based Kyoto mechanisms (Klepper and Peterson, 2006b). These studies find that hybrid emissions regulation (i.e. EU emissions trading in energy-intensive sectors and complementary domestic emissions regulation for the remaining segments) may lead to substantial excess costs — as compared to a comprehensive emissions trading system covering all segments of the economy or an emissions tax imposed unilaterally by each Member State. Moreover, they find that unlimited access to emissions abatement via CDM and JI substantially contributes to reducing the costs of meeting the European Kyoto targets. On the other hand, economic impacts of country-level trading under the Kyoto Protocol have been assessed through multi-model evaluations (see Springer, 2003 or Weyant and Hill, 1999), partly focusing on the economic potential of the CDM and associated investment barriers (Anger et al., 2007). While these studies focus *either* on the present EU ETS *or* government trading in the first commitment period of the Kyoto Protocol, a comprehensive simultaneous assessment of these parallel regulations in a future climate policy regime is still lacking.

Against this background, the contribution of the present paper is threefold: In a quantitative approach it (i) addresses the economic impacts of company-based emissions trading *beyond* the European ETS by linking to emerging non-EU schemes, (ii) analyzes the efficiency implications of linkage in the presence of *parallel* country-level trading and the CDM under a post-Kyoto regime, and (iii) introduces a possible *joint* future trading system between ETS companies and Kyoto governments. Based on a numerical multi-country, two-sector partial equilibrium model of the world carbon market economic impacts are assessed quantitatively.[1] The model features explicit marginal abatement cost functions for 2020 calibrated to energy-system data and considers transaction costs and investment risk for CDM host countries.

The remainder of this paper is organized as follows. In Section 2, the theoretical background for the analysis is derived. Section 3 lays out the numerical framework for the subsequent policy assessment. Section 4 specifies illustrative scenarios of climate policy in 2020. Quantitative simulation results are presented in Section 5 and Section 6 concludes.

2. Theoretical background

The theoretical foundations of the numerical simulation model employed in the next section can be derived by a simple analytical model of the emissions market. Given the heterogeneous

[1] Note that this analysis focuses on emissions trading of carbon dioxide as the most important greenhouse gas.

emissions reduction commitments under the Kyoto Protocol, first the analysis will focus on the emissions market behavior of countries with alternative reduction targets. Second, the efficiency aspects of emissions trading among ETS companies and governments will be discussed. Third, the parallel existence of linked ETS and government trading is introduced. In a stylized setting, R regions are assumed ($r=1,\ldots, R$) committing to individual emissions targets (e.g. targets under the Kyoto Protocol), yielding absolute emissions budgets $\bar{E}_r$ for each region. Abatement costs of energy-intensive sectors (in the following referred to as EIS) and non-energy-intensive sectors (in the following referred to as NEIS) in each region are denoted by $AC_r^{\text{EIS}}(e)$ and $AC_r^{\text{NEIS}}(e)$ respectively. Cost functions are decreasing, convex and differentiable in emissions e. Total abatement costs $\text{AC}_r(E_r)$ are the sum of sectoral costs $\text{AC}_r^{\text{EIS}}(e_r^{\text{EIS}})$ and $\text{AC}_r^{\text{NEIS}}(e_r^{\text{NEIS}})$.

2.1. Emissions market behaviour

On a competitive market for emissions R regions are considered, committing to alternative emissions targets. A region committing to a binding (absolute) emissions target $\bar{E}_r$ aims to minimize its total abatement costs for complying with its commitment. Moreover, it may either buy emissions permits from other committing regions (or import them from CDM and JI host countries) or sell them at the exogenous world-market price s, yielding the following cost minimization problem:

$$\min_{e_r^{\text{EIS}}, e_r^{\text{NEIS}}} \left[\text{AC}_r^{\text{EIS}}\left(e_r^{\text{EIS}}\right) + \text{AC}_r^{\text{NEIS}}\left(e_r^{\text{NEIS}}\right) + \sigma\left(e_r^{\text{EIS}} + e_r^{\text{NEIS}} - \bar{E}_r\right)\right]. \tag{1}$$

Here, a positive (negative) term $e^{\text{EIS}}+e^{\text{NEIS}}-\bar{E}_r$ implies that a region is an importer (exporter) of emissions permits. A region without a binding emissions target, such a CDM host country, aims to maximize its revenues from permit sales $\sigma(\bar{E}_r-e_r^{\text{EIS}}-e_r^{\text{NEIS}})$ less abatement costs from reducing emissions below the target $\bar{E}_r$ (which for these countries equals BAU emissions) and generating the respective credits. Its profit maximization problem directly corresponds to the cost minimization problem of condition (1): CDM host countries aim to minimize total abatement costs for credit generation and (negative) import costs (i.e. maximize revenues from permit exports).[2]

Consequently, for all regions cost minimization or profit maximization with respect to e_r^{EIS} and e_r^{NEIS} yields the following first-order condition:

$$\sigma = -\frac{\partial \text{AC}_r^{\text{EIS}}}{\partial e_r^{\text{EIS}}} = -\frac{\partial \text{AC}_r^{\text{NEIS}}}{\partial e_r^{\text{NEIS}}} = -\frac{\partial \text{AC}_r}{\partial \left(e_r^{\text{EIS}} + e_r^{\text{NEIS}}\right)}. \tag{2}$$

For each region and sector marginal abatement costs equal the permit price s and are thereby equalized across all emissions sources. A competitive emissions market therefore ensures that optimizing behavior of individual market participants with heterogeneous reduction commitments (such as parties of the Kyoto Protocol) and without any commitments (such as CDM host countries) leads to the aggregate cost-efficient solution of equalized marginal abatement costs. Optimal emissions can then be derived as E_r^*, $e_r^{\text{EIS}^*}$, $e_r^{\text{NEIS}^*}$ where $E_r^*=e_r^{\text{EIS}^*}+e_r^{\text{NEIS}^*}$. The difference between the total emissions budget $\bar{E}_r$ and aggregate optimal emissions E^* yields the optimal total trade volume in emissions permits.

[2] Since at a positive permit price any emissions reduction below the BAU level results in revenues from permit sales exceeding abatement costs, i.e. in profits, it can be assumed that for this region $e_r^{\text{EIS}}+e_r^{\text{NEIS}}<\bar{E}_r$ holds and no permits will be imported.

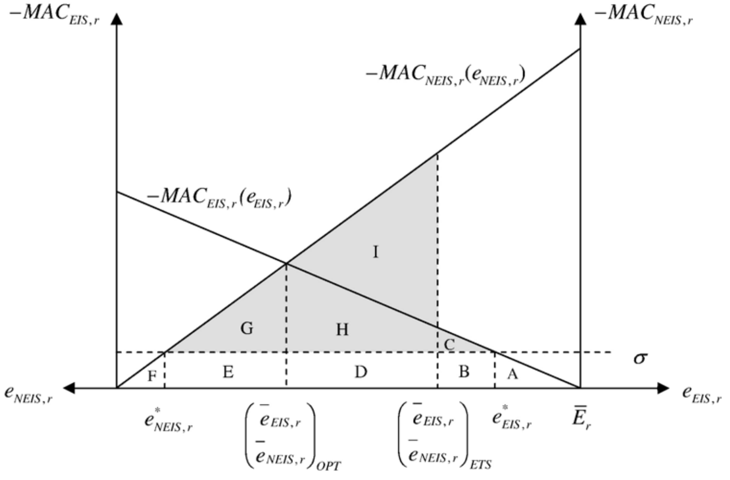

Fig. 1. Efficiency gains from international emissions trading under alternative regimes.

