Reducing Deforestation and Trading Emissions:

Economic Implications for the post-Kyoto Carbon Market

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Abstract. This paper quantitatively assesses the economic implications of crediting carbon abatement from reduced deforestation for the emissions market in 2020 by linking a numerical equilibrium model of the global carbon market with a dynamic partial equilibrium model of the forestry sector. We find that integrating avoided deforestation in international emissions trading considerably decreases the costs of post-Kyoto climate policy – even when accounting for conventional abatement options of developing countries under the CDM. At the same time, tropical rainforest regions receive substantial net revenues from exporting carbon-offset credits to the industrialized world. Moreover, reduced deforestation can increase environmental effectiveness by enabling industrialized countries to tighten their carbon constraints without increasing mitigation costs. Regarding uncertainties of this future carbon abatement option, we find both forestry transaction costs and deforestation baselines to play an important role for the post-Kyoto carbon market.

JEL classification: C60, D61, Q23, Q58

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1 Introduction

This year's assessment report of the Intergovernmental Panel on Climate Change (IPCC) reemphasized the urgency of combating climate change by stating that "continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century" (IPCC, 2007). As the primary causes of climate change the report highlights fossil fuel use and land use change, the latter accounting for roughly one fifth of total anthropogenic greenhouse gas emissions.

Assessing future strategies for solving the climate problem, Pacala and Socolow (2004) propose a set of options to reduce global carbon emissions within the next 50 years. One prominent option among the 15 proposed strategies is reducing tropical deforestation and the management of temperate and tropical forests. Emphasizing the importance of early international action for limiting global warming, also the Stern Review recently suggested emissions reductions from avoiding deforestation as a key element of cost-effective future climate policy (Stern, 2007). Forests play a twofold role in climate change by sequestering large quantities of carbon: while growing trees absorb carbon dioxide from the air and store carbon by the process of photosynthesis, forests can become a major emissions source when the stored carbon is released into the atmosphere by means of forest degradation and deforestation activities. Most commonly, the latter imply the logging or burning of rainforests for the production of wood and non-wood forest products or for agricultural land use. Recent studies estimate the net annual forest loss in Africa alone to amount to 4 million hectares, implying that the continuing decline of primary rainforest in tropical regions is a matter of growing concern (FAO, 2007).

Heal (1999) analyzes economic mechanisms through which goods and services provided by tropical forests and their biodiversity could be marketed. One discussed mechanism is the financial compensation for carbon sequestration services of forests under an international climate agreement, potentially generating incomes high enough to radically change the incentives for forest conservation. Supported by the Coalition for Rainforest Nations, Papua New Guinea recently proposed to address reducing emissions from deforestation and degradation (REDD) within the international climate regime (UNFCCC, 2005). Whereas under the Kyoto Protocol only forestation and reforestation activities are eligible for crediting the associated carbon abatement, the proposal suggested that developing countries might commit to reducing emissions from deforestation – in exchange for receiving tradable carbon abatement credits and participating in international post-Kyoto emissions trading.

Over the last decades, the most important obstacle for the implementation of ambitious climate policies has been the associated mitigation costs. As a prominent example, the long drawn negotiations of the Kyoto Protocol eventually allowed business-as-usual emissions and imposed negligible compliance costs of regulation (Böhringer and Vogt, 2003). Thus, a viable and environmentally effective strategy for future climate policy has to be economically attractive at the same time. Against this background, the World Bank has proposed Forest Carbon Finance as an "ungrasped opportunity" of reducing global carbon emissions at low costs (Chomitz et al., 2007). As the marginal costs for reducing carbon by reducing tropical deforestation are expected to be far lower than emissions abatement options in industrialized countries, these countries could finance farmers in tropical regions for forest conservation rather than pursuing costly emissions abatement efforts at home. Given the low economic returns of agricultural land use in tropical rainforest regions, such incentive payments for avoiding deforestation could at the same time benefit the developing world. Moreover, they may pave the way for developing countries to actively take part in emissions reduction efforts within an international climate policy regime (Dutschke and Wolf, 2007).

The economic aspects of international emissions trading have been assessed in a number of previous quantitative studies on the Kyoto Protocol and the EU Emissions Trading Scheme (EU ETS). These studies employ both partial and general equilibrium models to illustrate the economic efficiency gains from "where flexibility" of carbon abatement, and highlight the welfare costs of restricting emissions trading to energy-intensive sectors of the economy (Weyant and Hill, 1999; Böhringer et al., 2005; Klepper and Peterson, 2006). Furthermore, Anger (2007) shows that parallel carbon trading within the EU ETS and among post-Kyoto governments yields considerable efficiency gains and increases the economic importance of project-based emissions reductions in developing countries via the Clean Development Mechanism (CDM). Regarding the role of deforestation in international climate policy, several studies assessed the relationship between tropical deforestation and climate change as well as the institutional aspects of including forestry activities in a post-Kyoto agreement (Moutinho and Schwartzman, 2005; Schlamadinger and Bird, 2007; Amano and Sedjo, 2006). The quantitative economic literature assessing deforestation in the context of climate policy is comparably scant. Linking a forestry model to a climate-economy model, Sohngen and Mendelsohn (2003) analyze the role of forests in greenhouse gas mitigation, predicting forest sequestration to account for about one third of global carbon abatement within the next century. Tavoni et al. (2007) study the contribution of forestry management to long-term CO_2 stabilization policies, finding that increased forest sequestration could significantly lower the global costs of climate policy. These studies feature a strong integration of modeling frameworks and form an important scientific basis for the numerical analysis of interactions between forestry activities and future climate policy.

Against this background, we study the implications of crediting carbon abatement from reduced deforestation for the post-Kyoto carbon market. In order to quantitatively assess the corresponding economic impacts for industrialized and developing countries in the year 2020, we link two numerical simulation models at the global scale: a dynamic model of the global forestry sector and an equilibrium model of the world carbon market which is based on empirical allowance allocation. By simulating the response of the forestry sector to changes in future carbon prices, we generate marginal cost functions for carbon abatement from reduced deforestation. These cost functions are incorporated into the carbon-market model which covers international emissions trading on two levels: (i) on the government level, as facilitated by a post-Kyoto climate agreement and (ii) on the company level, as facilitated by the EU ETS and a future linkage to emerging schemes outside Europe. As opposed to previous studies, we are thus able to explicitly assess the global carbon permit trade flows generated from reducing deforestation. Furthermore, we analyze the so far unexplored carbon-market implications of uncertainties in transaction costs of forestry projects as well as the baseline against which reduced deforestation is measured.

The remainder of this paper is structured as follows. In Section 2 we present the numerical model framework for our quantitative analysis. Section 3 specifies illustrative scenarios of post-Kyoto climate policy in 2020. In Section 4 we present the simulation results, and in Section 5 we conclude.

2 Numerical model framework

For the quantitative assessment of reducing deforestation and trading emissions in 2020 we subsequently present our two numerical model frameworks: a dynamic model of the forestry sector and a static model of the world carbon market.

2.1 Modelling the forestry sector in tropical regions

In order to simulate the response of the forestry sector to changes in future carbon prices, we employ the dynamic partial equilibrium model *Generalized Comprehensive Mitigation Assessment Process* GCOMAP (Sathaye et al., 2005, 2006). This model explicitly analyzes the carbon benefits of forestation globally in ten regions and of reducing deforestation in four important tropical rainforest regions (FAO, 2007): Africa, South-East Asia, Central America and South America. It establishes a reference case level of land use, absent carbon prices, for 2000 to 2100 before simulating the response of forest land users (i.e. farmers) to changes in prices in forest land and products, as well as prices emerging in carbon markets. The model's objective is to estimate the land area that land users would plant above the reference case level, or prevent from being deforested, in response to carbon prices. As a result GCOMAP estimates the net changes in carbon stocks while meeting the annual demand for timber and non-timber products.

In order to assess the role of institutional barriers for crediting carbon abatement from reducing deforestation we investigate the impact of transaction costs of forestry projects and programs (hereafter also referred to as projects) on the carbon-price response of the forestry sector (see Antinori and Sathaye, 2007). Such transaction costs may arise from project search, feasibility studies, as well as negotiation, monitoring and verification, regulatory approval, and insurance costs. Antinori and Sathaye (2007) analyze four data sets of forestry and energy projects including projects associated with the CDM and the Global Environmental Facility (GEF). In each data set, they find strong economies of scale. The forestry project sizes range from 58 thousand to as much as 22 million tons of CO_2 mitigated over their life and include both forestation and deforestation projects. Project lifetimes range from five to 100 years. The estimated transaction costs range from 0.05 US$ per ton of CO_2 for large projects to 1.22 US$ per ton of CO_2 for smaller ones. For this study, we conduct Monte-Carlo simulations of carbon stock changes resulting from a sequence of carbon prices in 2020 that are subject to the spread of transaction costs determined for the forestry sub-group of projects in the Antinori and Sathaye (2007) study.

Moreover, we analyze the implications of the baseline against which reduced deforestation is measured for the level of carbon abatement in the forestry sector. As in the case of transaction costs we employ Monte-Carlo simulations of carbon stock changes resulting from a sequence of carbon prices for an interval of deforestation baseline levels for the tropical rainforest region South America. Data for annual variation in deforestation rates was available only for the Brazilian Amazon from 1989 to 2006, and hence we use these variations to simulate the potential variation in deforested area for the baseyear (INPE, 2007).

