Integration of REDD into the international carbon market: Implications for future commitments and market regulation

17 November 2008

Prepared for

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Abstract

Integrating reduced emissions from deforestation and degradation (REDD) into a post-Kyoto intergovernmental carbon market could significantly decrease global carbon prices and the costs of mitigating climate change. We investigate this impact by simulating the impact of the supply of REDD units on the international carbon market in 2020 under unlimited and restricted exchange conditions.

We find restricting supply or demand of REDD credits reduces such price impacts, but comes at the cost of economic efficiency. The introduction of deeper Annex I emissions reduction commitments reduces the impact on global carbon prices, but entails substantial compliance costs and wealth transfers. While REDD provides large economic benefits for tropical rainforest regions, any REDD fungibility scenario which results in a reduction in the international price of carbon also reduces transfers to the CDM host countries.

Our modelling indicates unrestricted exchange of REDD units reduces the international carbon price by half and cuts Annex I compliance costs by roughly one third if projected emissions reduction commitments are unchanged. Alternatively, Annex I reduction commitments could be increased by around 60 percent at constant carbon prices.

The findings of this research have relevance for policy makers and academics seeking to understand carbon market implications of supply variability and policymakers considering the introduction of REDD market mechanisms.

Introduction

With deforestation emissions representing up to 20 percent of anthropogenic emissions, reducing emissions from deforestation and degradation (REDD) has been proposed as a comparatively inexpensive and plentiful source of emission reductions.

Proposals for including REDD in the global response to climate change have gained momentum in recent years. While the basic premise of REDD is universal to all proposals—that emissions are avoided through reductions in the rate of deforestation—virtually all other aspects, from measurement methodologies to financing sources, are still being debated in the lead up to COP 15 at Copenhagen.

Most REDD proposals identify global funds or emissions trading markets (or both) as preferred sources of funding.

Advocates of market-based approaches cite the benefits of allocative efficiency and the ability to mobilise the large amounts of capital required to enable the potential large emissions reductions.

For a REDD market mechanism to advance, critics will need to be assured that:

- REDD units are environmentally equivalent to other international compliance units; and
- REDD units will not overwhelm the emissions markets in which they are traded.

This paper focuses on the second point – the impact of introducing fungible REDD units to emissions markets. Toward this end we quantitatively explore the integration of REDD credits into a post-2012 carbon market.

The prospect of maintaining international emissions prices through expanded commitments is explored. We also investigate the dynamics of several commonly suggested fungibility restrictions, supply restrictions and supplementarity requirements.

In this paper, it is assumed that the REDD-derived units (as delivered to the market) are environmentally equivalent to other trading units. This assumption frees us to discuss exclusively the carbon market impacts of REDD integration.

Improved near-term understanding of the potential impact of REDD on carbon markets is critical if market mechanisms are to be retained as an option for promoting REDD for the next commitment period. Failure to adequately grasp these issues risks REDD succumbing to the apparent fate of the CDM's Afforestation/Reforestation (A/R) activities, where "modalities and procedures….that were agreed in 2003 were designed to restrict activities whose inclusion was not taken into consideration when establishing targets" Baalman and Schlamadinger (2008).

We begin by reviewing common concerns about the impact of the introduction of REDD credits to carbon markets in Section 1. We summarise our simulation approach and review the trends in commitments which feed our assumptions in Section 2. We then discuss the modelling results and sensitivity analysis in Section 3. Section 4 discusses the implications of the results for negotiations, while Section 5 evaluates some limitations of our current approach. Section 6 concludes.

Further detail is available in the Appendices. Appendix A provides additional information on the model employed and supporting datasets. Appendix B provides details on the marginal abatement cost functions, while Appendix C expands on simulation results. Appendix D sets out the economic intuition underlying the results.

1. Robustness of carbon markets

Some Parties are concerned the inclusion of offset credits from CDM and REDD activities may adversely affect existing and planned emissions markets. The European Commission, for example, notes that the introduction of REDD units into the EU ETS would result in a serious supply and demand imbalance (European Commission, 2008). Others are concerned with the prospect of a diminished carbon price signal.

The European experience with Phase I of the European Union Emission Trading System (EU ETS) provides a historical example of emissions market volatility and the consequences of supply outstripping demand in compliance markets. Prices for Phase I units collapsed into the range of euro cents when it became apparent that the allocation of emissions allowances exceeded demand. EU belt tightening on Phase II targets has so far managed to avoid a similar experience.

The precise supply of REDD units is uncertain. Factors such as weather, commodity prices, and technology change may impact the supply of REDD credits at any given time. Although the design of a REDD scheme can mitigate some of this variability, its uncertainty cannot be eliminated.

An increase in commitments which is not ultimately met by a commensurate increase in supply of units (such as from REDD) will result in a higher overall market clearance price and compliance cost than would have otherwise occurred. Excessive increases in compliance costs could lead to a decreased appetite for adopting future commitments. In an extreme case, overly burdensome compliance costs could cause some participants to quit their obligations or cause a collapse of the treaty.

On the other hand, if REDD units are oversupplied to the market, unit prices and overall compliance costs will decline. Such an experience may promote willingness for the adoption of more aggressive targets in the future.

Assuming REDD units are environmentally robust, the over-supply and under-supply conditions described above are neutral with respect to the environment in the short term. In both cases, emissions reduction commitments are met. In the longer term, however, action against climate change can be affected negatively if post-Kyoto markets are not sufficiently robust to absorb supply shocks such as from REDD. As described above, a reduced willingness to take on commitments can result from an undersupply of REDD units which cannot be effectively substituted with alternate abatement.

In the case of oversupply, while nations could compensate by increasing commitments in subsequent periods, depressed carbon prices could negatively impact investments in capital intensive low-carbon technologies. The resulting investment in higher carbon intensity, long-lived technologies will result in an economic structure with higher carbon intensity than otherwise would have resulted.

Administrative considerations are also relevant. If transactions costs are too high or regulations too difficult to navigate, for example, anticipated supplies of REDD units may not develop. One study found transaction costs for CDM A/R projects are roughly twice the typical cost of other projects (Baalman & Schlamadinger, 2008). REDD crediting, depending on the methodology chosen, may be even more involved than A/R crediting. Pilot projects may be used to provide valuable information on transaction costs and accounting burdens.

The challenges posed by the uncertainty of REDD supply merit careful study. While the European Commission is cautious about the inclusion of REDD in the EU ETS, the Commission intends to test the inclusion of REDD units for government compliance (European Commission, 2008). In this project, we evaluate the robustness of the post-Kyoto carbon market to REDD supply shocks by undertaking a sensitivity analysis around the marginal abatement cost function of the forestry sectors in the REDD-supplying regions.