2.2. Efficiency implications of alternative trading regimes

Besides the emissions market behaviour of countries with alternative reduction targets, regions with binding commitments may face different compliance costs when deciding for government trading at the country level (in the following referred to as Kyoto trading) or company trading among linked emissions trading schemes (in the following referred to as ETS trading). In order to assess the economic impacts of parallel climate policies, first the two trading systems shall be contrasted theoretically. Fig. 1 illustrates the corresponding efficiency aspects from a sectoral perspective – for transparency, in the absence of CDM and JI – in terms of compliance costs.

The figure presents the economic impacts of the two trading schemes for a representative region r with energy-intensive and non-energy-intensive sectors and – for simplicity linear – respective marginal abatement costs $\mathrm{MAC}_{\mathrm{EIS},r}$ ($e_{\mathrm{EIS},r}$) and $\mathrm{MAC}_{\mathrm{NEIS},r}$ ($e_{\mathrm{NEIS},r}$). Marginal abatement costs for NEIS are assumed to be generally higher than for EIS (see Section 3.3 for a numerical underpinning and more complex functional forms). Equal maximum emissions are assumed for EIS and NEIS.

ETS trading currently implies a national allocation of permits $(\bar{e}_{\mathrm{EIS},r}, \bar{e}_{\mathrm{NEIS},r})_{\mathrm{ETS}}$, representing a relatively generous allocation to covered industries as compared to the optimal national allocation $(\bar{e}_{EIS,r}, \bar{e}_{\mathrm{NEIS},r})_{\mathrm{OPT}}$ (see also Section 3.2). Given a world-market permit price σ arising from the international trading activities among EIS, and a national emissions target $\bar{E}_r$, EIS face costs equal to areas A+B in order to comply with the emissions target implied by their sectoral budget. This yields internationally optimal emissions $e^*_{EIS,r}$, permit imports equal to $e^*_{EIS,r}-(\bar{e}_{\mathrm{EIS},r})_{\mathrm{ETS}}$ and cost-savings from international emissions trading equal to area C. NEIS face abatement costs equal to areas D+E+F+G+H+I in order to reach the sectoral target, yielding emissions $\bar{e}_{\mathrm{NEIS},r}$. For NEIS no cost-savings from international emissions trading occur since they do not participate in the trading scheme. Consequently, in the case of internationally linked ETS total compliance costs equal areas A+B+D+E+F+G+H+I including cost-savings from international emissions trading equal to *C*.

While ETS trading exclusively covers energy-intensive industries, country-level (Kyoto) trading *de facto* involves the entire economy. For transparency, in this case the same initial emissions allocation and the same world-market permit price as under ETS trading is assumed.

While for EIS the same efficiency implications as under ETS trading hold, NEIS may now participate in international emissions trading, facing compliance costs equal to areas D+E+F in order to reach the sectoral target. This yields optimal emissions $e^*_{\mathrm{NEIS},r}$ and cost-savings from international emissions trading equal to areas G+H+I. Consequently, in the case of international trading at the country level total compliance costs equal areas A+B+D+E+F including cost-savings from international emissions trading equal to G+H+I+C (highlighted).

In summary, Kyoto trading at the country level shows a large efficiency advantage over ETS trading. While the former yields optimal emissions levels by sector – independent of the national emissions allocation by sector – through unrestricted international emissions trading, the latter implies an exclusion of NEIS from international emissions trading *and* a generous allocation of permits to included EIS. Higher marginal abatement costs of NEIS as compared to EIS and large abatement efforts of non-trading NEIS induced by the allowance allocation explain the magnitude of this efficiency advantage.[3]

The project-based mechanisms CDM and JI could serve as an important substitute for high-priced emissions permits within the respective trading systems. The potential efficiency gains would however depend on relative permit prices of alternative policy regimes: Only for decreasing world-market prices through the inclusion of CDM and JI the cost-savings from international emissions trading (areas G+H+I and area C) can be increased.

2.3. Parallel existence of trading regimes

While the previous section focused on contrasting ETS trading to Kyoto trading from an efficiency perspective, this section presents the emissions market implications of a *parallel* existence of these two trading regimes. This is only the case if a post-Kyoto climate policy agreement establishes international government trading at the country level. A domestic ETS exclusively covering energy-intensive installations enables the respective companies to trade emissions internationally with other covered EIS companies. In the case of a coexisting Kyoto trading regime at the country level, a reasonable assumption is that no double regulation of industries covered by a national ETS takes place. Kyoto trading then only applies to the remaining industries of each region, i.e. takes place between the uncovered non-energy-intensive industries. From an intuitive perspective, trading between NEIS should be interpreted as trading activities of national governments *representing* these sectors. Fig. 2 extends the unilateral perspective of Fig. 1 by introducing an additional world region (yielding two regions, 1 and 2) with two sectors.

In the figure, regional marginal abatement costs are denoted by $\mathrm{MAC}_{\mathrm{NEIS},1}(e_{\mathrm{NEIS},1})$ and $\mathrm{MAC}_{\mathrm{NEIS},2}(e_{\mathrm{NEIS},2})$. The marginal abatement cost functions of region 2 represent more costly options than of region 1. For transparency, maximum total emissions of both regions are equal and both allocate the same amount of emissions allowances $(\overline{e}_{\mathrm{EIS},r}, \overline{e}_{\mathrm{NEIS},r})_{\mathrm{ETS}}$ to the two sectors. As there is no interconnection between the ETS and Kyoto emissions markets, there are two permit prices (σ_{EIS} and s_{NEIS}) arising from the sectoral market interactions — the price under Kyoto trading among NEIS (with more costly abatement options) resulting higher than from ETS trading among EIS. On the emissions market, region 2 is importing permits from region 1 in each sector: International trading activities of EIS under (linked) ETS trading equalize marginal abatement costs of the two regions, yielding efficiency gains in terms of export benefits for region 1 and

[3] The illustration of Fig. 1 applies to regions with relatively high marginal abatement costs, i.e. regions that are net buyers of emissions permits at the world market. A higher international permit price could transform a region into a net permit seller. The presented economic reasoning could however be applied analogically.

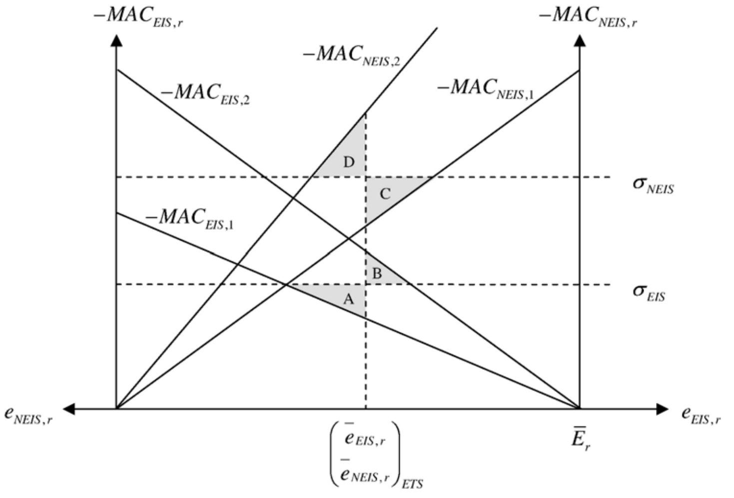

Fig. 2. Efficiency gains from parallel international emissions trading.

abatement cost-savings for region 2 (see areas A and B in Fig. 2). In parallel, permit export benefits and cost-savings from Kyoto trading apply to NEIS of the two regions (see areas C and D). As compared to the initial allocation, the low-cost region 1 emits less, while region 2 increases emissions. In this parallel-regime setting, Kyoto trading may serve as a compensation mechanism for the inefficiencies of ETS trading and the otherwise large compliance costs of NEIS.