2.2 Modelling the global carbon market

In order to quantitatively assess the emissions-market impacts of reducing deforestation we employ a numerical multi-country, two-sector partial equilibrium model of the global carbon market in 2020. For each region, the model incorporates calibrated marginal abatement cost functions for energy-intensive and non-energy-intensive sectors. Building on the modelling framework of Anger (2007), it represents parallel carbon markets for (i) companies covered by the EU ETS and emerging schemes outside Europe as well as (ii) post-Kyoto governments in 2020 and accounts for emissions reductions via the CDM. The objective of the model is to minimize compliance costs of carbon regulation by means of international emissions trading. An algebraic model summary is given in Anger (2007).

To generate marginal abatement cost (MAC) functions by region and sector we use data simulated by the well-known energy-system model POLES (Criqui et al., 1999), which explicitly covers energy technology options for emissions abatement in various world regions and sectors for the baseyear 2020. In the POLES simulations a sequence of carbon taxes (e.g. 0 to 100 US$ per ton of carbon) is imposed on the respective regions, resulting in associated sectoral emissions abatement. The coefficients for MAC functions in 2020 are estimated by an ordinary least squares (OLS) regression of tax levels (i.e. marginal abatement costs) on associated emissions abatement. Following Böhringer et al. (2005), in order to assure for functional flexibility a polynomial of third degree is chosen as the functional form of MAC functions.[1] For region *r* and sector *i* this results in the following equation (note that *EIS* and *NEIS* denote energy-intensive and non-energy-intensive sectors, respectively):

$$-MAC_{ir}(e_{ir}) = \beta_{1,ir}(e_{0ir} - e_{ir}) + \beta_{2,ir}(e_{0ir} - e_{ir})^2 + \beta_{3,ir}(e_{0ir} - e_{ir})^3 \qquad (3)$$

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

MAC functions for reducing deforestation are generated by imposing a sequence of carbon prices (here: 0 to 100 US$ per ton of carbon) in four tropical rainforest regions with the

[1] 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.

[2] 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].

GCOMAP model: Africa, South-East Asia, Central America and South America. This results in a sequence of regional net carbon stock changes and the corresponding carbon emissions reductions due to avoided deforestation. Based on these price-quantity pairs we are able to estimate the coefficients of regional MAC functions in 2020 by means of an OLS regression. Regarding transaction costs of forestry projects, we establish a triangular distribution of transaction costs with respect to the size of the project or program. Size is defined as the amount of carbon dioxide that is mitigated over the life of the project or program. We report the results for the 5th and 95th percentile values (implying high and low transaction costs) from the Monte-Carlo simulations of carbon stock changes for a sequence of carbon prices in 2020 and estimate the respective cost functions. Finally, these MAC coefficients are implemented into the carbon market model by covering tropical rainforest areas as explicit model regions. Within this linked model framework, tropical rainforest regions may export emissions reduction credits from reducing deforestation to industrialized model regions via the global carbon market. Table 4 in Appendix A.1 presents the estimated marginal abatement cost coefficients for avoided deforestation (in the cases of high and low transaction costs) for the four tropical regions in 2020.

2.3 Incorporating carbon market data

We incorporate three further inputs into the carbon market model: baseline emissions, emissions reduction commitments and allowance allocation associated with a potential post-Kyoto climate policy regime. Baseline, or business-as-usual (BAU), carbon dioxide emissions trajectories are based on van Vuuren et al. (2006) who provide a nationally downscaled dataset from the implementation of the global IPCC-SRES scenario B2 (IPCC, 2000) into the environmental assessment model IMAGE 2.2.

Emissions reduction targets

In order to analyze future climate policy scenarios we first have to assume regional emissions reduction commitments for the year 2020. Under the Kyoto Protocol, industrialized countries (listed in Annex B of the agreement) committed to cut their greenhouse gas emissions by 5.2 percent on average during 2008-2012 as compared to 1990 levels (UNFCCC, 1997). The EU Kyoto target of eight percent was then redistributed by an internal Burden Sharing Agreement among EU Member States (EU, 1999). Motivated by its ambitious current climate policy goals the EU is assumed to commit to a 20 percent emissions reduction versus 1990 levels in

2020 (EU, 2007a). We adopt the burden-sharing approach also for this ambitious future EU target, so that the aggregate EU commitment of effectively 27.2 percent versus business-as-usual emissions levels in 2020 implies very heterogeneous effective reduction targets across EU Member States. Given the leadership role of current European climate policy, non-EU regions are assumed to commit to less stringent emissions targets. Canada and Japan, who have ratified the Kyoto Protocol early, both assume a 20 percent effective reduction target versus business-as-usual emissions levels in 2020. The recent Kyoto-ratifier Australia and the non-ratifier United States commit to an effective reduction target of 15 percent versus BAU. Having received excess emissions permits under the Kyoto Protocol, the Former Soviet Union is assumed to hold its emissions constant in 2020, so that the phenomenon of "Hot Air" is not existent.[3]

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 or a regime crediting reduced deforestation requires a baseline, all developing regions are assigned their BAU emissions. Table 6 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 (the central year of the first Kyoto compliance period) and 2020. The table further shows the resulting emissions reduction requirements in 2010 and 2020 versus 1990 emissions levels, as well as the effective reduction requirements in 2020 versus BAU emissions levels in 2020.[4]

Emissions trading schemes and the allocation of allowances

As the most prominent instrument of current European climate policy, the EU Emissions Trading Scheme (ETS) is operating at the installation level in a "warm-up" phase since 2005 (EU, 2003). An important characteristic of the scheme is the exclusive coverage of energy-intensive companies. More recently, the EU has proposed to strengthen the European ETS by linking the scheme to emerging trading systems beyond Europe in order to achieve its climate policy objectives more cost-efficiently (EU, 2007c). At the same time, several non-EU countries such as Canada, Japan, Australia and the United States are contemplating the set up of domestic ETS with the intention of linking up to the EU ETS (see CEPA Environmental

[3] Our 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).
[4] Note that in our analysis Australia is approximated by the model region Pacific OECD.

Registry, 2005; Japanese Ministry of the Environment, 2004; Point Carbon, 2006; RGGI, 2007). As these schemes are also expected to cover mainly energy-intensive companies, the EU ETS may form the nucleus for a gradually expanding global emissions trading system for energy-intensive industries.

A central input for our policy assessment is the allocation of emissions allowances for EU Member States and linking candidates, which specifies an overall cap on emissions for those installations covered by the respective trading schemes. Here, we assume that the EU continues its predominant grandfathering method (i.e. the free allocation of allowances) to the covered installations in 2020. Numerically, emissions allocation can be described by so-called allocation factors, i.e. the fraction of baseline emissions that are freely allocated as allowances. In order to derive allocation factors for EU Member States in 2020 we build on empirical allocation data for the second trading period of the EU ETS (2008 to 2012) as published in the National Allocation Plan of each Member State and on recent emissions projections for 2010 (EU, 2007b). For the future trading period in 2020, we assume that the relative allowance allocation is decreased by 20 percent as compared to the second trading period.[5] This yields regional EU allocation factors ranging between 0.55 (Spain) and 0.85 (Sweden), implying emissions reduction requirements for the covered sectors between 45 and 15 percent versus BAU emissions, respectively.

In consistence with our national climate policy targets in 2020, non-EU regions also exhibit a less stringent allowance allocation than the EU for sectors covered by their emissions trading schemes: the early Kyoto-ratifiers Japan and Canada implement an allocation factor of 0.80, while the recent ratifier Australia and the non-ratifier United States allocate emissions allowances based on a factor of 0.85 in 2020. For the Former Soviet Union we assume an allocation factor equal to one in 2020, consistently implying no allocation of excess permits to installations covered by a domestic ETS.[6] Table 7 summarizes all resulting allocation factors for EU and non-EU regions.

[5] Two limitations apply here: Due to lacking information for Bulgaria and Romania, for these countries we start from an allocation factor equal to one in the second trading period. Moreover, allocation factors are chosen so that emissions reductions of the covered sectors do not exceed the respective national reduction requirement (this applies to the regions Greece, Sweden and Central Europe).

[6] Excess emissions permits (so-called "Hot Air") are due to lower projected baseline emissions than the target level implied by the Former Soviet Union's reduction commitment in 2020. We abstract from "Hot Air" here, as a grandfathered allowance allocation of "Hot Air" would imply an indirect subsidy for installations of this region (the allocated permits could be directly exported to other ETS regions). It is not unambiguous if such an ETS design may prevail or even be linked to an EU scheme.

3 Climate policy scenarios

The post-Koyto carbon market is expected to feature international emissions trading on two levels: (i) on the government level, as facilitated by the Kyoto Protocol and a potential post-Kyoto climate policy agreement and (ii) on the company level, as facilitated by the EU ETS and emerging schemes outside Europe. As the linked ETS are also expected to be restricted to energy-intensive industries, national Annex B governments may engage in country-level emissions trading as facilitated by a post-Kyoto agreement in order to represent their remaining, non-energy-intensive industries on the future carbon market (Anger, 2007).

In the following we specify scenarios of international emissions trading in the framework of a post-Kyoto agreement in 2020. The scenarios can be classified by two dimensions: the *regional* dimension distinguishes scenarios of countries participating in international emissions trading, whereas the *institutional* dimension lays out alternative designs of carbon regulation. Table 1 presents our 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.[7] Scenario EU^{+} indicates carbon trading among countries that have ratified the Kyoto Protocol relatively early: EU Member States, Japan, Canada and the Former Soviet Union. Scenario EU^{++} assumes that not only Kyoto ratifiers trade carbon emissions among each other, but also countries that have only recently or not yet ratified the Kyoto Protocol: Australia and the United States. For all regional scenarios 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.[8] Moreover, we include four tropical rainforest regions that are eligible for generating tradable offset credits for carbon abatement from reduced deforestation: Africa, South-East Asia, Central America and South America.