2. Modelling of REDD carbon market interactions

2.1 Introduction to selected methodology

We employ a numerical multi-country, two-sector partial equilibrium model of the global carbon market to quantify the carbon market impacts of reducing deforestation (Anger and Sathaye, 2008; Anger, 2008). The modelling framework features explicit marginal abatement cost functions based on energy-system data and is calibrated to represent the carbon market under a post-Kyoto agreement in the year 2020. Furthermore, marginal abatement cost functions for REDD are implemented into the model by covering tropical rainforest areas as explicit model regions. Within this model framework, developing countries may export emissions reduction credits from reducing deforestation to Annex I regions via the global carbon market.

In order to represent the response of the forestry sector to changes in future carbon prices, we use data from the dynamic partial equilibrium model *Generalized Comprehensive Mitigation Assessment Process* GCOMAP (Sathaye et al., 2005, 2006).

Further detail on the model employed for this study is provided in Appendix A.

2.2 Assumptions and parameters

Regions

Table 1 presents the regional groupings of the carbon-market model as well as the classification of regions into Annex I regions, CDM host countries and tropical rainforest regions.

Table 1 Regional participation in 2020

International emissions trading (Annex I) regions	CDM regions	Tropical rainforest regions
EU-27 Canada Japan Former Soviet Union Pacific OECD* United States	Brazil China India Mexico South Korea	Africa South-East Asia Central America South America

* The Pacific OECD region essentially comprises Australia and New Zealand.

Business-as-usual emissions

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

Our study assumes that the framework established under the Kyoto Protocol is retained for the 2012-2020 period. In particular, it is assumed that Kyoto mechanisms remain in place and that the Parties with commitments are restricted to those parties in Annex I that have commitments under Kyoto. Of course, these matters are currently the subject of negotiation.

The COP 13 (Bali) decision to launch negotiations on strengthening international actions to address climate change indicates that at a high level all Parties are willing to take actions beyond what they have already agreed to under the Convention and, for some Parties, under the Protocol. During and after COP 13, many Annex I Parties made statements indicating their willingness to take on new and more demanding commitments.

Our modelling uses post-Kyoto emissions reduction targets for Annex I Parties[1] based on public announcements of emissions targets for 2020, where available.
Three of the largest Annex I players have yet to make declarations akin to those announced by most other Annex I parties: the United States, Russia and Ukraine.

The United States is not participating in the Kyoto Protocol. President-elect Barak Obama, however advocates a national cap-and-trade scheme for emissions and a target of reducing US emissions to 1990 levels by 2020 (Obama and Biden, 2008). Ultimately, the nature of the participation will depend on the machinations of the US political system and the political willingness to make any such commitments at a time of, or immediately following, an economic downturn.

Russia and the Ukraine are expected to have surplus AAUs at the end of the first commitment period.[2] However, whether either would agree to deeper reductions than what they agreed under Kyoto is open to question. Both have relatively low incomes in GDP per capita terms compared with most other Annex I countries (Ukraine in particular).[3] The approach that the EU has tended to take to equivalent EU countries in setting targets has been to allow such countries to increase their emissions, but at a reducing rate. The approach taken to this issue will be an important signal to developing countries for whether they consider it viable to take on commitments.

The final assumptions about commitments follow below. If countries announced two targets, with the higher depending on full international agreement, the lower target was chosen:

- the EU applies its target of 20 percent reduction from 1990 levels, rather than 30 percent;[4]

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[1] Consistent with Article 3.1 of the Kyoto Protocol, we refer to Parties assigned commitments under the Protocol as "Annex I Parties". The Article 3.1 reference to Annex I Parties is a reference to those Parties listed in Annex I of the United Nations Framework Convention on Climate Change. However, it should be noted that one Annex I Party, Turkey, was not assigned a target in Annex B of the Protocol.

[2] Refer to Box 11.1, p. 170, Eliasch, 2008.

[3] International Monetary Fund, World Economic Outlook Database, October 2008.

[4] At the 2007 European Spring Council, the EU set a unilateral target of 20 percent emissions reductions relative to 1990 levels for 2020. "Provided that other developed countries commit themselves to comparable emission reductions and economically more advanced developing countries contribute adequately according to their responsibilities and respective capabilities" the target will be increased to 30 percent"(Council of the European Union, 2007).

- the United States participates in a post-2012 agreement with a target of a 0 percent reduction in emissions relative to 1990 levels;
- Canada has a target of reducing emissions by 20 percent relative to 2006 levels by 2020 (Government of Canada, 2008);
- Japan has a target of reducing emissions by 14 percent relative to 2005 levels by 2020 (Fukuda, 2008);
- the Pacific OECD (Australia and New Zealand) has a target of 10 percent reduction relative to 2000 levels by 2020;[5] and
- the former Soviet Union has a target of no increase over current projections for 2020 emissions.[6]

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[5] Note that this was the target initially proposed Professor Garnaut. In the *Final report,* which was published after these parameters were selected, the recommended target is a 25percent reduction relative to 2000 levels by 2020 "so long as the components of that agreement add up to the concentrations objective [of 450 ppm CO_2e]" (page xiv). If the objective is 550 ppm CO_2e the *Final report* recommends a target of 10percent below 2000 levels by 2020 (Garnaut, 2008).

[6] As assumed in Anger and Sathaye (2007).

Table 2 Baseline emissions and emission reduction targets by region in 2020 ***(explicit commitments in bold numbers)***

Region	CO_2 emissions in 1990 ($Mt\ CO_2$)	CO_2 emissions in 2000 ($Mt\ CO_2$)	CO_2 emissions in 2005 ($Mt\ CO_2$)	CO_2 emissions in 2020 ($Mt\ CO_2$)	Reduction requirements in 2020 (% vs. 1990)	Reduction requirements in 2020 (% vs. 2000)	Reduction requirements in 2020 (% vs. 2005)	Reduction requirements in 2020 (% vs. 2020)
Austria	59.6			74.1	24.3			39.1
Belgium	110.1			143.9	19.6			38.5
Denmark	50.4			59.1	31.3			41.4
Finland	54.2			65.2	13.0			27.7
France	377.3			421.0	13.0			22.1
Germany	988.3			963.0	31.3			29.5
Greece	75.8			106.1	-8.7			22.3
Ireland	33.0			49.8	1.7			34.9
Italy	417.5			511.7	18.7			33.7
Netherlands	158.5			201.8	18.3			35.8
Portugal	43.6			74.7	-10.4			35.6
Spain	225.8			351.1	0.0			35.7
Sweden	49.8			49.8	9.6			9.6
United Kingdom	577.4			646.5	23.9			32.0
Eastern Europe	1042.1			1110.4	8.8			14.4
EU-27	4263.4			4828.1	**20.0**			27.2
Canada	427.5	521.8	578.5	602.3	-8.3		**20.0**	23.2
Japan	1091.4	1225.6	1271.1	1168.3	-0.2		**14.0**	6.4
Former Soviet Union	3605.4	2311.4	2401.0	2764.3	23.3			**0.0**
Pacific OECD	292.0	369.2	420.4	446.1	-13.8	**10.0**		25.5
United States	4890.8	5766.2	6237.5	6500.0	**0.0**			24.8
Brazil	214.0			838.2	-			-
China	2495.7			6491.2	-			-
India	616.1			2934.5	-			-
Mexico	309.0			733.7	-			-
South Korea	253.7			853.0	-			-

2.3 Policy scenarios

Importing substantial numbers of emissions credits into a cap-and-trade system risks creating oversupply, leading to price collapse. To better understand the magnitude of such impacts, various policy scenarios are modelled as summarised in Table 3.