Unlimited access to the project-based mechanisms CDM and JI may establish a connection between the otherwise separated (parallel) carbon markets. If both EIS and NEIS of trading regions have access to the international pool of project-based credits, for a lower CER price than the world-market prices for emissions permits the CDM may de facto interconnect the two segments internationally and induce full where-flexibility. In contrast, a potential restriction of CDM access would decrease the chances of such efficiency gains.

3. Numerical specification

3.1. Baseline emissions and a post-Kyoto regime

This section summarizes baseline emissions and reduction commitments associated with a potential post-Kyoto climate policy regime. Baseline (i.e. BAU) carbon dioxide emissions trajectories are based on Van Vuuren et al. (2006) who provide a nationally downscaled dataset from the implementation of global IPCC-SRES scenarios (IPCC, 2001) into the environmental assessment model IMAGE 2.2. Emissions reduction targets represent a possible post-Kyoto regime building on the Kyoto Protocol, in which industrial countries agreed on cutting greenhouse gas emissions by 5.2% on average during 2008–2012 as compared to 1990 levels. For this reason, the derivation of post-Kyoto reduction commitments in the year 2020 starts from 2010 as the central year of the protocol's first commitment period.[4] Generally 2020 is chosen as the reference year here, since

[4] The assumption of an existing binding international agreement in 2020 building on the Kyoto Protocol abstracts from long-term stability aspects of such agreements. For a comprehensive introduction into related game-theoretic approaches to international environmental agreements see Finus (2001).

domestic emissions trading schemes can be expected to be developed and linked on the global level only in the medium-term.

Emissions reduction targets in 2010 for countries that have ratified the agreement correspond to the targets outlined in Annex-B of the protocol. For EU Member States the aggregate eight percent target under Kyoto is redistributed according to an internal Burden Sharing Agreement (EU, 1999). Regarding non-ratifying Annex-B parties, the United States national commitment to reduce its greenhouse gas intensity (i.e. emissions levels per GDP) by 18% by 2012 is translated into an absolute requirement (White House, 2002). Australia is assigned its Kyoto target as the government intends to comply with this commitment despite non-ratification of the Protocol (Commonwealth of Australia, 2002). For non-Annex-B regions no emissions reduction commitments are assumed, as developing countries have so far refrained from assuming any quantified targets under the Kyoto Protocol. As the inclusion of these countries under the CDM requires a baseline, developing regions are assigned their BAU emissions.

Reduction commitments in 2020 are then extrapolated from the 2010 targets: For EU Member States, in 2020 an aggregate emissions reduction of 15% versus 1990 levels is assumed, which represents the lower bound of a recently proposed range of 15–30% (Council of the EU, 2005). It is further assumed that all EU Member States have to contribute the same relative proportion to this aggregate target as in 2010. Emissions reduction commitments of non-EU industrial countries in 2020 are derived from the EU-wide rate of reduction. As these countries have committed to lower reduction targets than the EU in 2010, they are assumed to also exhibit a less ambitious pace of reduction: Emissions reduction rates from 2010 to 2020 are five percentage points below the EU-wide rate of reduction in the same period. Similar to the year 2010, developing countries are assumed to not have committed to any quantified reduction targets in 2020.

Table 3 in Appendix A.1 lists regional carbon dioxide emissions from energy and industry for 1990 (the reference year of the Kyoto commitments), as well as projected emissions for 2010 and for 2020. The table further shows the resulting emissions reduction requirements in 2010 and 2020 versus to 1990 emissions levels, as well as the effective reduction requirements in 2020 versus BAU emissions levels in 2020. The table illustrates regional emissions reduction requirements to be very heterogeneous but to become stricter for all regions when moving from 2010 to 2020. The negative reduction requirement of the Former Soviet Union in 2020 versus BAU levels reflects excess emissions permits – so-called "Hot Air" – due to lower projected BAU emissions than the target level implied by its reduction commitment in 2020.

3.2. Allocation of emissions allowances in 2020

At present the EU emissions trading directive exclusively covers energy-intensive installations while the remaining industries of EU economies such as households or the transport sector have to be regulated by complementary abatement policies in order to meet the countries' overall emissions budgets. One reason for the exclusive sectoral coverage are administrative and monitoring tasks within the scheme. In the absence of a potential use of CDM and JI, domestic policies may include e.g. emissions taxes or subsidies for renewable energy use. If the allocation to covered sectors is relatively generous and these sectors feature relatively low-cost abatement options, such a hybrid regulation may cause large inefficiencies: The market segmentation then restricts potential efficiency gains from where — flexibility of international emissions trading and shifts abatement to costly reduction options of non-trading sectors (Böhringer et al., 2005). As the Canadian or Japanese proposals also aim to include mainly energy-intensive industries, the European ETS could likely serve as a "blueprint" for emerging non-EU schemes.

The EU directive prescribes the allocation of emissions allowances to installations according to historic levels by means of National Allocation Plans (NAPs) of the respective Member States, specifying an overall cap in emissions for the covered sectors. Emissions allocation can be described by *allocation factors* as the fraction of baseline emissions that are freely allocated in terms of emissions allowances. In this paper, allocation factors for EU Member States in the year 2020 are derived from a recent study on European emissions allocation in 2005 (Gilbert et al., 2004). The 2005 values, which are presented in Table 4 of Appendix A.1, were then extrapolated to the year 2020 assuming a 20% decrease of values in 2020 compared to the year 2005.[5] Consistently, also for non-EU regions allocation factors in 2020 represent a 20% decrease as compared to 2005. For these regions, 2005 "benchmark" allocation factors of equal to one were conservatively chosen according to the lowest EU factors, as the EU scheme is likely to serve as a blueprint for emerging trading systems outside Europe. The base year for emissions allocation reflects the target year of reduction requirements. Table 4 lists the corresponding allocation factors by region and year.

The table shows that the current allocation implies very low reduction efforts for energy-intensive sectors due to a relatively generous allocation of emissions (for political-economy determinants of inefficiencies in current environmental policy see Anger et al., 2006). Note that for the Former Soviet Union allocation factors in 2010 and 2020 are based on the reasoning that the region's excess permits – due to lower BAU emissions than the target level implied by its reduction commitment in the respective year – are allocated to energy-intensive installations proportionally to the corresponding sectors' share of emissions in the entire economy's emissions.[6] Moreover, for some regions the level allocation factors was assigned a minimum value so that EIS at most account for the national effective emissions reduction requirement (this holds for the regions Sweden, Central Europe and the United States).