[7] 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.

[8] 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.

Table 1: Regional scenarios for 2020

Regional scenario	Regions participating in emissions trading	CDM regions	Tropical rainforest regions
EU	EU-27	Brazil China India Mexico South Korea	Africa South-East Asia Central America South America
EU^{+}	EU-27 Japan Canada Former Soviet Union		
EU^{++}	EU-27 Japan Canada Former Soviet Union Pacific OECD United States		

Table 2 lists our institutional scenarios, which involve four cases. Scenario *Emissions Trading* denotes international emissions trading among industrialized regions on two levels. On the first level, it represents company-based emissions trading within linked EU and non-EU emissions trading schemes, assuming the sectoral emissions allocation in 2020 as laid out in the previous section. Here, we approximate emissions trading at the company level by trading at the sectoral level. Moreover, all regions that have not (yet) set up an emissions trading scheme are assumed to comply with their emissions reduction target by cost-efficient domestic emissions regulation, imposing a uniform carbon tax on their entire economy. On its second level, scenario *Emissions Trading* represents parallel government trading under a post-Kyoto Protocol, which for the sake of illustration only applies to the linked ETS regions. In such a setting of coexisting emissions trading regimes, a reasonable assumption is that no double regulation of energy-intensive industries covered by a national ETS takes place. As carbon trading among linked ETS is approximated by emissions trading among energy-intensive sectors (EIS), government trading only applies to the remaining, non-energy-intensive sectors (NEIS) of each region. These parallel government trading activities should be interpreted as national authorities *representing* their non-energy-intensive industries on the carbon market.[9]

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

Table 2: Institutional scenarios for 2020

Institutional scenario	CO_2 regulation		International emissions trading		CDM access	REDD access	Forestry transact-ion costs
	EIS	NEIS	EIS with	NEIS with	EIS and NEIS		
Emissions Trading	Permits	Permits	foreign EIS	foreign NEIS	No	No	-
CDM					Yes	No	-
Deforestation_highTC					Yes	Yes	high
Deforestation_lowTC					Yes	Yes	low

Considering the access to low-cost abatement options in developing countries, scenario *CDM* represents scenario *Emissions Trading* including the option of unlimited CDM offset credit imports by Annex B regions from undertaking CDM projects in non-Annex-B regions. In this setting, both companies covered by linked emissions trading schemes and post-Kyoto governments (i.e. all sectors of the economy) have access to CDM credits.[10]

The model considers the following barriers to CDM projects: first, it features transaction costs for the purchase of CDM credits of 0.5 US$ (1 US$) per ton of CO_2 for energy-intensive (non energy-intensive) sectors of developing countries.[11] Second, following Böhringer and Löschel (2002) country-specific investment risk for CDM projects, e.g. from country and project risks, is derived by 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, 2000). Third, a CDM adaptation tax is incorporated amounting to two percent of CDM revenues as proposed under the Marrakech Accords (UNFCCC, 2002). CDM transaction costs, investment risk and the CDM tax enter the model via a premium on

[10] The amending directive linking the EU ETS with the Kyoto Protocol's project-based mechanisms grants European companies to generate emissions reductions via the CDM and use the associated credits as a substitute for EU allowances (EU, 2004).

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

marginal abatement costs of CDM host countries, thereby increasing the international CDM credit price.[12]

Finally, the two scenarios *Deforestation_highTC* and *Deforestation_lowTC* represent scenario *CDM* including the access for all sectors of industrialized economies to carbon abatement options in tropical rainforest regions. These scenarios consider all institutional barriers to offset crediting as mentioned above. By reducing emissions from deforestation and degradation (REDD) the four tropical regions may export carbon-offset credits to Annex B regions. As noted in Sections 2.1 and 2.2, the two scenarios are distinguished by assuming high and low transaction costs of forestry projects, respectively. This is the most integrated climate policy scenario, facilitating not only CDM access but also international trading of offset credits from reduced deforestation on the carbon market.

In the following, alternative scenario combinations of the regional and institutional climate policy dimension are implemented in the carbon-market model. For example, scenario combination *CDM [EU^+]* represents linked emissions trading schemes and government emissions trading among *EU^+* regions including CDM access for all sectors of the participating economies, while all other regions fulfil their emissions reduction targets by cost-efficient domestic action only.

4 Simulation results

In this section we simulate the impacts of reducing deforestation and trading emissions on the post-Kyoto carbon-market in 2020 using the numerical model of the global carbon market (as presented in Section 2.2) that incorporates carbon abatement cost data from the numerical forestry model (as presented in Section 2.1). We start the discussion of results with the economic impacts for Annex B regions, before turning to the implications for CDM host countries and tropical rainforest regions. Finally, we address the implications of reduced deforestation for the case of more ambitious carbon constraints. All tables presenting the numerical simulation results are compiled in Appendix A.2.

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

4.1 Impacts on the international permit price

Emissions trading among Annex B regions

Focusing first on the emissions market equilibrium in 2020 in the absence of developing countries, Table 8 in the Appendix shows that for Annex B carbon trading (institutional scenario *Emissions Trading*) the permit price crucially depends on the regional scenario and differs between energy-intensive sectors (EIS) and non-energy-intensive sectors (NEIS). The table shows that for emissions trading among EU Member States only (regional scenario *EU)* the carbon price amounts to roughly 55 € per ton of CO_2 in EIS covered by the EU ETS, whereas it results in 248 € on the parallel carbon market for EU governments that represent their NEIS. Generally, the sectoral permit price is determined both by the stringency of emissions reduction requirements and marginal abatement costs in the respective industries. Since in our case the EU carbon constraints on energy-intensive sectors (as imposed by the allocation factors within the EU ETS) and non-energy-intensive industries (as imposed by the effective national reduction requirement) are comparable, it is the more costly abatement options in European NEIS that lead to a much higher carbon price than in EIS.[13]

By including Canada, Japan and the Former Soviet Union on the carbon market (yielding regional scenario EU^+), the international permit price substantially decreases to 28 € and 89 € per ton of CO_2 in the two sectors. In this setting, the three non-EU regions can trade carbon permits with European economies both within linked emissions trading schemes (among EIS) and on the post-Kyoto government carbon market (among NEIS). The lower carbon price originates from two sources. First, despite of the relatively costly emissions abatement options in Japan and Canada, their comparably low national reduction targets and loose allowance allocation to energy-intensive industries results in relatively low *levels* of marginal abatement costs in EIS and NEIS.[14] This limits the permit demand of these two regions on the carbon market. Second, as a region in economic transition the Former Soviet Union features relatively low-cost abatement options as compared to the EU, Japan and Canada. It thus represents a major supplier of carbon permits on the linked emissions market by reducing emissions below BAU levels. Note that we abstract from the allocation of potential excess permits to the covered ETS companies in the Former Soviet Union, so that the lower permit price in scenario EU^+ only originates from low-cost abatement options in this region.

[13] For regional allocation factors and effective national reduction requirements see again Table 6 and Table 7.
[14] An assessment of marginal abatement costs across OECD countries is presented in Criqui et al. (1999).

Figure 1 illustrates that establishing the most integrated emissions trading system including Australia and the United States (regional scenario EU^{++}) causes the carbon price to decrease further in 2020, resulting in 19 € and 78 € per ton of CO_2. These efficiency gains on the enlarged carbon market originate from an increased supply of emissions permit by Australia and the United States, who impose the lowest national reduction targets and highest relative allowance allocation to their energy-intensive industries. Furthermore the United States feature relatively low-cost abatement options. Consequently, the two regions exhibit marginal abatement cost levels that are lower than the permit price on the original emissions market (regional scenario EU^{+}) and thus join the Former Soviet Union as carbon permit exporters – both within linked emissions trading schemes and on the post-Kyoto government carbon market. However, in all regional settings of institutional scenario *Emissions Trading* the parallel carbon markets of EIS and NEIS are still separated (and sectoral permit prices different), as international trading is feasible only between the same sectors of the participating economies.