Table 3 Carbon market scenarios for 2020

<table>
<tr><th>Institutional scenario</th><th>International emissions trading</th><th>REDD access</th><th>REDD restriction</th><th>Commitment levels</th></tr>
<tr><td>IET</td><td>Governmental emissions trading</td><td rowspan="2">No</td><td rowspan="2">–</td><td rowspan="3">Core</td></tr>
<tr><td>BASE CASE</td><td rowspan="11">Governmental emissions trading including the CDM</td></tr>
<tr><td>REDD</td><td rowspan="2">Unlimited</td><td rowspan="2">No</td></tr>
<tr><td>REDD_EXP</td><td>Expanded</td></tr>
<tr><td>REDD_DEM</td><td rowspan="2">Demand-side restriction</td><td rowspan="2">20% of Annex I region's reduction requirement in 2020</td><td>Core</td></tr>
<tr><td>REDD_DEM_EXP</td><td>Expanded</td></tr>
<tr><td>REDD_SUP</td><td rowspan="2">Supply-side Restriction</td><td rowspan="2">Equivalent (in aggregate) in supply terms to the demand restriction**</td><td>Core</td></tr>
<tr><td>REDD_SUP_EXP</td><td>Expanded</td></tr>
<tr><td>REDD_MAC</td><td rowspan="4">Unlimited</td><td>Halving of REDD marginal abatement costs</td><td rowspan="2">Core</td></tr>
<tr><td>REDD_MAC+</td><td>Doubling of REDD marginal abatement costs</td></tr>
<tr><td>REDD_MAC_EXP</td><td>Halving of REDD marginal abatement costs</td><td rowspan="2">Expanded to match REDD_EXP commitments</td></tr>
<tr><td>REDD_MAC+_EXP</td><td>Doubling of REDD marginal abatement costs</td></tr>
</table>

Our base case is comprised of expected commitments that would develop without the import of any REDD credits. These core commitments are described in Table 2.

Against this base case, we have modelled a scenario with unlimited REDD credit imports but with the same level of emissions reductions. This scenario tests the impact of unlimited REDD fungibility and represents the "maximum price impact" scenario. It also provides a metric against which the other policy scenarios can be measured.

Managed (or restricted) fungibility of REDD units has been proposed to mitigate concerns about both the quality of REDD units and the impact of REDD units on emissions markets. One way of restricting the fungibility of REDD units is by imposing demand restrictions on market participants. An example is a supplementarity requirement that limits the proportion of emissions reductions which can be offset by imported units. Another approach to limit total REDD credits available to the market is to impose supply restrictions. Under supply restrictions, supplying nations or regions are only able to sell a specified quantity of units.

Demand-side and supply-side restrictions are represented in scenarios REDD_DEM and REDD_SUP respectively. For the demand-side restriction, each region subject to commitments is restricted to importing a maximum of 20 percent of the 2020 required emissions reductions. For the supply-side restriction scenario, the total export of REDD units is limited to 20 percent of the aggregate 2020 emissions reductions requirements. Each REDD supply region is restricted to exporting a share of these units proportional to the REDD region's share of current term deforestation.

Expanded commitments are represented in scenarios REDD_EXP, REDD_DEM_EXP and REDD_SUP_EXP. For these scenarios commitment levels are expanded to yield a similar carbon price to the base case.

An international emissions trading (IET) scenario represents intergovernmental trading at projected emissions reductions commitment levels without any CDM imports. This scenario is intended for reference only, as the commitment levels agreed to under Kyoto were based on the expectation that CDM units would be available. A comparison between the IET and base case scenarios demonstrates the scale of the impact of the CDM.

The MAC scenarios enable sensitivity assessment around the supply and cost of REDD units and are discussed in Section 3.3.

3. Modelling results and assessment

3.1 Results and assessment for core commitments

This section presents and discusses the simulation results for the core emissions reduction commitments of Annex I countries (as presented in Section 2.2) across the alternative policy scenarios. A complete set of quantitative results is presented in Appendix C.

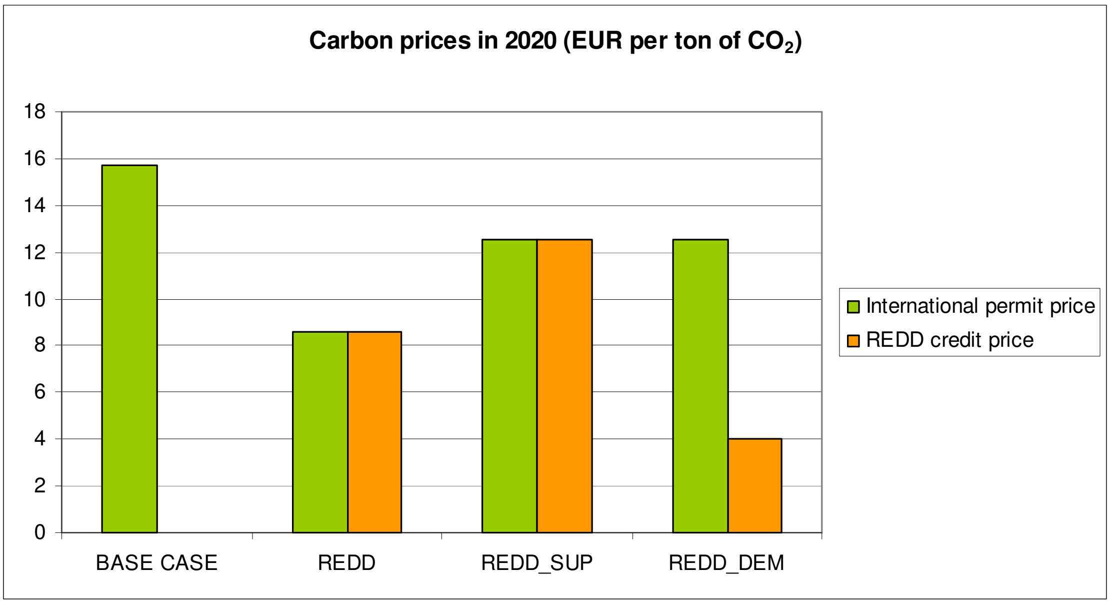
We begin our quantitative analysis by assessing the carbon price impacts of alternative climate policy designs in the year 2020. The carbon constraints of Annex I countries result in an international permit price of roughly €38 per ton of CO_2 if only governmental emissions trading is allowed (scenario IET)[7]. The global carbon price decreases to €16 under our base case when we account for unlimited access by industrialized countries to the CDM, as the Annex I region is able to import carbon credits from low-cost emission abatement options in developing countries (scenario *BASE CASE*). This finding is consistent with previous studies (see e.g. Klepper and Peterson, 2006; Böhringer et al., 2005).