3.3. Model implementation and marginal abatement costs

To assess the magnitude of economic impacts caused by parallel trading regimes including the CDM for a greater number of regions than in Section 2, a numerical multi-country equilibrium model of the world carbon market is applied. Empirical data on baseline emissions and emissions allocation, as presented in the previous sections, is implemented into the numerical framework. In order to account for real-world complexities, the model incorporates calibrated marginal abatement cost functions and explicitly divides the regional economies into energy-intensive sectors (EIS) and remaining industries (NEIS). Building on the EU-wide version of Böhringer et al. (2005), the extended model explicitly features separated (parallel) carbon markets for ETS and Kyoto trading, incorporates CDM host countries as well as CDM access restrictions, and is calibrated to represent the world carbon market in the year 2020. An algebraic formulation is given in Appendix A.2.[7]

To generate marginal abatement cost functions by region and sector, data simulated by the well-known energy-system model POLES is used (Criqui et al., 1999), which explicitly covers energy technology options for emissions abatement in various world regions as well as in energy-

[5] This assumption is in line with the European Commission's planned shortage of the EU's total emissions allocation in the second ETS period (from 2008 on) to some six percent below the first ETS period allocation (EU, 2005). For simplicity it is further assumed that the sectoral coverage by domestic ETS of all regions in 2020 corresponds to the current EU ETS coverage.

[6] The assumption of excess permit allocation to installations will be relaxed in Section 5.4.

[7] Note that in this analysis, installation-based trading is implemented as trading at the sectoral level.

Table 1
Regional scenarios for 2020

Regional scenario	Regions participating in emissions trading	CDM regions
EU	EU-27	Brazil, China, India, Mexico, South Korea
EU^{+}	EU-27, Japan, Canada, Former Soviet Union	
EU^{++}	EU-27, Japan, Canada, Former Soviet Union, Pacific OECD, United States	

intensive sectors (EIS) and remaining industries (NEIS) for the base-year 2020. In the POLES simulations a sequence of carbon taxes (e.g. 0 to 400 US$/ton of carbon) is imposed on the respective regions, resulting in associated sectoral emissions abatement.

To estimate the coefficients for marginal abatement cost functions in 2020, an ordinary least squares (OLS) regression of tax levels (i.e. marginal abatement costs) on associated emissions abatement is employed. Following Böhringer et al. (2005), in order to assure for functional flexibility a polynomial of third degree is chosen as the functional form of marginal abatement cost functions.[8] For region r and sector i this results in the following equation:

$$-\mathrm{MAC}_{ir}(e_{ir}) = \beta_{1,ir}(e_{0ir} - e_{ir}) + \beta_{2,ir}(e_{0ir} - e_{ir})^2 + \beta_{3,ir}(e_{0ir} - e_{ir})^3 \quad (3)$$

with MAC_{ir} as marginal abatement cost in region r and sector $i \in \{\mathrm{EIS, NEIS}\}$, $\beta_{1,ir}$, $\beta_{2,ir}$ and $\beta_{3,ir}$ as marginal abatement cost coefficients, $^{e}{}_{0ir}$ as baseline emissions level and e_{ir} as emissions level after abatement. Table 5 in Appendix A.1 shows the resulting least-square estimates of marginal abatement cost coefficients by region and sector in 2020.[9]

4. Scenarios of future climate policy

In the following, scenarios of linking emissions trading schemes in the presence of a post-Kyoto agreement in 2020 are specified. The scenarios can be classified by two dimensions: The *regional* dimension distinguishes scenarios of countries that establish a climate policy regime, whereas the *institutional* dimension distinguishes alternative schemes of carbon regulation. Table 1 presents the three regional scenarios: As a reference case, scenario EU represents EU ETS participants in 2020, i.e. current members of the European Union including the recently acceded countries Bulgaria and Romania.[10] Scenario *EU*$^{+}$ indicates the potential linkage of the current EU ETS to emerging ETS in countries that ratified the Kyoto Protocol: Japan, Canada and the Former Soviet Union. Scenario *EU*$^{++}$ assumes linking the current EU ETS not only to Kyoto ratifiers but to emerging ETS in countries that have not ratified the Kyoto Protocol, such as Australia and the United States. For all regional scenarios

[8] We use the OLS approach as a standard estimation technique, which for our data yields parameter estimations with a high overall goodness-of-fit. Clearly alternative estimation approaches and functional forms could be chosen here.We use the OLS approach as a standard estimation technique, which for our data yields parameter estimations with a high overall goodness-of-fit. Clearly alternative estimation approaches and functional forms could be chosen here.

[9] The marginal abatement cost coefficients have the following units: $\beta_{1,ir}$ [(€ 2005/tCO_2)/($MtCO_2$)], $\beta_{2,ir}$ [(€ 2005/tCO_2)/($MtCO_2$)^2] and $\beta_{3,ir}$ [(€ 2005/tCO_2)/($MtCO_2$)^3].

[10] Note that the region EU-27 is approximated by EU-15 Member States (excluding Luxemburg) and the POLES model region Central Europe, which essentially covers new Member States as well as Bulgaria and Romania.

Table 2
Institutional scenarios for 2020

Institutional scenario	CO_2 regulation		International emissions trading		CDM access	
	EIS	NEIS	EIS with	NEIS with	EIS	NEIS
NOTRADE	Tax	Tax	None	None	No	No
ETS	Permits	Tax	Foreign EIS	None	No	No
ETS_CDM					Unlimited	No
ETS_SUP					10% of allocation	No
PARALLEL	Permits	Permits	Foreign EIS	Foreign NEIS	No	No
PARALLEL_CDM					Unlimited	Unlimited
PARALLEL_SUP					10% of allocation	50% of reduction
JOINT	Permits	Permits	Foreign EIS & foreign NEIS	Foreign EIS & foreign NEIS	No	No
JOINT_CDM					Unlimited	Unlimited
JOINT_SUP					50% of national reduction	

alike five central developing countries are assumed to host CDM projects, representing major suppliers on the CDM carbon market (World Bank, 2006): China, India, Brazil, Mexico and South Korea.[11]

Table 2 lists institutional scenarios which in total involve ten cases. As a reference case, *NOTRADE* represents cost-efficient domestic action by the respective regions, e.g. by sectorally uniform domestic carbon taxation. Clearly this scenario should not be interpreted as a representation of real-world climate policy in the absence of emissions trading, but as an economically efficient reference case. In order to assess linked emissions trading schemes, scenario *ETS* describes international emissions trading only between energy-intensive companies (i.e. sectors), reflecting hybrid regulation with permits and taxes and assuming the sectoral emissions allocation in 2020 shown in Table 4 of Appendix A.1. For transparency, this setting abstracts from the existence of a country-level trading regime. Scenario *PARALLEL* introduces government trading under a post-Kyoto Protocol, existing in parallel to the linked emissions trading schemes (and for the sake of illustration, applying only to the linked regions). This regime assumes a post-Kyoto climate policy agreement establishing international trading at the country level. In such a setting of coexisting trading regimes, a reasonable assumption is that no double regulation of industries covered by a national ETS takes place — Kyoto trading then only applies to the remaining industries of each region.[12] Consequently, *PARALLEL* describes ETS trading for energy-intensive sectors, while it assumes Kyoto trading among the remaining non-energy-intensive sectors.[13] Finally, scenario *JOINT* represents a potential interconnection between ETS and Kyoto trading: International emissions trading both among energy-intensive sectors via companies and among countries via governments and *between* companies and governments. This institutional setting is equivalent to international trading across all sectors and regions, except of intranational and international trading between different sectors.

Regarding CDM and JI, the Marrakech Accords to the Kyoto Protocol demand that “the use of the mechanisms shall be supplemental to domestic action” (UNFCCC, 2002). Although the Marrakech formulation lacks precision, one attempt to quantify a CER import limit was made by

[11] The present analysis focuses on the CDM as a project-based mechanism, as JI projects are hosted by Annex-B parties who participate in international emissions trading. Abstracting from its project-based character, JI may therefore be represented by international emissions trading of the respective regions.