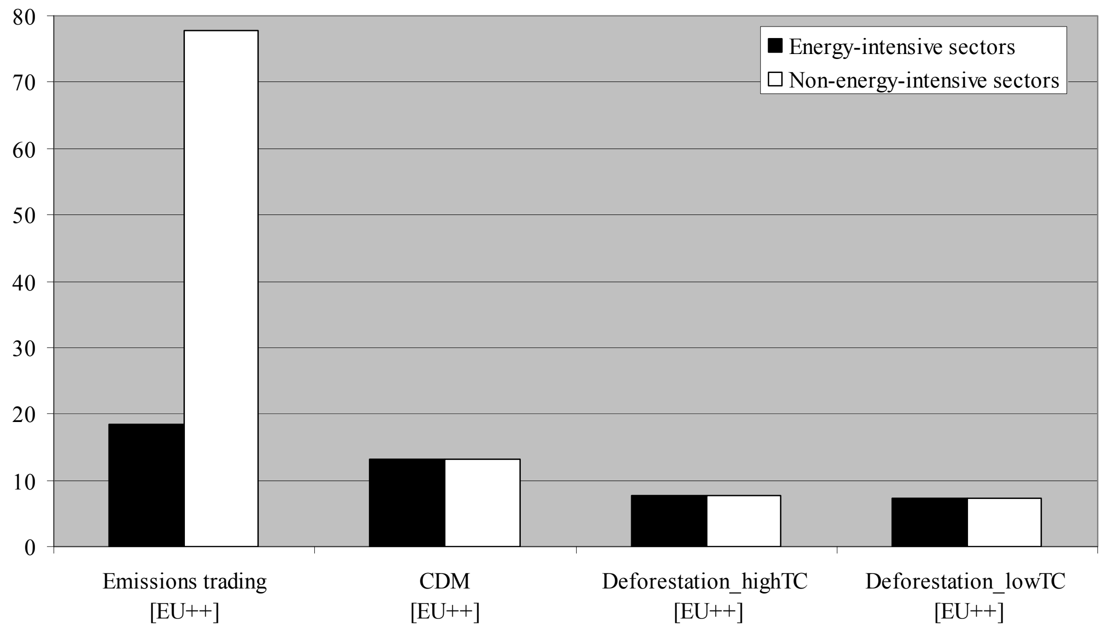

Figure 1: International carbon permit price for regional scenario EU^{++} by sector and institutional scenario (€2005 per ton CO_2)

Crediting carbon abatement via the CDM

Generating emissions reduction credits in developing countries via CDM projects may serve as a substitute for emissions permits traded between industrial countries. Figure 1 presents an interesting pattern of permit prices arising from CDM access for Annex B countries (see institutional scenario *CDM*). First it shows that the access to low-cost abatement in developing countries drastically decreases the permit price in the most integrated emissions market to roughly 13 € per ton of CO_2. As the resulting permit price is lower than both sectoral carbon price levels on the original Annex B market, this yields a sectorally uniform carbon price which de facto interconnects the formerly separated carbon markets of linked emissions trading schemes (among EIS) and post-Kyoto governments (among NEIS). The CDM thus yields not only large efficiency gains by decreasing the permit price, but establishes full where-flexibility of carbon abatement between sectors and regions. Moreover, the carbon price decreases more in the high-cost NEIS by CDM, underlining the economic importance of CDM access for Annex B governments. Table 8 in the Appendix finally shows that in the case of CDM access the carbon price is the higher, the more Annex B parties are involved in international emissions trading (i.e. lowest in a purely EU trading regime). Clearly, the increased number of participants on the carbon market with higher marginal abatement costs than developing countries drive up the CDM credit demand from EIS and NEIS and thereby increase the carbon price level.

Crediting carbon abatement from reduced deforestation

When the import of low-cost carbon abatement from developing countries is not only feasible via the CDM but also by crediting carbon abatement from avoided deforestation, the international permit price further decreases. Figure 1 shows that even when accounting for high transaction costs of forestry projects, issuing tradable carbon-offset credits for avoided deforestation reduces the sectorally uniform carbon price by more than 40 percent in 2020. The resulting price level amounts to less than 8 € per ton of CO_2 on the EU^{++} carbon market (see scenario *Deforestation_highTC*). The reason is that the relatively low returns of land use and forest products in tropical regions imply a low opportunity cost of reducing deforestation, so that its marginal abatement costs are lower than the incremental costs of conventional carbon abatement options in CDM host countries. The higher level of competition on the supply side of the emissions market thus decreases the international permit price. In the following sections we will see how the possibility of exporting carbon-offset credits from reduced deforestation for tropical rainforest regions affects the competitive position of CDM host countries on the carbon market. Furthermore, Figure 1 suggests that the carbon price differences between the cases of high and low transaction costs amount to roughly 5 percent (carbon prices of 7.6 and 7.2 € per ton of CO_2, respectively). Regarding the permit price impacts in alternative regional trading constellations, Table 8 in the Appendix shows that – as in the case of CDM access for Annex B countries – the carbon price will be the higher, the more Annex B parties are involved in international emissions trading (ranging from 5 to 8 € per ton of CO_2 across regional scenarios).

4.2 Emissions reductions and permit trade flows

In the following we assess the regional emissions reductions and permit flows on the global carbon market for our alternative climate policy scenarios. Table 10 in the Appendix presents the associated numerical simulation results. It shows that domestic reductions of Annex B carbon emissions generally decrease for regionally enlarged international emissions trading and are substantially diminished when industrialized countries are granted access to carbon-offset credits via the CDM. Clearly these effects correspond to the decreasing permit price across scenarios, diminishing the incentives for domestic carbon abatement. We find that integrating reduced deforestation further cuts Annex B emissions reductions and induces large abatement efforts in tropical rainforest regions. On the most integrated carbon market (regional scenario EU^{++}) Africa reduces almost two thirds of its carbon emissions from deforestation – even when accounting for high transaction costs – followed by Central and South America (16 and 15 percent reduction) and South-East Asia (8 percent).[15]

These regional emissions abatement patterns translate into international permit flows on the post-Kyoto carbon market. For transparency abstracting from emissions trading among Annex B regions only, Figure 2 illustrates imports and exports of carbon-offset credits on the most integrated emissions market (regional scenario EU^{++}). It shows that the aggregate Annex B region imports more than one gigaton of CO_2 from low-cost abatement options in CDM host countries. Moreover, Annex B imports of CDM credits are much higher in non-energy-intensive sectors that feature more costly abatement options (see Table 10 for trade flows at the sectoral level). We find that industrialized regions increase their imports of carbon-offset credits by more than 40 percent when, additional to the CDM, reduced deforestation is included into international emissions trading. The volume of offset-credit imports is even higher when transaction costs of forestry projects are low.

[15] Note than in the table, emissions reductions of the four tropical rainforest regions only refer to reduced deforestation.

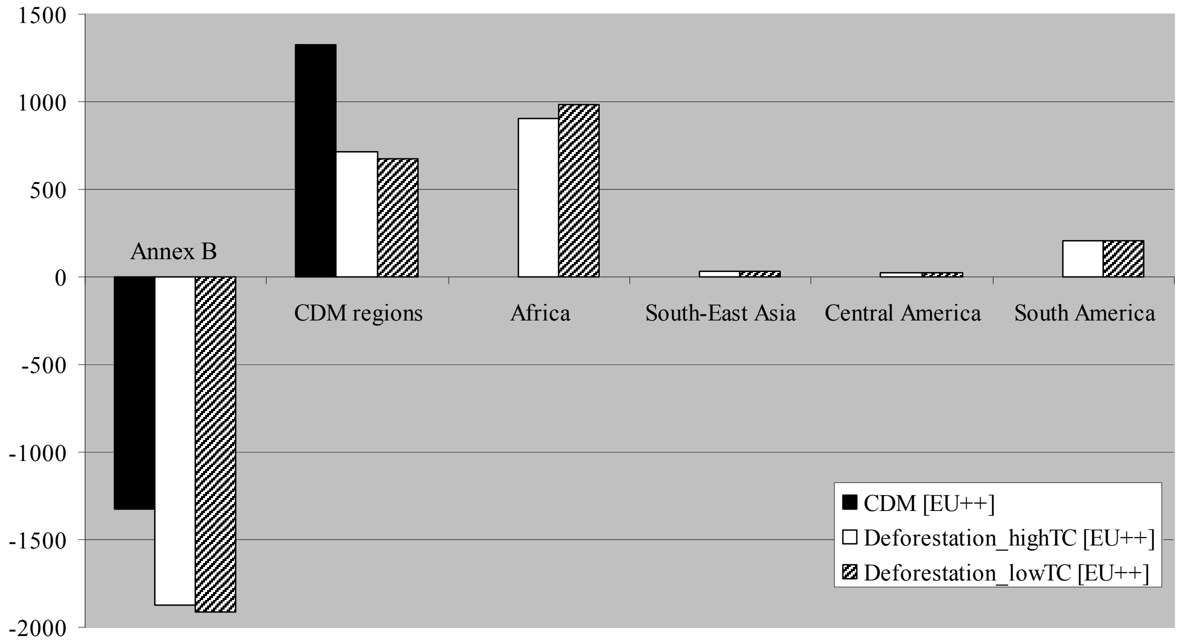

Figure 2: Offset credit exports (positive) and imports (negative) by region and scenario (Mt CO_2)

Figure 2 further illustrates that crediting carbon abatement from reduced deforestation is disadvantageous for traditional CDM host countries that feature only conventional abatement options. When tropical rainforest regions increase the supply of low-cost carbon abatement on the emissions market, aggregate permit exports of CDM regions decrease by roughly 50 percent. In this case, Africa represents the dominant supplier on the carbon market, featuring a larger export volume than all CDM regions together (amounting to almost one gigaton of CO_2). Among the regions reducing deforestation, Africa is followed by South America and South-East Asia in terms of credit-export volume. Finally, Figure 2 suggests that the export activity of tropical regions is more pronounced in the case of low forestry transaction costs: for Africa, offset-credit exports are almost ten percent higher.

4.3 Compliance costs and benefits from carbon trading

Economic impacts for industrialized regions

In the following we assess the overall compliance costs of carbon regulation and the potential benefits from reducing deforestation and trading emissions in 2020. Focusing first on industrialized countries, Figure 3 shows the resulting compliance costs for regional constellation EU^{++} associated with fulfilling the national Annex B emissions reduction targets across institutional scenarios (all numerical results are compiled in Table 11 of the Appendix).

Reflecting the sectorally heterogeneous marginal abatement cost levels and permit prices under pure Annex B emissions trading, we find that economic adjustment costs of NEIS amount to more than three times the compliance costs of EIS.