Against this background, Figure 1 illustrates the carbon price impacts of introducing REDD into a future climate policy regime. We find that the international permit price is reduced by 45 percent to roughly €9 per ton of CO_2 if Annex I countries are granted unlimited access to carbon credits from avoided deforestation (scenario *REDD*). This price impact reflects the greater availability of carbon abatement options from REDD with lower marginal abatement costs than those CDM options used in the original carbon market equilibrium. The reason is that the relatively low returns on land use and forest products in tropical regions imply a low opportunity cost of reducing deforestation, so that marginal abatement costs are lower than the incremental costs of conventional carbon abatement options in CDM host countries. The increased competition on the supply side of the emissions market thus decreases the international permit price to the level of the REDD credit price.

Figure 1 further shows that restricting supply or demand for REDD credits to 20 percent of each Annex I region's emission reduction requirement in the year 2020 limits the price-decreasing impacts of introducing REDD. We find that the international permit price generated under both the scenario *REDD_SUP* and scenario *REDD_DEM* is roughly €13 per ton of CO_2, which represents a more moderate price decrease of 20 percent compared to the base case. The reason is that in both cases the amount of low-cost REDD credits on the market is lower than in the case of unlimited REDD fungibility. However, in the case of a demand-side restriction the REDD credit price decreases substantially to €4 per ton of CO_2 : a REDD demand restriction thus drives a wedge between the REDD credit price and the international permit price.

[7] The commitment levels assumed for our modelling have been proposed by Parties with the expectation that inexpensive CDM emissions reductions will be available to offset some developed country emissions. As a consequence, the IET scenario is provided to illustrate the sensitivity of the model.

Figure 1 Prices for international carbon permits and REDD credits by scenario

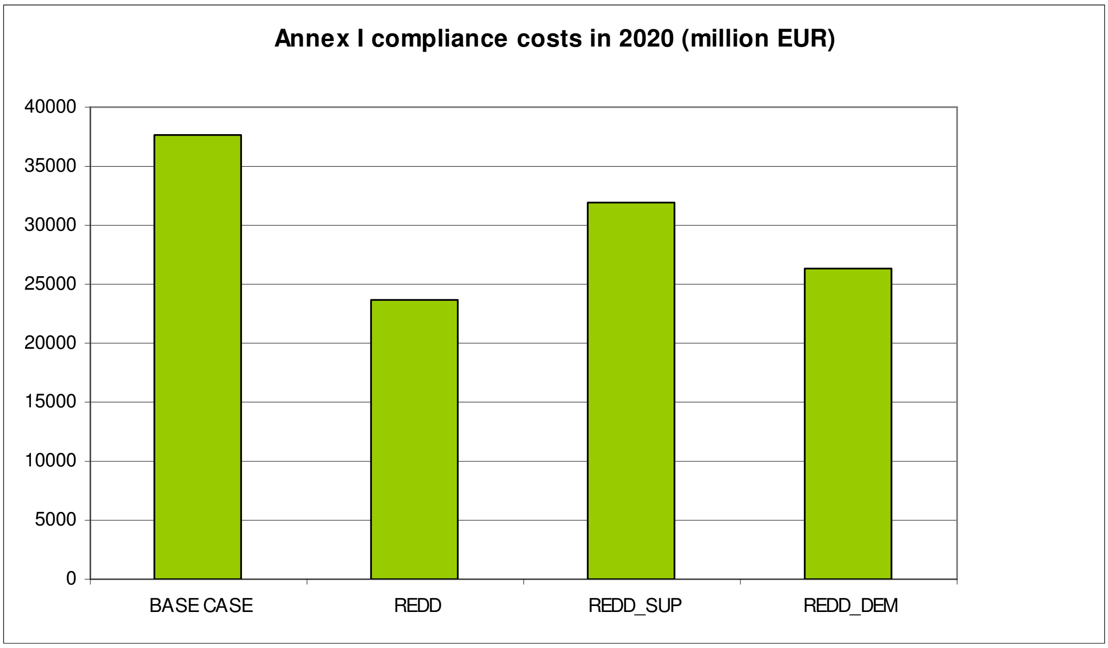


We now turn to the total costs for complying with the assumed emissions reduction commitments across alternative policy designs in the year 2020. Figure 2 shows that total compliance costs reflect the carbon-price effects discussed above, including the cost-decreasing effect of unlimited CDM access. Most importantly, we find that integrating reduced deforestation on the international carbon market yields large economic efficiency gains, decreasing Annex I compliance costs by more than one third.

As noted in Section 1, the potential reduction in carbon price resulting from allowing unrestricted REDD access has raised concerns that this could cause critical delays in crucial technological change necessary for achieving long term emissions targets, such as carbon capture and storage. For this reason, restrictions on either the flows of REDD units onto emissions markets (supply restrictions) or the use of REDD unit for compliance purposes (demand restrictions or "supplementarity") have been proposed.