[12] As in Section 2.3, trading between NEIS should be interpreted as trading activities of national governments *representing* their non-energy-intensive sectors.

[13] Here it is assumed that each ETS region has committed to a post-Kyoto agreement enabling government emissions trading.

the European Union, essentially stating that no more than 50% of an Annex-B party reduction commitment may be fulfilled by imports from the project-based mechanisms (Langrock and Sterk, 2004). Besides the supplementarity issue under the Kyoto Protocol regarding government trading, there is a separate supplementarity debate regarding installation-based trading: The EU ETS amending directive states that “Member States may allow operators to use CERs and ERUs from project activities in the Community scheme up to a percentage of the allocation of allowances to each installation” (EU, 2004). Also in the EU ETS amending directive no quantitative limit for the import of CDM and JI credits is specified and it is the obligation of each Member State to ensure that the use of the Kyoto mechanisms is supplemental to domestic action by means of its national allocation plan. However, in a recent communication to the European Parliament the Commission states that it will assess consistency with supplementary obligations based on an import limit of ten percent of a Member State’s assigned emissions cap (EU, 2006).

Within the institutional scenarios for the present analysis, the following CDM regimes are applied: While the reference case *ETS_CDM* assumes the *ETS* trading regime including the option of unlimited CER imports (only) by EIS companies from conducting CDM projects, *PARALLEL_CDM* and *JOINT_CDM* represent the respective regime with unlimited CDM access for governments, i.e. all sectors. Supplementarity considerations are taken into account by three scenarios: *ETS_SUP* restricts CER imports of energy-intensive industries to ten percent of allocated permits. *PARALLEL_SUP* reflects a sectorally differentiated supplementarity rule, limiting CDM access of EIS to ten percent of allocated allowances, while regulating that in NEIS a maximum of 50% of the (sectorally downscaled) NEIS emissions reduction commitment may be fulfilled via the CDM. Finally, *JOINT_SUP* assumes one uniform CDM restriction across all sectors, i.e. a 50% maximum CDM import share of the national reduction commitment, as sectors are de facto interconnected via joint trading.[14]

The model considers the following barriers to CDM projects: First, it features transaction costs for the purchase of CERs of 0.5 US$ (1 US$)/ton of CO_2 for energy-intensive (non energy-intensive) sectors of CDM host countries.[15] Second, following Böhringer and Löschel (2002) country-specific investment risk for CDM projects, e.g. from country and project risks, is derived by CDM-region-specific bond-yield spreads between long-term government bonds of the respective developing country and the United States (as a risk-free reference region). It is assumed that investors are risk-neutral and discount the value of emissions reduction credits generated by CDM projects with the mean risk value of the respective host country. The underlying data stems from the International Monetary Fund’s International Financial Statistics (IMF, 2001). Third, a CDM adaptation tax is incorporated amounting to two percent of CER revenues as proposed under the Marrakech Accords (UNFCCC, 2002). Transaction costs, investment risk and the CDM tax enter the model via a premium on marginal abatement costs of CDM host countries, thereby increasing the international CER price.[16]

5. Simulation results

In this section, the economic impacts of linking emissions trading schemes in the presence of a post-Kyoto agreement in 2020 are simulated using the numerical multi-country equilibrium model of the world carbon market presented in Section 3.3. Regarding climate policy scenarios

[14] Regarding supplementarity rules of non-EU regions, as in the case of sectoral emissions allocation similar regulation as in the EU is assumed.

[15] The magnitude of transaction costs is in line with recent estimates (see Michaelowa and Jotzo, 2005).

[16] An alternative approach to account for barriers to CDM project development is presented in Kallbekken et al. (2006), who introduces a “participation rate” reflecting that only some share of the potentially profitable CDM projects will be implemented.

laid out in the previous section, alternative combinations of the regional and institutional dimension are implemented as scenarios in the simulation model. First, the efficiency aspects of alternative trading regimes, such as *ETS*, *PARALLEL* and *JOINT* trading schemes are assessed. Subsequently, the role of the CDM and the associated supplementarity considerations for the international carbon market are addressed.

5.1. Economic impacts of linking ETS

As a reference case, the economic impact assessment starts with the climate policy setting of linking the EU ETS with emerging schemes outside Europe in the absence of a post-Kyoto agreement establishing country-level trading and CDM. The efficiency implications are presented in terms of sectoral and total compliance costs associated with the fulfillment of national emissions reduction commitments and are contrasted to the cost-efficient *NOTRADE* reference scenario. Fig. 3 first illustrates the corresponding numerical simulation results for the EU in the institutional scenario *ETS* for various regional constellations of linked schemes (for the entire set of simulation results see Table 7 in Appendix A.3). In the figure, e.g. scenario *ETS* [EU^{+}] represents institutional scenario *ETS* in combination with regional scenario EU^{+}.

Focusing first on the European Union, it shows that for all regional constellations aggregate EU compliance costs under scenario *ETS* are drastically higher than under *NOTRADE*: Trading emissions among European energy-intensive companies – at a permit price amounting to 28.5 €/ton of CO_2 – implies substantially higher overall adjustment costs than efficient domestic action (assuming an economy-wide uniform carbon tax). This inefficiency is due to a generous emissions allocation to the (benefiting) EIS causing high reduction efforts of NEIS which are excluded from the trading scheme. Considering their high marginal abatement costs, these sectors almost account for the entire economic burden of the reduction commitment (sectoral burden shifting).

Comparing regional trading scenarios, the results suggest that linking the European ETS to other domestic schemes is not able to decrease total EU compliance costs by more than one percent (moving from *ETS* [*EU*] *to ETS* [EU^{++}]). As ETS trading exclusively covers energy-intensive sectors, only these industries benefit from an enlarged trading scheme (restricted where-flexibility). The essential part of the economic burden is carried by non-trading sectors and cannot be reduced by linking ETS.

The economic impacts for non-EU countries from linking to the EU scheme are very heterogeneous: Linking of Canada, Japan and the Former Soviet Union (yielding regional scenario

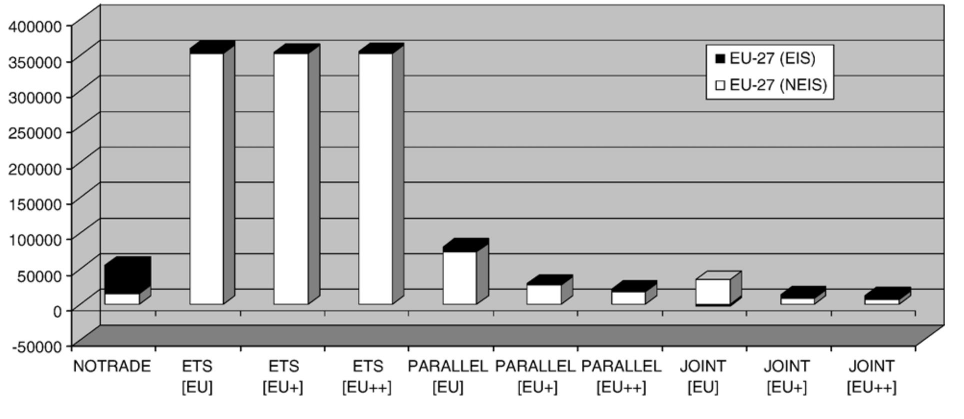

Fig. 3. Trading regimes — EU compliance costs by sector and scenario (million € 2005).