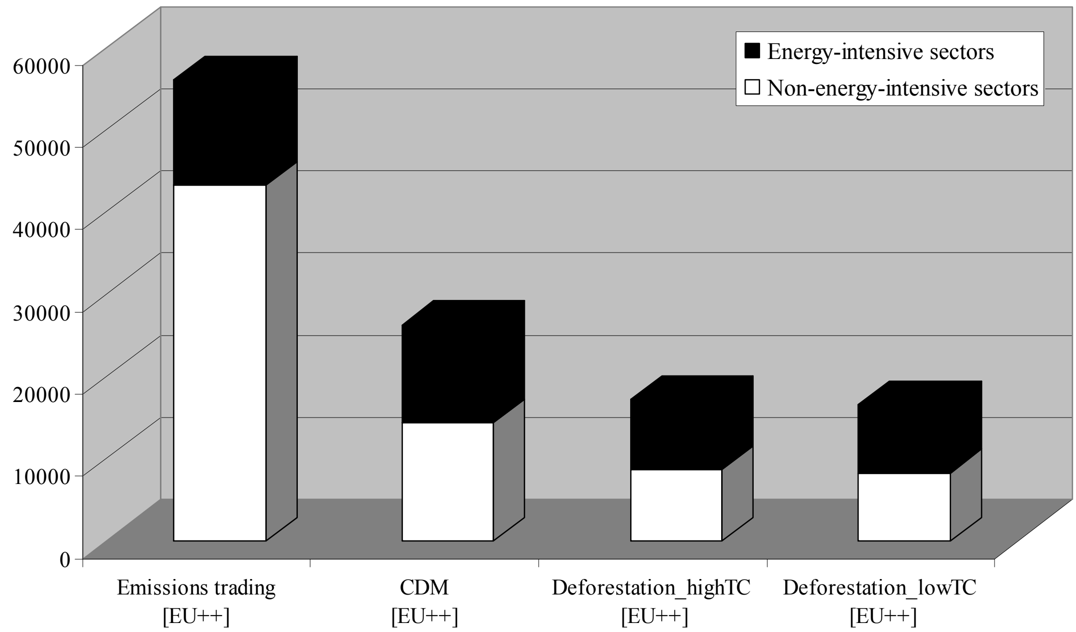

Figure 3: Annex B compliance costs by sector and scenario (million €2005)

The figure shows that the access to low-cost emissions abatement in CDM host countries decreases overall Annex B compliance costs by more than 50 percent. As the high-cost NEIS benefit more from project-based emissions crediting in developing countries through their national governments, the CDM diminishes the previous difference in sectoral economic burdens under pure emissions trading. Most importantly, we find that integrating avoided deforestation into international emissions trading induces a further substantial decrease in the costs of post-Kyoto climate policy. Total Annex B compliance costs fall by more than one third if also tropical rainforest regions may export carbon-offset credits to the industrialized world. As in the case of the CDM, it shows that NEIS of Annex B regions are benefiting to a larger extent from the access to credits from reducing deforestation than EIS, largely aligning the economic compliance burden of the two sectors in industrialized countries.

Figure 3 further suggests that consistent with the permit price impact of transaction costs related to forestry projects, their effect on overall costs is considerable: total compliance costs are resulting almost five percent higher in the case of high transaction costs as compared to low transaction costs. Finally, the numerical results in Table 11 imply that both the beneficial impact of crediting reduced deforestation and the cost-increasing impact of transaction costs are attenuated in the case of less integrated emissions trading systems (i.e. in regional scenarios *EU* and EU^{+}), as the demand for carbon-offset credits is lower in these regional constellations.

Economic impacts for developing regions

We now turn to the overall carbon-market impacts of climate policy in 2020 for developing countries. For transparency focusing on institutional scenarios involving the CDM and reduced deforestation with high transaction costs, Figure 4 shows negative compliance costs (i.e. net revenues) for regions which are exporters of permits on the international carbon market: the five CDM host countries, the four tropical rainforest regions and, for the sake of illustration, also the Former Soviet Union.[16]

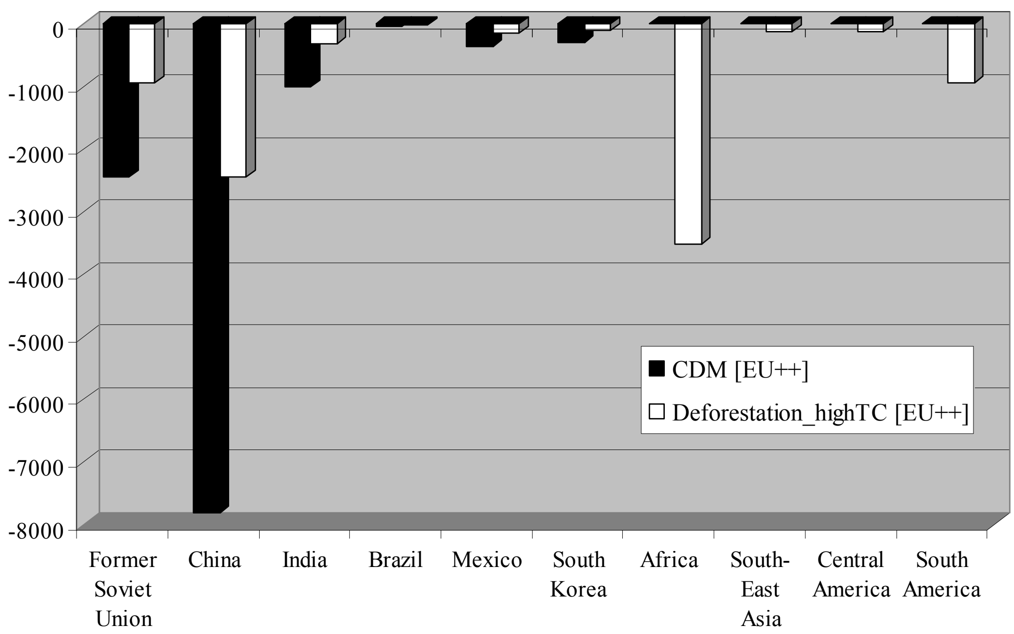

Figure 4: Compliance costs for developing regions by region and scenario (million €2005)

For the most integrated emissions trading system (regional scenario EU^{++}) the figure suggests that – consistent with the impacts on regional permit flows – including avoided deforestation in international emissions trading results in disadvantageous carbon-market impacts on the original carbon permit exporters. As soon as tropical rainforest regions may export carbon-offset credits to the industrialized world, the Former Soviet Union and all five CDM host

[16] Note that in the figure, the net revenues for the regions Brazil and Mexico only originate from CDM projects, while the numbers for Central and South America only include net revenues from reduced deforestation. For these regions, the carbon-market implications of the two scenarios would counteract on an aggregate level.

countries face substantially decreased revenues on the carbon market. While net benefits of the Former Soviet Union decrease by more than half, China, India and Brazil even face revenue losses of more than two thirds, even when accounting for high transaction costs of forestry projects. The increased competition on the emissions market decreases both the permit price and net revenues for the original permit exporters. Instead, tropical rainforest regions receive large net benefits from reducing deforestation, as their revenues from exporting the associated carbon-offset credits exceed their abatement costs in terms of foregone revenues from land use and forest product sales. Figure 4 indicates that the impact of avoided deforestation on the carbon market is large enough for Africa to replace China as the most benefiting permit supplier.

4.4 The role of the deforestation baseline

The economic implications of crediting forest conservation may be substantially influenced by the baseline against which the reductions in deforestation are measured. Obviously, higher deforestation baselines *ceteris paribus* imply higher levels of credited carbon abatement and vice versa. In this section we investigate this issue by simulating net carbon stock changes for alternative deforestation baselines with the numerical model of the forestry sector described in Section 2.1. For the sake of illustration we focus on alternative baselines for one exemplary tropical rainforest region, South America, assume CDM access for Annex B regions and median transaction cost values of forestry projects. From the results of Monte-Carlo simulations we choose the 5th and 95th percentile values (implying low and high deforestation baselines) of carbon stock changes for a sequence of carbon prices in 2020 and estimate the alternative marginal abatement cost coefficients for South America by the procedure described in Section 2.2. The resulting cost coefficients are presented in Table 5 of the Appendix.

Table 9 in the Appendix presents the resulting carbon-market implications in terms of the carbon price emerging from low and high deforestation baselines (scenarios *Deforestation_lowBase and Deforestation_highBase*). The simulation results show that a high baseline of South America results in an international permit price that is more than five percent lower than for a low baseline of deforestation. Clearly, the higher volume of generated carbon-offset credits supplied to the carbon market for a high deforestation baseline leads to a decrease in the permit price. Figure 5 illustrates how these carbon price impacts translate into changes in trade flows of emissions permits for the most integrated emissions trading system.