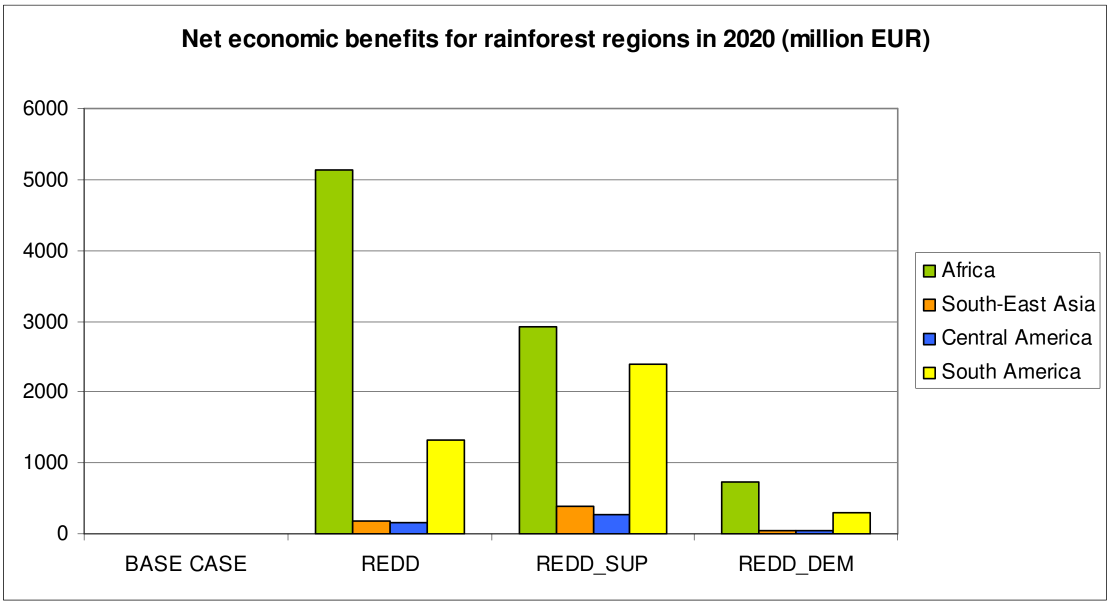
Against this background, Figure 2 and Figure 3 together indicate that limiting carbon price decreases through the restriction of REDD supply or demand is at the expense of economic efficiency-while total compliance costs of industrialized countries are still diminished through the introduction of REDD as compared to CDM access only, the cost savings from REDD are considerably lower when REDD supply and demand are regulated. However, Figure 2 shows that compliance costs are significantly lower for the case of limited REDD demand than for the case of restricted supply-Annex I cost savings from REDD amount to 30 percent for a demand limit, but only 15 percent for the supply limit. This central result can be explained by the distribution of economic rents resulting from market regulations: While restricting REDD demand decreases the REDD credit price, thereby reducing the producer surplus for tropical rainforest regions and increasing the consumer surplus of Annex I regions, restricting REDD supply has the opposite effect (compare the economic intuition illustrated in Figure 13 and Figure 14). In other words, the wedge between the REDD credit price and the international permit price caused by a demand-side restriction decreases the total costs of REDD credit imports for Annex I regions and thus induces lower total compliance costs than a supply-side regulation.

Figure 2 Aggregate compliance costs for the Annex I region by scenario



In conclusion, of the two options the method of maintaining the international permit price that best limits Annex I compliance costs is restricting REDD demand. However, demand restriction is the less desirable option for developing countries because they earn less from REDD activity, as shown in Figure 3.

Figure 3　　Net economic benefits (revenues less costs) by rainforest region and scenario



We now discuss the implications for the international trade of carbon permits. Figure 4 presents regional net REDD credit exports across our policy scenarios. It shows that for unlimited REDD fungibility, Africa is the dominant credit exporter to Annex I countries, followed by South America. In comparison, the tropical regions of South-East Asia and Central America play a rather minor role on the market for REDD credits. The reason for Africa's dominance is the relatively low opportunity costs of abatement in this region (in terms of low returns of land use and forest products) combined with a large quantitative potential of reducing deforestation (in terms of forest area and deforestation activity).[8]

The situation is somewhat different under restricted REDD supply, which the reader will recall from Figure 2 results in a REDD price equal to the international permit price. This results in greater REDD activity in the regions other than Africa because the higher price means it is now more economic in these higher REDD MAC regions. Under this scenario REDD credits from Africa are roughly equal to South American exports and the level of REDD activity relative to business-as-usual is similar in all tropical rainforest regions.

Figure 5 presents the corresponding regional reductions of carbon emissions.

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[8] Some readers may note that not all nations currently possess sufficient institutional or technological capacity to participate effectively in a REDD regime. The potential inability to develop REDD programs in some locales needs to be taken into account when considering the large number of REDD credits generated from Africa in our modelling.

Figure 4 Net exports (exports less imports) of REDD credits by region and scenario

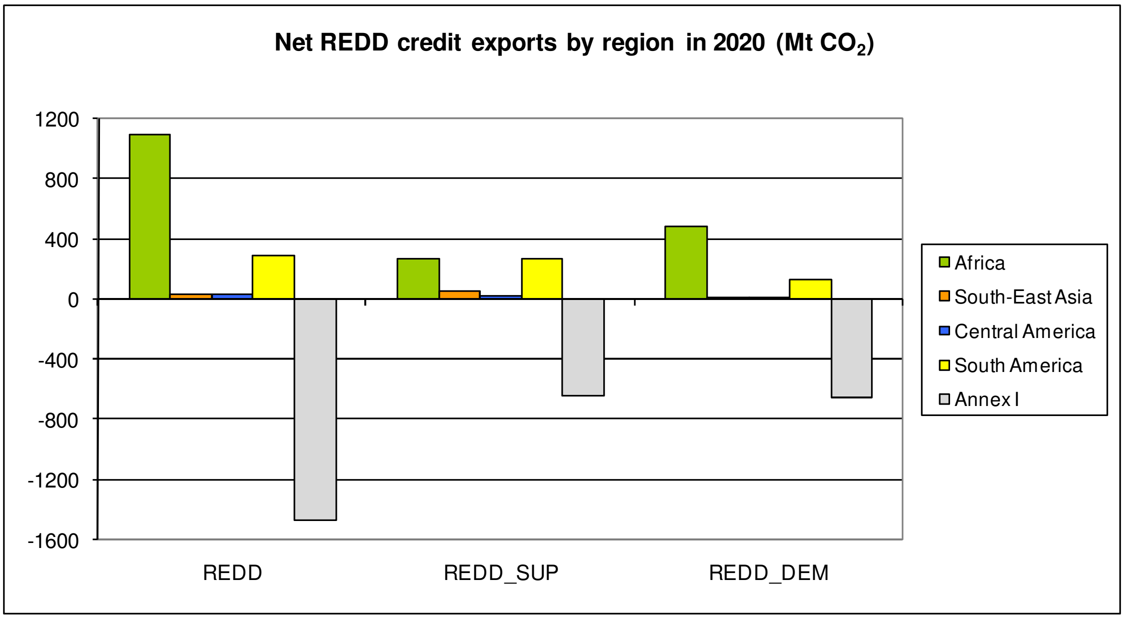
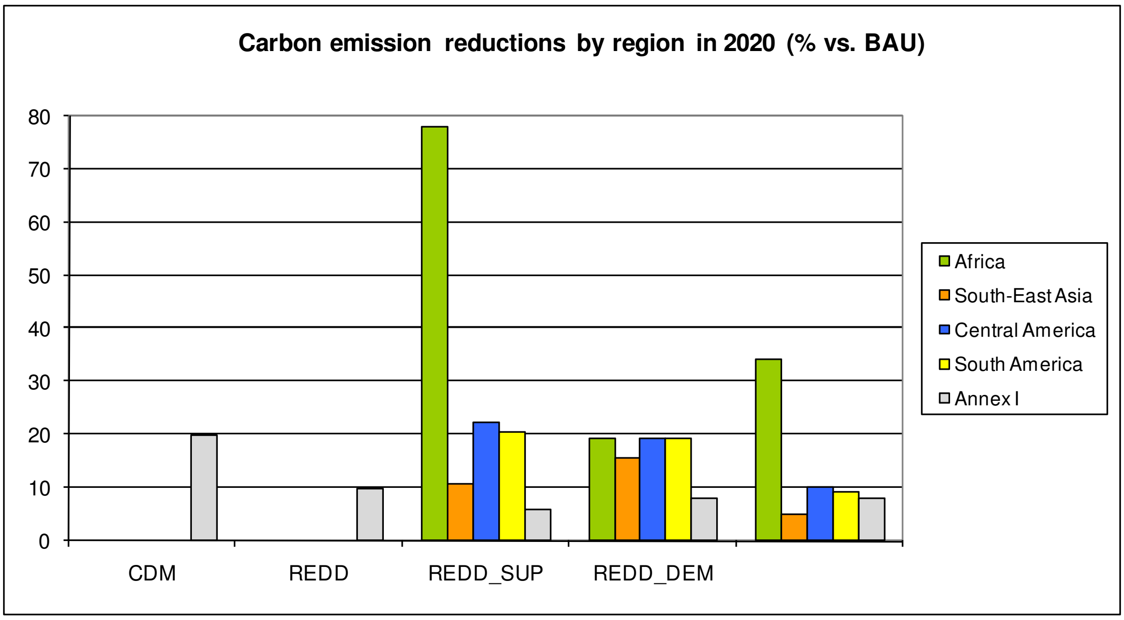
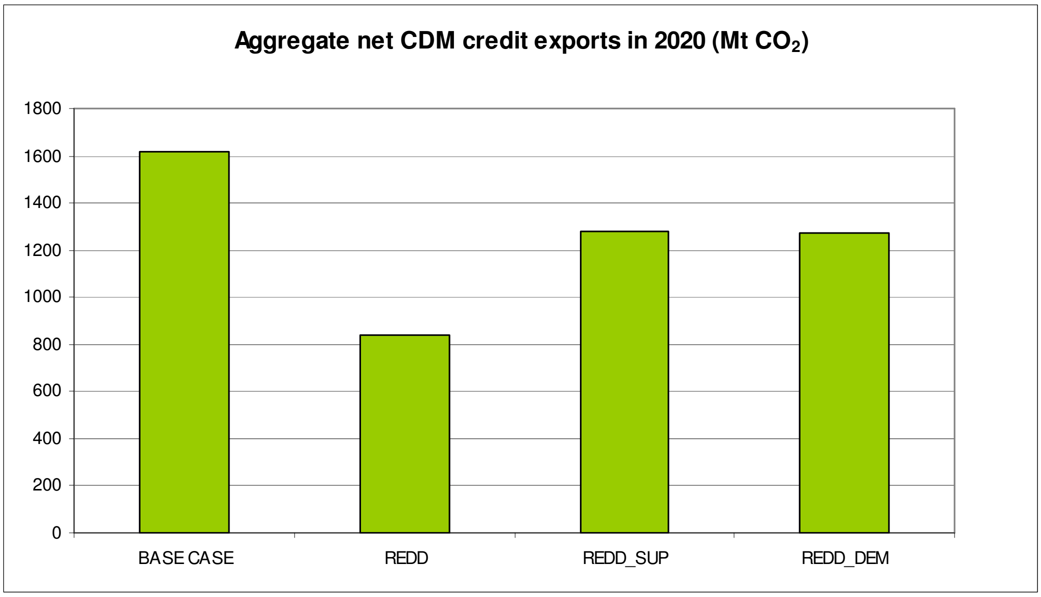