EU^{+}) implies drastic compliance costs for Canada, while Japan is benefiting and the Former Soviet Union is even net-benefiting from joining the EU scheme.[17] Although for Canada's EIS compliance costs are decreased substantially, overall adjustment costs of this region exceed total costs from cost-efficient domestic action, an effect which – as in the case of the EU – can be explained by an inefficient domestic allocation of emissions between sectors. Linking to the European Union cannot compensate for the domestic burden-shifting to non-energy-intensive sectors, since exactly these sectors do not benefit from emissions trading. The beneficial effect for Japan is the cause of a relatively heavy economic burden of EIS under domestic action, which can be significantly decreased by international emissions trading of these sectors. The international ETS permit price falls from 28.5 to 5.0 €/ton of CO_2 due to the sale of "Hot Air" by the Former Soviet Union, which generates large revenues from excess permit exports at the emissions market.

The perspectives of a further enlargement of the EU ETS are even less optimistic: Both Canada and Japan face higher compliance costs when the interlinked ETS with the European Union is further enlarged by Australia and the USA (yielding regional scenario EU^{++}). This effect is due to the increased demand for emissions permits of the new participants which causes a rise in the ETS permit price from 5.0 to 8.3 €. The United States and Australia again face higher compliance costs than under *NOTRADE* due to domestic inefficiencies. As a consequence, linking domestic ETS under the regional constellation EU^{++} is not beneficial for any participant except of the Former Soviet Union, which profits from the increased demand (and price) for its excess permits.

5.2. The presence of Kyoto trading

In the presence of a post-Kyoto agreement that enables international emissions trading at the country level, linking the European economies internationally has very different implications. Fig. 3 further shows the respective simulation results for the *PARALLEL* and *JOINT* trading scenarios. Focusing first on a parallel ETS and Kyoto trading regime, it shows that already in the absence of linking, the European Union faces efficiency improvements through government trading: Scenario *PARALLEL* [*EU*] induces drastically lower adjustment costs than *ETS* [*EU*], although total costs in the parallel setting are still higher than under efficient domestic action. Kyoto trading serves as a compensation mechanism, largely alleviating the inefficiencies of the EU ETS through parallel international trading among the formerly burdened non-energy-intensive sectors excluded from the scheme. Furthermore, linking the European economies to non-EU regions in the presence of enlarged Kyoto trading leads to a much greater fall in compliance costs — by linking to Canada, Japan and the Former Soviet Union (yielding regional scenario EU^{+}) total EU compliance costs can be reduced by more than 6%. The isolated economic impacts from linking the European ETS are obviously similar to the case of absent Kyoto trading, yielding the same economic impacts for EIS – who do not participate in government emissions trading – at a permit price of 5.0 €/ton of CO_2. Thus, it is NEIS that benefit from increased compliance-cost reduction through international Kyoto trading of the same countries — at a permit price of 51.2 €, which is drastically lower than NEIS marginal abatement costs under domestic action. A further enlargement of ETS and Kyoto trading to Australia and the USA (yielding regional scenario EU^{++}) yields increased benefits from a larger emissions market for NEIS, decreasing the permit price to 31.7 € and cutting EU compliance costs by almost 3%. Also for non-EU regions parallel trading regimes would result beneficial: All regions except of

[17] By definition, in each scenario of linking ETS non-participating regions face compliance costs equal to the *NO-TRADE* scenario.

the Former Soviet Union (revenues from permit sales decrease by more than 30%) face lower compliance costs when linking to the European scheme and trading in parallel at the country level. However, emissions markets are still separated – and where-flexibility still restricted – as international trading is feasible only between the same sectors of the linked economies.

A joint emissions trading regime interconnecting energy-intensive companies and national governments is de facto equivalent to full where-flexibility, establishing international trading activities between all regions and sectors. Fig. 3 shows that in the absence of linking, only the interconnected trading system *JOINT* [*EU*] implies efficiency gains for Europe as compared to cost-efficient domestic action. Here, EU compliance costs amount to only 40% of a parallel system and to less than ten percent of *ETS* trading. Linking the EU economies internationally in a *JOINT* trading system enables the participating energy-intensive ETS companies not only to trade internationally among each other, but also with governments of the participating countries. Hereby, also an enlarged trading system causes a much stronger fall in EU compliance costs than under *ETS* or even *PARALLEL* trading, since now all sectors can benefit jointly from extended trading activities. Here, the cost decrease is most substantial moving from *EU* to EU^{+}, as the dominant emissions permit exporter Former Soviet Union is able to decrease the international permit price from 69.6 to 14 €. Consequently, also all non-EU regions benefit substantially from enlarged joint emissions trading to EU^{++} except of the Former Soviet Union, which due to a lower market price generates smaller revenues. Of all three trading regimes, this region benefits most from parallel trading (with all sectors trading at relatively high permit prices), followed by joint and ETS trading.

5.3. The role of the Clean Development Mechanism

Generating emissions reduction credits in developing countries via CDM projects may serve a substitute for emissions permits traded between industrial countries under the future climate policy regimes presented in Section 4. Fig. 4 illustrates that the impact of the CDM crucially depends on the underlying trading regime (for detailed simulation results see Table 8 in Appendix A.3): While under linked ETS trading only energy-intensive sectors may import CDM permits, under a parallel or joint regime both EIS and NEIS may participate in project-based emissions crediting through national governments. As a consequence, in the context of an ETS regime unlimited CDM access only slightly reduces total compliance costs for all participating regions (see scenarios *ETS_CDM* [EU^{+}] to [EU^{++}]). This holds true although the CDM significantly

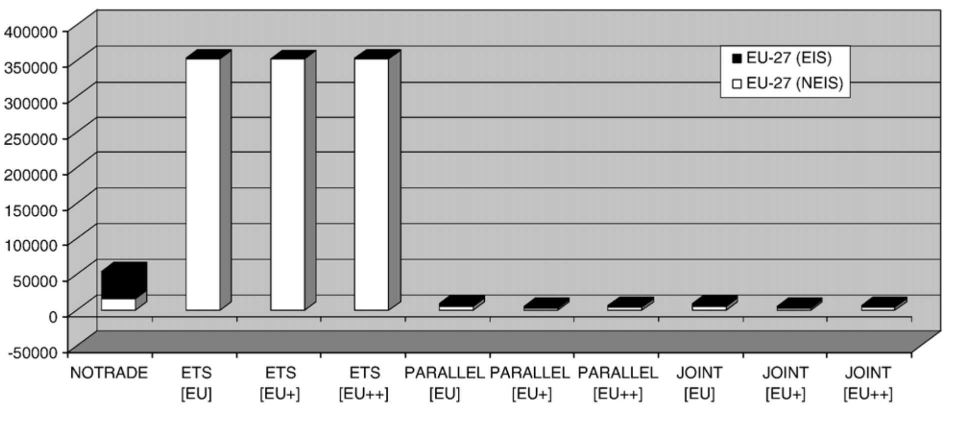

Fig. 4. CDM access — EU compliance costs by sector and scenario (million € 2005).

lowers the ETS permit price for the energy-intensive part of the economy (carrying only a minor compliance burden), e.g. within the EU scheme from 28.5 to 4.5 €/ton of CO_2.