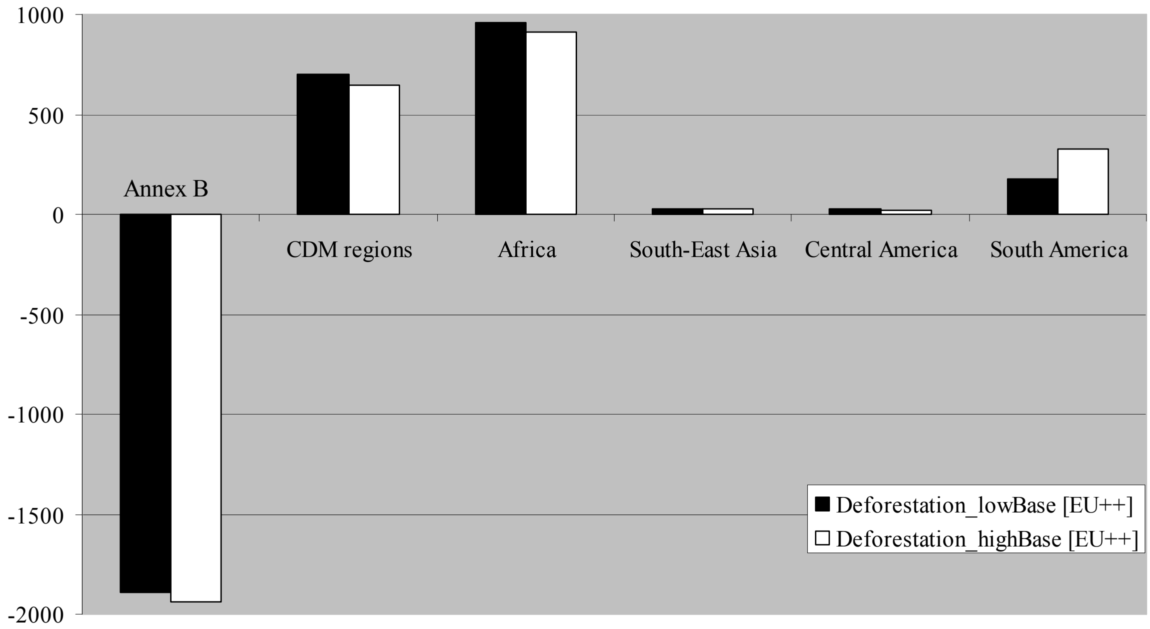

Figure 5: Offset credit exports (positive) and imports (negative) by region and scenario (Mt CO_2)

While industrialized countries import slightly more carbon-offset credits from the developing world in the case of a high deforestation baseline, traditional CDM host countries face lower permit exports due to the larger supply of low-cost carbon credits on the emissions market. Most importantly, South America's exports of carbon-offset credits to Annex B countries are more than 80 percent higher for a high deforestation baseline, causing the permit exports of the competing tropical rainforest regions Africa, South-East Asia and Central America to drop by five to eight percent. These results are underlined by the emissions reductions in Table 12 of the Appendix, implying that South America almost features double the amount of abatement from reduced deforestation for a high baseline.

Table 12 further shows that South America receives more than 50 percent higher net revenues from avoiding deforestation and exporting the associated offset credits in the case of a high baseline, while the three remaining tropical rainforest regions face lower benefits on the carbon market. Moreover, the simulations results across regional scenarios imply that the economic differences between high and low deforestation baselines become more pronounced in more integrated regional emissions trading constellations, as then both the international permit demand and the carbon price are higher. We conclude that uncertainties in deforestation baselines play an important role for the carbon market, even when concerning a single region only. However, our results suggest that while alternative baseline levels of one region do affect the economic impacts for the remaining rainforest regions via the carbon market, they are most substantial for the respective region itself.

4.5 Tightening Annex B carbon constraints

The previous sections showed that crediting carbon abatement from reduced deforestation represents an important mechanism for cost-efficient climate policy. However, the low-cost carbon abatement option of reduced deforestation may not only improve economic efficiency for the achievement of given global carbon constraints. It may also increase environmental effectiveness by enabling industrialized countries to tighten their carbon regulation at a given level of mitigation costs. In the following, we analyze this role of tropical forest conservation in greater detail.

We start with a more ambitious climate policy setting by suggesting more stringent carbon constraints of Annex B regions in 2020: as compared to the national emissions reduction targets presented in Section 2.3, industrialized countries are assumed to decrease their national emissions budgets granted by a post-Kyoto agreement by five percent. Consistently, we also tighten regional allocation factors within domestic emissions trading schemes by five percent. In the following, we compare two policy cases: (i) the original carbon constraints as presented in Section 2.3 including only CDM access for Annex B countries and (ii) five percent tighter carbon constraints including additional Annex B access to carbon-offset credits from reduced deforestation. Table 13 in the Appendix presents the resulting compliance costs by region and scenario. We find that for the most integrated emissions trading system (regional scenario EU^{++}) total compliance costs of the aggregate Annex B region result in comparable levels for case (i) and case (ii), amounting to 26.3 and 25.9 billion € respectively, even when accounting for high transaction costs of forestry projects. The access to carbon-offset credits from reduced deforestation enables the industrialized world to tighten its carbon constraints substantially at similar levels of mitigation costs.

However, Table 13 implies that these comparable effects on the aggregate Annex B level originate from heterogeneous cost effects across regions. While permit importers benefit from the access to low-cost abatement options from reducing deforestation despite of the stricter emissions reduction targets, those Annex B regions exporting permits to others (such as Eastern European economies or the Former Soviet Union) face higher compliance costs in case (ii). For these countries, the combination of lower revenues from permit sales (due to the higher aggregate permit supply) and stricter reduction targets results in economic losses. Moreover, we find divergent impacts of tightening Annex B carbon constraints at the sectoral level: while for energy-intensive industries the cost-increasing tightening of allowance allocation within linked ETS cannot be compensated by the access to offset credits from reducing deforestation, non-energy-intensive sectors experience a beneficial effect in regional scenario EU^{++}.

In less integrated emissions trading systems (regional scenarios EU and EU^{+}) total compliance costs are substantially even *lower* for the respective participants in the case of stricter climate policy and the access to carbon abatement from reduced deforestation. In these regional constellations the global demand for carbon-offset credits is lower, so that the cost-decreasing impact of reduced deforestation is stronger. This effect is underlined by Table 14 in the Appendix, which shows lower carbon prices for less integrated trading scenarios. An international climate regime with less Annex B participants could thus tighten regional carbon constraints by an even greater extent than five percent at constant mitigation costs, when the access to carbon abatement from reduced deforestation is facilitated.

5 Conclusions

Among future strategies to combat global warming, the reduction of tropical deforestation and the preservation of carbon-absorbing rainforests have gained increasing attention. This paper quantitatively assessed the implications of crediting carbon abatement from reduced deforestation for the global emissions market in 2020. In the framework of a post-Kyoto climate policy agreement, tropical rainforest regions would be able to export carbon-offset credits from reduced deforestation to the industrialized world. For our quantitative assessment we linked a numerical multi-country equilibrium model of the global carbon market with a dynamic model of the forestry sector by explicitly incorporating marginal cost functions of carbon abatement from reduced deforestation.

The simulation results show that integrating avoided deforestation into international emissions trading substantially decreases the costs of post-Kyoto climate policy. We find that the international carbon permit price is almost halved due to the low-cost credit supply from tropical rainforest regions. Consequently, total compliance costs for industrialized countries are decreased by more than one third if tropical rainforest regions may export carbon-offset credits to the industrialized world – even when accounting for conventional low-cost abatement options in developing countries via the CDM. Decomposition of these effects at the sectoral level shows that the compliance cost savings from crediting reduced deforestation are more substantial for non-energy-intensive sectors of Annex B countries, as these industries originally feature relatively high marginal abatement costs.

At the same time, tropical rainforest regions receive substantial net revenues from exporting carbon-offset credits from reducing deforestation to the industrialized world. However, as a consequence of including forestry management in the carbon market CDM host countries face decreasing revenues due to the increased competition for carbon-offset credit supply. Regarding international permit flows, we find that Africa represents the dominant supplier of carbon-offset credits from avoiding deforestation, reducing emissions from deforestation by roughly two thirds and exporting almost one gigatonne of CO_2. Africa is followed by South America, South-East Asia and Central America as secondary carbon credit exporters.

Regarding institutional barriers to reducing deforestation, we find that transaction costs of forestry projects arising from search, negotiation or insurance costs increase the international carbon price to a considerable extent. High levels of transaction costs may thus decrease the permit export activity of tropical rainforest regions, thereby increasing Annex B compliance costs by almost five percent. Furthermore, we show that the impact of forestry transaction costs generally increases with the number of Annex B countries participating in international emissions trading due to the higher global demand for carbon-offset credits.

The economic implications of crediting carbon abatement from avoided deforestation may be substantially influenced by the baseline against which the reductions in deforestation are measured. Simulating the economic implications for the case of South America, we find that deforestation baselines play an important role for the carbon market – even when concerning only a single region. South America almost doubles its exports of carbon-offset credits and receives more than 50 percent higher net revenues on the carbon market in the case of a high deforestation baseline. A higher baseline of one region also affects the economic impacts for others via the carbon market: both the remaining tropical rainforest regions and traditional CDM host countries exhibit lower permit exports.

Finally, the low-cost carbon abatement option of reduced deforestation may not only improve economic efficiency for the achievement of given global carbon constraints: it may also increase environmental effectiveness by enabling Annex B countries to strengthen their carbon regulation. Our simulation results show that crediting carbon abatement from reduced deforestation enables the industrialized world to tighten its carbon constraints by at least five percent – at constant levels of mitigation costs for post-Kyoto climate policy.