Figure 5 Carbon emission reductions by region by scenario



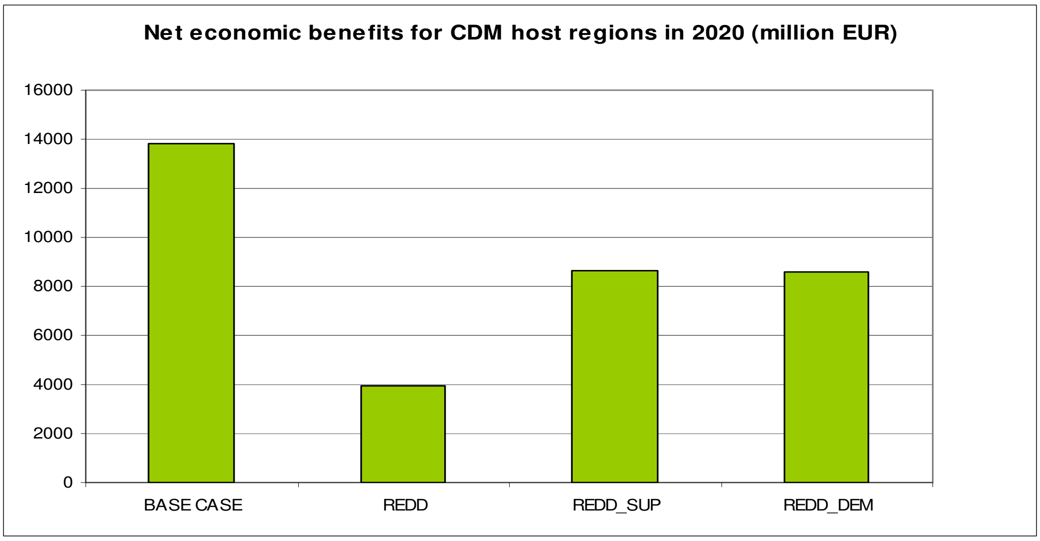
As well as improving overall efficiency by reducing Annex I compliance costs, the other key impact of REDD is to reduce the activity of the CDM through increased credit supply competition, as shown in Figure 6. Base case CDM credit exports are reduced by around a half under unrestricted REDD access and by around a quarter under the supply and demand restrictions. This occurs because emissions abatement of REDD occurs at a lower marginal cost than conventional abatement options of the CDM due to the low opportunity costs of land use and forest products in rainforest regions.

Figure 6 *Net credit exports (exports less imports) of CDM host regions by scenario*



The substitution of REDD exports to Annex I countries for CDM credits translates into substantially lower net benefits to CDM host regions, as shown in Figure 7. In particular, under the unrestricted REDD access scenario (Scenario *REDD*) net economic benefits to CDM host regions drop to roughly one third of that for the base case without REDD, and decrease to less than two thirds in the case of supply or demand restrictions. This suggests that the combination of unlimited REDD access with no increase in Annex I commitments may significantly reduce CDM activity because of the greater economic attractiveness of REDD for Annex I regions.