By contrast, in a *PARALLEL* trading regime the CDM reduces adjustment costs by almost 90% for the European scheme (see *PARALLEL_CDM* [*EU*]) as compared to the same scenario in the absence of the CDM. In this setting of coexisting trading regimes the sectorally uniform permit price amounts to 9.1 €. Fig. 4 shows that compliance costs are in particular lowered for the formerly burdened NEIS who are now granted access to project-based credits, while for EIS the CDM induces even higher adjustment costs in the parallel-regime than under *ETS_CDM* due to an increased CER demand and price for EU energy-intensive industries. This leads to a more even cost distribution between sectors and lower aggregate compliance costs than under *NOTRADE*. The additional efficiency gains via the CDM under a parallel-regime reflect a stronger compliance-cost reduction of non-energy-intensive industries by abatement options in all sectors of CDM host countries, which are less costly than abatement options of NEIS in (industrialized) Kyoto countries.

Furthermore, Fig. 4 shows that the economic effects of the CDM under a *JOINT* trading regime are for all regions identical to those of a parallel setting: As both EIS and NEIS of trading regions have access to the international pool of project-based credits, the CDM de facto interconnects the two sectors internationally and – due to a lower CER price than the world-market price for emissions permits – induces full where-flexibility and identical outcomes in both trading regimes. While in a parallel or joint trading system all regions are generally benefiting from demanding CDM credits, the Former Soviet Union is disadvantaged by the enlarged trading activities with developing countries, generating smaller revenues from emissions permit sales due to a decreased demand and price.

Comparing regional scenarios involving the CDM implies that the economic benefits of enlarged emissions trading schemes are generally diminished in the presence of the CDM and can even be reversed: Under *PARALLEL_CDM* and *JOINT_CDM* trading, moving from *EU* to EU^{+} still cuts European compliance costs by almost half (dropping the ETS permit price from 9.1 to 4.8 €) and benefits the permit buyers Canada and Japan. However, further enlarging trading activities to EU^{++} causes efficiency losses by driving the permit price up to 6.4 €. This effect is due to an increased demand for emissions permits and CERs by linking to Australia and the USA. These two regions do however benefit from joining an EU^{++} regime despite the increased permit price, due to their higher marginal abatement costs under *NOTRADE*.

As a synopsis of the previous sections, Fig. 5 presents the resulting permit prices within linked ETS for alternative trading regimes in the absence and presence of CDM access.

As one climate policy objective of the European Union is to achieve a major fraction of emissions abatement within its trading scheme, strong substitution patterns in favor of the CDM put supplementarity considerations, i.e. restrictions on CER imports, on the political agenda of the linking process. Table 8 in Appendix A.3 shows that only in the absence of linking ETS, the alternative supplementarity scenarios laid out in Section 4 have an impact on the emissions market for the EU. First, under scenario *ETS* [*EU*] a restriction of CER imports of EU energy-intensive industries to ten percent of allocated allowances only slightly increases total EU compliance costs (see scenario *ETS_SUP* [*EU*]). Due to the already minor contribution of unlimited CDM under ETS trading, this result holds despite a permit price increase from 4.5 to 15.1 €.

A supplementarity criterion in a parallel trading regime would restrict EIS imports from the CDM similarly to ETS trading, while NEIS may import a maximum of 50% of the downscaled NEIS reduction commitment. Total EU compliance costs may then result even *lower* as under unlimited CDM access: The (binding) import restriction in EIS again induces only a minor cost increase in these sectors of the EU, but the lower EIS demand decreases the CER price for governments (from

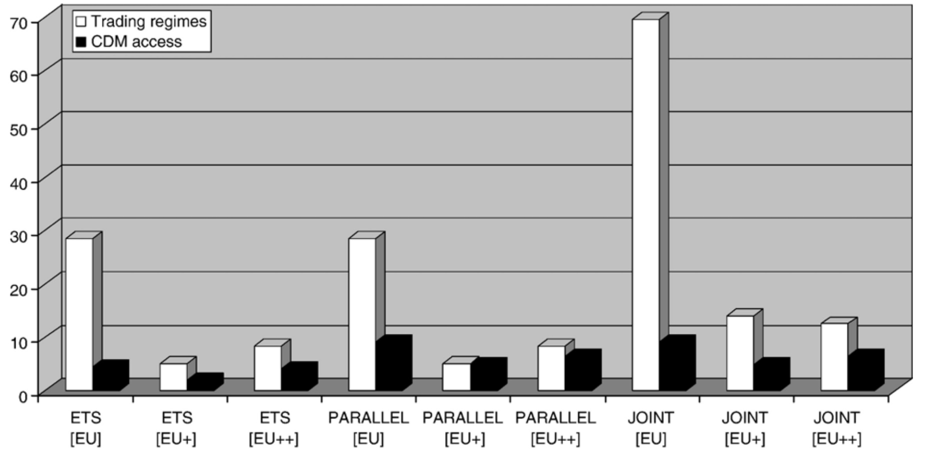

Fig. 5. Trading regimes and CDM access — ETS permit price by scenario (€ 2005/ton CO_2).

9.1 to 8.2 €) enough to transfer relatively larger cost-savings to NEIS, for which the 50% import limit is not strict enough to be binding.

By contrast, in a joint emissions trading regime EU adjustment costs are more than ten percent higher when only 50% of the *national* emissions reduction commitment may be imported by all sectors via the CDM: Limiting the access to low-cost emissions reductions from developing countries reduces potential cost-savings from project-based crediting in particular for non-energy-intensive EU industries (facing a sectorally uniform permit price of 26.4 €). Unlike the economic effects for Europe, for all non-EU regions the application of the supplementarity criterions within the enlarged trading schemes does not change the economic impacts of CDM access, as the respective thresholds of CDM imports are not reached under unlimited CDM access (see e.g. total compliance costs under *PARALLEL_CDM* [EU^{++}] versus *PARALLEL_SUP* [EU^{++}]).

5.4. Sensitivity analyses

5.4.1. The case of stricter allowance allocation

As a first sensitivity analysis of the core simulation results described in the previous sections, an alternative allocation of emissions allowances (previously described in Section 3.2) may be assumed. Against the background of the medium-term trend implied by the European Commission's planned shortage of the EU's total emissions allocation in the second ETS period, in this section we assume a stricter allowance allocation implying further decreased allocation factors (EU, 2005). Specifically, a 30% decrease of allocation factor values in 2020 compared to the year 2005 is assumed (previously: 20%). The corresponding simulation results are presented in Table 9 and Table 10 of Appendix A.4.

It shows that while for all trading regimes the stricter allowance allocation to energy-intensive industries induces a sectoral burden shifting from NEIS to EIS, in a *JOINT* trading regime overall compliance costs de facto remain unchanged due to full where-flexibility. Under *ETS* trading and a *PARALLEL* trading regime overall compliance costs are however significantly decreased for regions committing to emissions reduction targets, as a larger part of the national abatement efforts is undertaken by energy-intensive industries that feature less costly abatement options. In a parallel setting a stricter allowance allocation thereby increases the ETS permit price (for EIS) and decreases the price on the government emissions market (for NEIS). For institutional scenarios limiting CDM access by supplementarity rules, the similarly induced increase in the CDM demand of EIS leads to a counterintuitive result: In a parallel setting, a stricter allocation may then even induce higher overall compliance costs as the relatively restrictive CDM access limit for EIS now induces an additional burden that is more than compensating the lower burden of NEIS.