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Appendix A

A.1 Emissions market data

Table 3: Conventional abatement options: Marginal abatement cost coefficients in 2020 (€2005)

Regions	Energy-intensive sectors (EIS)			Non-energy-intensive sectors (NEIS)		
	$\beta_{1,EIS,r}$	$\beta_{2,EIS,r}$	$\beta_{3,EIS,r}$	$\beta_{1,NEIS,r}$	$\beta_{2,NEIS,r}$	$\beta_{3,NEIS,r}$
Austria	21.1480	-3.3392	0.8094	11.4095	2.8620	-0.1012
Belgium	2.8430	-0.0984	0.0026	5.8176	0.1881	0.0176
Denmark	11.1840	-0.5817	0.0235	59.6656	-12.7515	5.7710
Finland	3.0710	-0.0566	0.0032	75.2956	-14.0624	1.5541
France	0.9439	-0.0078	0.0002	1.5191	0.0784	-0.0007
Germany	0.3668	-0.0017	0.0000	0.9417	0.0111	0.0000
Greece	1.8843	-0.0118	0.0005	30.8964	-1.6083	0.3375
Ireland	3.0683	-0.1585	0.0110	23.4662	-0.3972	0.2788
Italy	0.9413	0.0036	0.0001	2.5992	0.1511	-0.0005
Netherlands	0.8665	0.0393	-0.0004	10.9863	-0.4063	0.1088
Portugal	11.0386	-0.5740	0.0175	56.1921	-9.2007	2.4941
Spain	0.8090	-0.0097	0.0002	10.3924	-0.4192	0.0137
Sweden	7.7433	-0.2814	0.0102	12.5684	1.7070	0.3807
United Kingdom	0.4066	-0.0022	0.0000	1.4731	0.0244	-0.0001
Central Europe	0.1466	0.0001	0.0000	0.7554	0.0008	0.0000
Canada	0.2766	0.0007	0.0000	0.8316	0.0044	0.0001
Japan	0.2666	0.0023	0.0000	1.3130	0.0313	-0.0001
Former Soviet Union	0.0218	0.0002	0.0000	0.1075	0.0004	0.0000
Pacifc OECD	0.7244	-0.0094	0.0001	1.8636	-0.0315	0.0005
United States	0.0245	0.0000	0.0000	0.1453	0.0000	0.0000
Brazil	11.5525	-0.0631	0.0001	4.1163	0.0006	0.0004
China	0.0129	0.0000	0.0000	0.3052	-0.0004	0.0000
India	0.0960	-0.0001	0.0000	2.2685	-0.0346	0.0008
Mexico	0.0116	0.0191	-0.0001	0.3852	0.0204	-0.0001
South Korea	0.3405	-0.0011	0.0000	4.1598	-0.0027	0.0010

Table 4: Avoided deforestation: Marginal abatement cost coefficients in 2020 (€2005)

Regions	High transaction costs			Low transaction costs		
	$\beta_{1,r}$	$\beta_{2,r}$	$\beta_{3,r}$	$\beta_{1,r}$	$\beta_{2,r}$	$\beta_{3,r}$
Africa	0.0175	-0.0001	0.0000	0.0191	-0.0001	0.0000
South-East Asia	0.2234	-0.0018	0.0000	0.1993	-0.0004	0.0000
Central America	0.2467	-0.0021	0.0000	0.2197	-0.0004	0.0000
South America	0.0303	0.0000	0.0000	0.0270	0.0000	0.0000

Table 5: Avoided deforestation – alternative baseline for South America: Marginal abatement cost coefficients in 2020 (€2005)

Regions	Low baseline			High baseline		
	$\beta_{1,r}$	$\beta_{2,r}$	$\beta_{3,r}$	$\beta_{1,r}$	$\beta_{2,r}$	$\beta_{3,r}$
Africa	0.0175	-0.0001	0.0000	0.0191	-0.0001	0.0000
South-East Asia	0.2234	-0.0018	0.0000	0.1993	-0.0004	0.0000
Central America	0.2467	-0.0021	0.0000	0.2197	-0.0004	0.0000
South America	0.0158	0.0005	0.0000	0.0166	0.0000	0.0000

Table 6: CO_2 benchmark emissions and reduction requirements by region and year

Regions	CO_2 emissions in 1990 (Mt CO_2)	CO_2 emissions in 2010 (Mt CO_2)	CO_2 emissions in 2020 (Mt CO_2)	Reduction requirements in 2010 (% vs. 1990)	Reduction requirements in 2020 (% vs. 1990)	Reduction requirements in 2020 (% vs. 2020)
Austria	59.6	73.4	74.1	13.0	24.3	39.1
Belgium	110.1	142.7	143.9	7.5	19.6	38.5
Denmark	50.4	58.6	59.1	21.0	31.3	41.4
Finland	54.2	64.7	65.2	0.0	13.0	27.7
France	377.3	418.0	421.0	0.0	13.0	22.1
Germany	988.3	954.6	963.0	21.0	31.3	29.5
Greece	75.8	105.5	106.1	-25.0	-8.7	22.3
Ireland	33.0	49.5	49.8	-13.0	1.7	34.9
Italy	417.5	508.4	511.7	6.5	18.7	33.7
Netherlands	158.5	200.3	201.8	6.0	18.3	35.8
Portugal	43.6	74.3	74.7	-27.0	-10.4	35.6
Spain	225.8	349.0	351.1	-15.0	0.0	35.7
Sweden	49.8	49.8	49.8	-4.0	9.6	9.6
United Kingdom	577.4	640.0	646.5	12.5	23.9	32.0
Central Europe	1042.1	893.2	1110.4	-4.8	8.8	14.4
Canada	427.5	597.9	602.3	6.0	-12.7	20.0
Japan	1091.4	1264.8	1168.3	6.0	14.4	20.0
Former Soviet Union	3605.4	2489.4	2764.3	0.0	23.3	0.0
Pacific OECD	292.0	449.7	446.1	(-8.0)	-29.9	15.0
United States	4890.8	6410.1	6500.0	(7.0)	-13.0	15.0
Brazil	214.0	567.4	838.2	-	-	-
China	2495.7	5038.3	6491.2	-	-	-
India	616.1	1764.9	2934.5	-	-	-
Mexico	309.0	572.4	733.7	-	-	-
South Korea	253.7	658.7	853.0	-	-	-

Sources: Netherlands Environment Assessment Agency (Van Vuuren et al., 2006), UNFCCC (1997), EU (2007a); own calculations

Table 7: Allocation factors by region in 2010 and 2020

Model region	Allocation factor in 2010	Allocation factor in 2020
Austria	0.813	0.650
Belgium	0.943	0.755
Germany	0.876	0.701
Denmark	0.822	0.657
Spain	0.693	0.554
France	0.907	0.726
Finland	1.000	0.800
Greece	0.865	0.692
Ireland	0.750	0.600
Italy	0.849	0.679
Netherlands	0.893	0.715
Portugal	0.839	0.671
Sweden	1.065	0.852
United Kingdom	0.900	0.720
Central Europe	0.928	0.742
Canada	-	0.800
Japan	-	0.800
Former Soviet Union	-	1.000
Pacific OECD	-	0.850
United States	-	0.850

A.2 Numerical simulation results

Table 8: Core scenarios: Carbon permit price by scenario and sector in 2020 (€2005 per tCO_2)

Scenario \ Scenario	***Emissions Trading***		***CDM***	
	EIS	***NEIS***	***EIS***	***NEIS***
[EU]	54.9	248.2	9.2	9.2
[EU⁺]	27.6	88.7	10.8	10.8
[EU⁺⁺]	18.5	77.7	13.2	13.2
Scenario \ Scenario	***Deforestation_highTC***		***Deforestation_lowTC***	
	EIS	***NEIS***	***EIS***	***NEIS***
[EU]	5	5	4.9	4.9
[EU⁺]	5.8	5.8	5.2	5.2
[EU⁺⁺]	7.6	7.6	7.2	7.2

Table 9: Alternative baseline for South America: Carbon permit price by scenario and sector (€2005 per tCO_2)

Scenario \ Scenario	***Deforestation_lowBase***		***Deforestation_highBase***	
	EIS	***NEIS***	***EIS***	***NEIS***
[EU]	4.9	4.9	4.7	4.7
[EU⁺]	5.5	5.5	5.3	5.3
[EU⁺⁺]	7.5	7.5	7	7

Table 10: Core scenarios: Total emissions reductions (% of BAU) and sectoral net exports of carbon-offset credits by scenario and region in 2020 (Mt CO_2)

Scenario / Region	***Emissions Trading [EU]***			***CDM [EU]***			***Deforestation_highTC [EU]***			***Deforestation_lowTC [EU]***		
	Reduction TOTAL	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***
EU	54.1	0	0	8.2	-584.9	-522.6	4.6	-659.8	-539.8	4.4	-662.9	-540.6
EU+	35.5	0	0	11.8	-584.9	-522.6	9.9	-659.8	-539.8	9.8	-662.9	-540.6
EU++	33.1	0	0	19.6	-584.9	-522.6	18.5	-659.8	-539.8	18.5	-662.9	-540.6
Africa	0	0	0	0	0	0	26.9	378.6		27.9	392.5	
South-East Asia	0	0	0	0	0	0	4.5	17.3		4.8	18.1	
Central America	0	0	0	0	0	0	9.6	15.1		10.1	15.8	
South America	0	0	0	0	0	0	8.7	123		9.1	128.8	

Scenario / Region	***Emissions Trading [EU+]***			***CDM [EU+]***			***Deforestation_highTC [EU+]***			***Deforestation_lowTC [EU+]***		
	Reduction TOTAL	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***
EU	30.1	0	0	9.6	-398.4	-488.4	5.2	-537.2	-529.5	4.7	-552.6	-533.8
EU+	35.5	0	0	12.3	-477.8	-592.1	7.4	-659.1	-652	6.7	-682.5	-659.4
EU++	33.1	0	0	19.9	-477.8	-592.1	17	-659.1	-652	16.6	-682.5	-659.4
Africa	0	0	0	0	0	0	42.6	599.3		49.8	700.9	
South-East Asia	0	0	0	0	0	0	5.4	20.8		5.2	19.7	
Central America	0	0	0	0	0	0	11.5	18.1		11	17.3	
South America	0	0	0	0	0	0	10.4	147.4		9.9	140.5	