Figure 7 *Net economic benefits (revenues less costs) for CDM host regions by scenario*



3.2 Results and assessment for expanded commitments

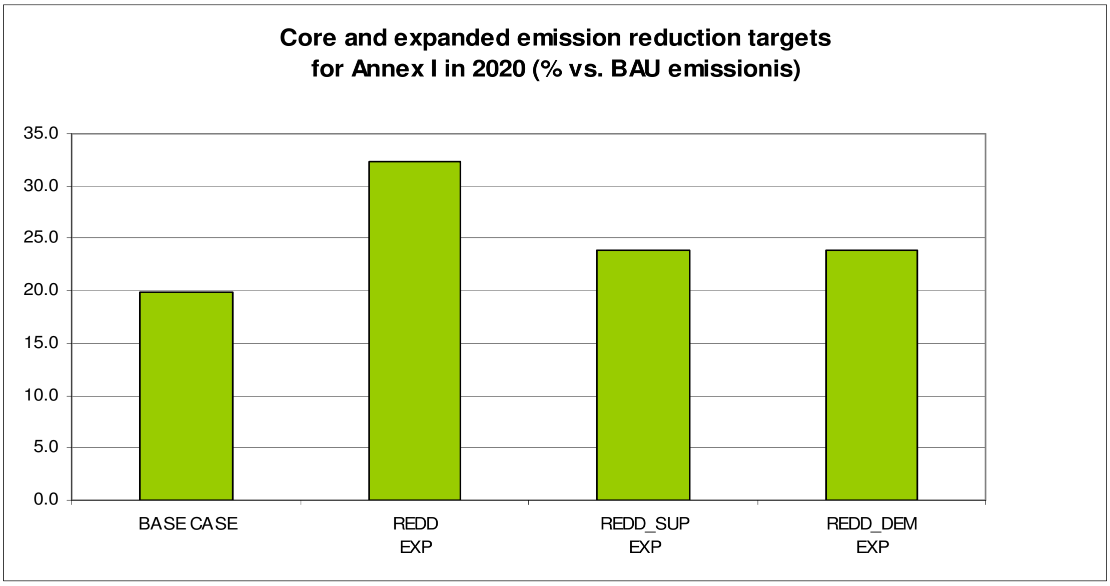
This section presents and discusses the simulation results for expanded emission reduction commitments of Annex I countries across the alternative policy scenarios. Our central findings are illustrated in the figures set out in this section (the complete set of quantitative results is presented in Appendix C).

Taking advantage of the low cost of REDD abatement allows Annex I commitments to be extended by a significant degree with a consequent increase in emission reductions. As noted in Section 2.3, we have maintained the international carbon permit price at the same level in our expanded commitments scenarios as under the base case.

Relative to our base case, unrestricted access to REDD allows Annex I commitments to increase by 62 percent. This results in an average Annex I target of 32 percent relative to business as usual, or 24 percent compared to 1990 levels. This is approaching the lower end of the range of 25-40 percent reductions vs. 1990 levels identified as necessary by the IPCC to achieve a concentration target of 450ppm CO_2e (Gupta *et al.*, 2006).

Figure 8 shows expanded commitment levels for each of our policy scenarios. With REDD unit supply or demand restrictions Annex I commitments are only increased by 20 percent relative to the base case for constant international permit prices.

Figure 8 Core and expanded Annex I commitments levels by scenario



Despite the constant carbon price across scenarios, expanding commitments increases compliance costs for Annex I. Figure 9 shows that compliance costs for expanded commitments with unrestricted REDD access are approximately double the compliance costs in the base case. This is because of the large increase in the quantity of (mainly

REDD) units purchased relative to the base case. With REDD demand and supply restrictions fewer units are purchased leading to compliance costs around a third lower than with unrestricted access to REDD – but abatement is lower as well. The compliance cost of expanded targets is around a fifth lower with REDD demand restrictions compared with supply restrictions. As previously, this is because the impact of REDD demand restrictions is to lower the REDD unit price – as shown in Figure 10 – and since the REDD unit price is not increased by expanded targets, the overall cost of purchasing units is lower.

Figure 9 Aggregate compliance costs for the Annex I region by scenario

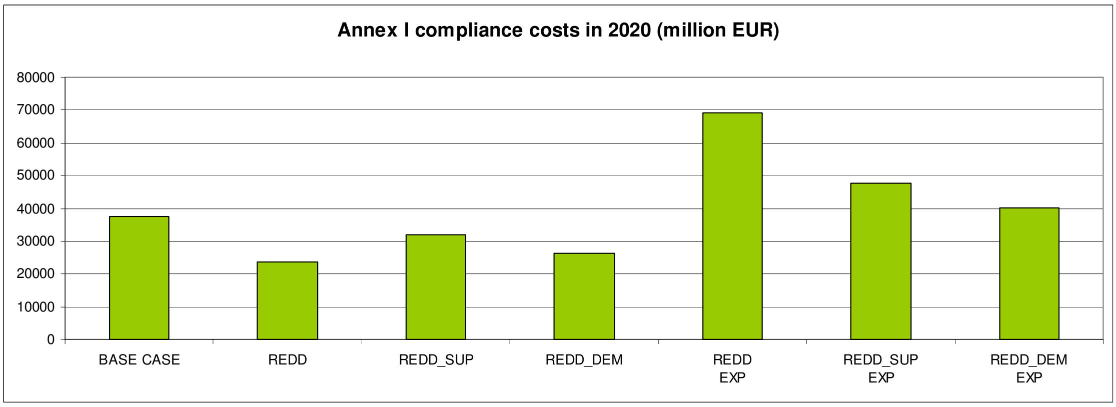
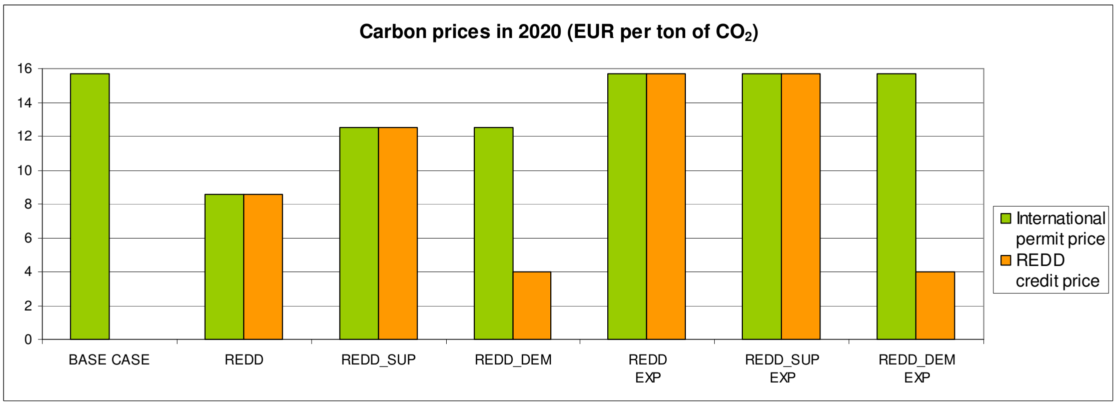