5.4.2. The case of no "Hot Air" allocation

The simulation results presented in the previous sections implicitly assume an international climate policy regime in which excess emissions permits of the Former Soviet Union ("Hot Air") are allocated for free to the respective national installations. This situation would de facto imply a subsidy for EIS since allocated excess permits could directly be exported to other ETS regions. It is however not unambiguous whether such a strategy will prevail in the future: On the one hand, refraining from excess allocation could be a prerequisite for linking to the European scheme due to potential international competitiveness distortions between companies arising from the linking process. On the other, incentives for strategic behaviour of the Former Soviet Union as a quasi monopolist on the emissions market could also restrict permit allocation to installations.[18]

For this reason, a second sensitivity case is introduced assuming that no excess permits will be allocated to installations of the Former Soviet Union. In this case, the region is assigned an emissions reduction target versus 1990 levels that resembles its BAU emissions in 2020 (here: 23.3%) and an allocation factor equal to one.

Tables 11 and 12 in Appendix A.4 present the corresponding regional compliance costs. It shows that the previous findings are generally robust to the existence of "Hot Air" from the Former Soviet Union. In the absence of allocated excess permits in each scenario involving this region all other countries face higher compliance costs due to a lower supply of the Former Soviet Union and an increased permit price. However, the higher adjustment costs for permit demanders do not necessarily imply larger revenues from permit sales: Only under *ETS* and *PARALLEL* trading regimes and regional constellation [EU^+] the lack of excess permits results beneficial for the Former Soviet Union — in all other scenarios the higher market price cannot compensate for the lower amount of permits exports.

6. Conclusions

Linkage of the EU Greenhouse Gas emissions trading scheme (ETS) to emerging schemes beyond Europe is a central strategic issue of current EU climate policy. At present, non-European countries like Canada, Japan or Australia are contemplating the set up of domestic ETS with the intention of linking up to the European scheme. From 2008 on, company trading among linked schemes would however occur in parallel to trading among countries, as the Kyoto Protocol facilitates international government trading of greenhouse gas emissions at the country level. Moreover, both companies and governments may undertake project-based emissions reductions in developing countries via the Clean Development Mechanism (CDM).

The present paper assesses the economic impacts of linking the EU ETS in the presence of a post-Kyoto agreement in 2020. Based on a numerical multi-country, two-sector partial equilibrium model of the world carbon market the economic impacts of parallel climate policies are assessed quantitatively. The model covers explicit sectoral marginal abatement cost functions for the year 2020 calibrated to energy-system data, and considers transaction costs as well as investment risk for CDM host countries.

[18] The present paper abstracts from such strategic behavior. For a quantitative analysis of near-term implications of emissions market power by the Former Soviet Union see Böhringer et al. (in press).

The simulations show that in the absence of post-Kyoto government trading, linking the European ETS induces no or only marginal economic benefits for the EU: Total compliance costs decrease no more than one percent in all linked schemes. As where-flexibility of international emissions trading is restricted to energy-intensive industries that are assigned generous initial emissions, the major compliance burden is carried by sectors excluded from the linked ETS (i.e. non-energy-intensive industries). These non-trading segments of the economy are not able to benefit from an enlarged trading scheme. Moreover, the economic impacts for non-EU countries from linking to the European scheme are very heterogeneous: Linking to Canada, Japan and the Former Soviet Union implies drastic compliance costs for Canada due to domestic inefficiencies, while Japan is benefiting and the Former Soviet Union is even net-benefiting from joining the EU scheme. A further linking process to Australia and the USA is not beneficial for any participant except for the Former Soviet Union which profits from an increased demand and price for its excess emissions permits ("Hot Air").

In the presence of parallel government trading under a post-Kyoto agreement, international emissions trading is not only feasible among energy-intensive sectors of linked ETS, but also among non-energy-intensive industries (represented by their governments). Linking the European economies to non-EU regions then leads to a much stronger fall in adjustment costs: By linking to Canada, Japan and the Former Soviet Union total EU compliance costs can be reduced by more than 60%. Here, it is the non-energy-intensive sectors that benefit from cost attenuation through enlarged international government trading of the same countries. A further linkage to Australia and the USA yields increased benefits from a larger emissions market, especially for non-energy-intensive sectors, further cutting EU compliance costs by almost 30%. Also for non-EU regions these parallel trading regimes would result beneficial. However, emissions markets are still separated – and where-flexibility still restricted – as international trading is feasible only among the same sectors of the linked economies.

From an efficiency perspective, a desirable future climate policy regime represents a joint trading system that enables international emissions trading between ETS companies and governments under a post-Kyoto agreement. Such a joint regime is de facto equivalent to full where-flexibility, establishing international trading activities between all regions and sectors. Via such a joint regime the formerly separated markets can be interconnected, generating large efficiency gains: Linking the EU economies internationally in a joint trading system causes an even stronger fall in EU compliance costs than under a parallel-regime, since now all sectors can benefit jointly from extended trading activities. Here, the cost decrease is most substantial when linking to Canada, Japan and the Former Soviet Union, as the latter region is able to decrease the international permit price by supplying excess permits to a large extent.

The CDM is not able to alleviate the inefficiencies of linked ETS, since also project-based crediting is restricted to energy-intensive industries of ETS. By contrast, in a parallel trading regime government access to low-cost abatement options of developing countries induces large efficiency gains. Here, the CDM provides additional cost-savings of more than 90% within the European scheme, largely reducing the compliance costs of non-energy-intensive industries. By providing access to project-based crediting for both energy-intensive and non-energy-intensive sectors, the CDM establishes an indirect link between the two segments of the economy and assures full where-flexibility. Due to this provision of an international credit pool for all sectors the CDM levels out the economic impacts under parallel and joint trading regimes. A restriction of CDM activities via a supplementarity criterion does not significantly decrease the economic benefits from project-based crediting, as the respective thresholds of CDM imports are generally not yet reached under unlimited CDM access.

While representing a fairly transparent model framework, the present partial market analysis clearly can only provide a restricted description of economic reactions to international climate policy. One limitation of partial analysis is the neglect of market interactions and spillovers (for related studies see Böhringer and Rutherford, 2002, Bernard et al., 2003 or Klepper and Peterson, 2006a). Moreover, the direct costs of abatement may be altered by terms-of-trade effects on fossil fuel markets. However, these effects depend on the extent of global cuts in demand for fossil fuels as well as the level of regional fossil fuel supply elasticities, and may only be addressed in a multi-market, i.e. general equilibrium framework.

This paper laid out the efficiency implications of internationally linked emissions trading schemes, as well as alternative country-level compensation mechanisms for the expected inefficiencies of future schemes. In the long run however, uncertainties about future post-Kyoto agreements and the exhaustion of low-cost abatement options in developing countries raise concerns about the availability of such mechanisms. The projected large economic potentials of the CDM could also be substantially downscaled by the existence of implicit investment barriers such as incomplete information. Moreover, given the large number of participants it is company-based trading that provides a fertile ground for developing a competitive market for emissions. Considering the potential for efficiency improvements of future ETS – such as a stricter allowance allocation to covered installations or an enlarged sectoral scope – linking emissions trading schemes beyond Europe may thus become not only a fall-back option for a lacking international agreement, but a vital option for future climate policy at the global level.

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Appendix A. Supplementary material

Emissions market data, an algebraic model summary and all numerical simulation results (Appendix A.1 to A.4) associated with this article can be found, in the online version, at doi:10.1016/j.eneco.2007.08.002.

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