Scenario / Region	***Emissions Trading [EU++]***			***CDM [EU++]***			***Deforestation_highTC [EU++]***			***Deforestation_lowTC [EU++]***		
	Reduction TOTAL	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***
EU	23.6	0	0	11.7	-277.9	-630.1	6.8	-573.8	-677.6	6.5	-589.9	-681.5
EU+	29.2	0	0	14.5	-334.9	-742	9.2	-689.6	-815.4	8.8	-711.3	-821.6
EU++	33.1	0	0	16.4	-368.9	-959.9	9.9	-808.6	-1066.6	9.4	-840.8	-1074.7
Africa	0	0	0	0	0	0	64	901		69.7	981.3	
South-East Asia	0	0	0	0	0	0	7.6	28.9		7.7	29.2	
Central America	0	0	0	0	0	0	16	25.2		16.2	25.5	
South America	0	0	0	0	0	0	14.5	205.2		14.6	207.6	

Table 11: Core scenarios: Compliance costs by scenario, region and sector in 2020 (million €2005)

Scenario / Region	***Emissions Trading [EU]***			***CDM [EU]***			***Deforestation_highTC [EU]***			***Deforestation_lowTC [EU]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	75487.6	17776.6	57711	11171.8	6166.3	5005.5	6336.1	3557.5	2778.6	6129.9	3443.9	2686
EU^{+}	100954.8	21940.8	79014	36639	10330.5	26308.5	31803.3	7721.7	24081.6	31597.1	7608.1	23989
EU^{++}	120949.2	25431.9	95517.3	56633.4	13821.6	42811.8	51797.7	11212.8	40584.9	51591.5	11099.2	40492.3
Africa	0	0	0	0	0	0	-1042.4			-990.1		
South-East Asia	0	0	0	0	0	0	-54			-55.1		
Central America	0	0	0	0	0	0	-48.2			-49.3		
South America	0	0	0	0	0	0	-391.9			-400.5		
Scenario / Region	***Emissions Trading [EU^{+}]***			***CDM [EU^{+}]***			***Deforestation_highTC [EU^{+}]***			***Deforestation_lowTC [EU^{+}]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	50496.2	14113.6	36382.6	12915.8	7079.5	5836.3	7244.6	4055.3	3189.3	6541	3670	2871
EU^{+}	38944.3	11193.3	27751	14545.6	7407.1	7138.5	8571.8	4558.4	4013.4	7787	4161.6	3625.4
EU^{++}	58938.7	14684.4	44254.3	34540	10898.2	23641.8	28566.2	8049.5	20516.7	27781.4	7652.7	20128.7
Africa	0	0	0	0	0	0	-1708.3			-1585.9		
South-East Asia	0	0	0	0	0	0	-72.9			-63.7		
Central America	0	0	0	0	0	0	-65.1			-56.9		
South America	0	0	0	0	0	0	-529.1			-462.5		
Scenario / Region	***Emissions Trading [EU^{++}]***			***CDM [EU^{++}]***			***Deforestation_highTC [EU^{++}]***			***Deforestation_lowTC [EU^{++}]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	43893.6	10827.1	33066.5	15429.9	8365.7	7064.2	9310.1	5174.6	4135.5	8852.7	4928.4	3924.3
EU^{+}	37514.6	10121.9	27392.7	16985.9	8458.5	8527.4	10820.4	5669.2	5151.2	10329.6	5430.2	4899.4
EU^{++}	56108.2	12835.6	43272.6	26293.2	11889.1	14404.1	17258.1	8580.8	8677.3	16503	8252.1	8250.9
Africa	0	0	0	0	0	0	-3522.7			-3705.1		
South-East Asia	0	0	0	0	0	0	-127.7			-124		
Central America	0	0	0	0	0	0	-114.2			-111.1		
South America	0	0	0	0	0	0	-928.7			-903.2		

Table 12: Alternative baseline for South America: Total emissions reductions (% of BAU), sectoral net exports of carbon-offset credits and compliance costs by scenario and region in 2020 (Mt CO_2)

Scenario / Region	***Deforestation_lowBase [EU]***			***Deforestation_highBase [EU]***			***Deforestation_lowBase [EU]***			***Deforestation_highBase [EU]***		
	Reduction TOTAL	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***
EU	4.5	-662	-540.4	4.3	-665.5	-541.2	6186.2	3475	2711.2	5952.4	3346.2	2606.2
EU^{+}	9.8	-662	-540.4	9.8	-665.5	-541.2	31653.4	7639.2	24014.2	31419.6	7510.4	23909.2
EU^{++}	18.5	-662	-540.4	18.4	-665.5	-541.2	51647.8	11130.3	40517.5	51414	11001.5	40412.5
Africa	28	394.6		24.2	340.7		-1027.8			-886.3		
South-East Asia	4.6	17.6		4.4	16.7		-54			-49.6		
Central America	9.8	15.4		9.3	14.6		-48.2			-44.3		
South America	8.6	121.9		14.2	201.4		-412.3			-610.1		

Scenario / Region	***Deforestation_lowBase [EU^{+}]***			***Deforestation_highBase [EU^{+}]***			***Deforestation_lowBase [EU^{+}]***			***Deforestation_highBase [EU^{+}]***		
	Reduction TOTAL	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***
EU	5	-545.6	-531.8	4.8	-551.2	-533.2	6867.9	3849.4	3018.5	6673.5	3743	2930.5
EU^{+}	7	-671.7	-655.8	6.8	-678.1	-658.1	8152.8	4347.3	3805.5	7935.5	4237.3	3698.2
EU^{++}	16.8	-671.7	-655.8	16.7	-678.1	-658.1	28147.2	7838.4	20308.8	27929.9	7728.4	20201.5
Africa	47.1	662.7		41.9	589.8		-1684.7			-1484.2		
South-East Asia	5.3	20.3		5.1	19.5		-68.1			-64		
Central America	11.3	17.7		10.8	17.1		-60.9			-57.1		
South America	9.5	134.7		16.5	234.5		-503.1			-786.4		

Scenario / Region	***Deforestation_lowBase [EU^{++}]***			***Deforestation_highBase [EU^{++}]***			***Deforestation_lowBase [EU^{++}]***			***Deforestation_highBase [EU^{++}]***		
	Reduction TOTAL	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***
EU	6.7	-578.1	-679	6.2	-600.8	-683.6	9162.1	5094.9	4067.2	8598.4	4791.1	3807.3
EU^{+}	9	-696.6	-817.5	8.6	-723.3	-824.8	10661.9	5592	5069.9	10054.9	5295.7	4759.2
EU^{++}	9.7	-818.9	-1069.3	9.1	-859	-1078.9	17014.7	8475.2	8539.5	16078.4	8064.8	8013.6
Africa	67.9	956.6		64.9	913.7		-3758.6			-3237.3		
South-East Asia	7.7	29.5		7.1	27.2		-129.1			-112.1		
Central America	16.4	25.8		15.1	23.8		-115.6			-100.3		
South America	12.4	175.4		22.9	325		-868.8			-1376.2		

Table 13: Tighter carbon constraints: Compliance costs by scenario, region and sector (million €2005)

Region \ Scenario	***CDM [EU]*** ***- Original carbon contraints -***			***Deforestation_highTC [EU]*** ***- Tighter carbon constraints -***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	11171.8	6166.3	5005.5	7784.8	4314.7	3470.1
EU^+	36639	10330.5	26308.5	47553.3	10874.2	36679.1
EU^{++}	56633.4	13821.6	42811.8	80931.6	16588.1	64343.5
Africa	0	0	0	-1363.4		
South-East Asia	0	0	0	-63.8		
Central America	0	0	0	-57		
South America	0	0	0	-463.1		
Region \ Scenario	***CDM [EU^+]*** ***- Original carbon contraints -***			***Deforestation_highTC [EU^+]*** ***- Tighter carbon constraints -***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	12915.8	7079.5	5836.3	8752.4	4838.6	3913.8
EU^+	14545.6	7407.1	7138.5	11412.9	6049	5363.9
EU^{++}	34540	10898.2	23641.8	44791.2	11762.9	33028.3
Africa	0	0	0	-2075.4		
South-East Asia	0	0	0	-82.7		
Central America	0	0	0	-73.9		
South America	0	0	0	-600.9		
Region \ Scenario	***CDM [EU^{++}]*** ***- Original carbon contraints -***			***Deforestation_highTC [EU^{++}]*** ***- Tighter carbon constraints -***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	15429.9	8365.7	7064.2	12489	6832.2	5656.8
EU^+	16985.9	8458.5	8527.4	15965	8304	7661
EU^{++}	26293.2	11889.1	14404.1	25932.9	12873.1	13059.8
Africa	0	0	0	-5056.7		
South-East Asia	0	0	0	-182.5		
Central America	0	0	0	-163.5		
South America	0	0	0	-1329.3		

Table 14: Tighter carbon constraints: Carbon permit price by scenario and sector (€2005 per tCO_2)

Scenario \ Scenario	***CDM*** ***- Original carbon contraints -***		***Deforestation_highTC*** ***- Tighter carbon constraints -***	
	EIS	***NEIS***	***EIS***	***NEIS***
[EU]	9.2	9.2	5.5	5.5
[EU^+]	10.8	10.8	6.2	6.2
[EU^{++}]	13.2	13.2	9	9