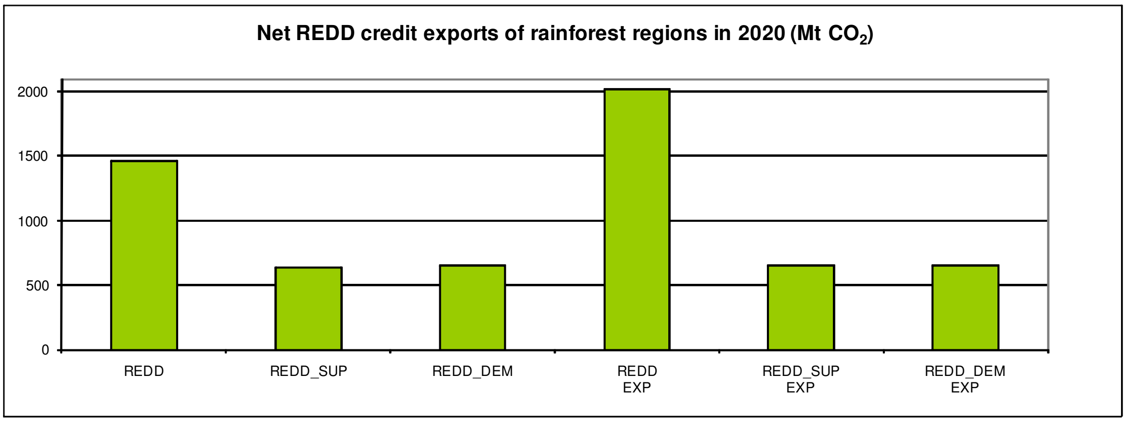
Figure 10 Prices for international carbon permits and REDD credits by scenario



The impact of increased Annex I commitments under the unrestricted REDD access scenario is to increase exports of REDD credits relative to the core commitments scenario (scenario *REDD*), as shown in Figure 11. This is because the higher unit price means abatement that was not economic under core commitments becomes economic under the higher emissions price that results from increased commitments.

Figure 11 also shows that REDD credit exports remain fixed with expanded commitments under both the supply and demand restrictions. The intuition behind this is explained in Figure 16 and Figure 17 in Appendix D. Figure 16 illustrates that the impact of expanded commitments with a demand restriction is to shift the demand curve outward within the range of the restriction, resulting in unchanged cost and exports of REDD units. Figure 17 shows the effect of a supply restriction is an outwards shift of the REDD demand curve but with supply unchanged, which results in an increase in the price for REDD units. The effect of the increased price under the latter scenario is a transfer of rents from Annex I to REDD-supplying nations.

Figure 11 Net exports (exports less imports) of REDD credits of rainforest regions by scenario



3.3 Sensitivity analysis

The presence of potentially significant uncertainties around the cost of REDD was discussed in Section 1. As these uncertainties are derived from both REDD policy choices and the uncertainties in the forestry data input we have utilised, we have provided a sensitivity analysis around REDD marginal abatement cost.

The sensitivity analysis demonstrates the dynamics of the carbon market in 2020 over a broad range of REDD costs. As shown in Table 4, the low-cost scenario (*REDD_MAC*) doubles the number of REDD units supplied at any given REDD price compared to the REDD scenario. The high-cost scenario (*REDD_MAC+*) halves the number of REDD units that are supplied at any given REDD price compared to the REDD scenario. These scenarios are otherwise identical to the REDD scenario.[9]

Collectively these three scenarios help demonstrate the impact of a range of REDD cost assumptions on carbon prices, associated compliance costs, and transfers. It serves to illustrate not only the expected level of volatility of carbon markets with respect to uncertainties in REDD supply costs, but also demonstrates the impact that REDD policy decisions could have on markets if emissions reduction targets are set independently.

[9] The double/half supply levels were selected, in part, to be consistent with modelling done by the Environmental Defense Fund (Cabezas and Keohane, 2008).

We find that international carbon permit prices are relatively robust to the tested changes in REDD supply functions. As shown in Table 5, the impact on the international carbon price is within the +/- 20 percent range—a level that could be considered reasonable given the large swing in supply costs of REDD units. This holds true for both core commitments and expanded commitments. The impact on CDM exporters, however, is greater with CDM exporters receiving a windfall of an additional 50 percent net economic benefit with REDD supply costs increased, and losing 40 percent of the economic benefit of the REDD scenario with REDD supply costs decreased. Impacts on CDM supplying regions are somewhat less dramatic under expanded commitments with the net economic benefit within a +/- 35 percent range of the benefit under the REDD expanded commitments scenario.

In order to account for different levels of supply under expanded targets, two additional scenarios were modelled at the expanded commitment level for unlimited REDD access. Again, marginal REDD supply costs are halved and doubled at each REDD quantity in these scenarios, which are denoted *REDD_MAC_EXP* and *REDD_MAC+_EXP* respectively.

As REDD supply quantity and costs are uncertain, and policy issues can effect supply, the *REDD_MAC_EXP* and *REDD_MAC+_EXP* scenarios demonstrate the potential impact of large under- or over-estimates of REDD supply costs.

The corresponding simulation results are presented in the following tables.

Table 4 Total compliance costs and economic benefits by region and scenario (million €2005)

Region \ Scenario	BASE CASE	REDD	REDD_ MAC	REDD_ MAC+	REDD EXP	REDD_ MAC EXP	REDD_ MAC+ EXP
EU-27	17874.3	10415.2	8300.4	12476	30633.1	25018.7	35338.9
Canada	1659.1	1027.2	831.8	1211	3013.9	2495.5	3437.5
Japan	724.9	495.6	410.7	570	1452.3	1227.5	1626.1
Former Soviet Union	-3308.6	-1173.6	-768.3	-1650	-3297.4	-2273.5	-4298.3
Pacific OECD	1499.6	898.1	717.9	1071	2606.2	2147.5	2973.5
United States	19195.1	11977.6	9697.1	14108	34843.3	28927.9	39622.6
Annex I regions	**37644.4**	**23640.1**	**19189.6**	**27787**	**69251.4**	**57543.6**	**78700.3**
Brazil	-40.1	-11.7	-7.1	-17.6	-40	-25.6	-54.9
China	-11353	-3231.1	-1939.4	-4885	-11307.8	-7214.5	-15513.4
South Korea	-412.4	-119.9	-72.8	-180	-410.8	-263.3	-564.2
Mexico	-495.2	-184.9	-124.1	-255	-493.6	-346	-636.8
India	-1496.8	-416	-250.5	-629	-1490.4	-934.3	-2093.5
CDM regions	**-13798**	**-3963.6**	**-2393.9**	**-5967**	**-13742.6**	**-8783.7**	**-18862.8**
Africa		-5136.8	-2505.2	-6124	-14113.1	-8805.8	-16213.2
South-East Asia		-180.4	-13.8	-194	-617.6	-58.3	-610.6
Central America		-162.7	-24.9	-171	-556.8	-95.1	-539.1
South America		-1323.8	-202.9	-1394	-4530	-773.7	-4386.1
REDD regions		**-6803.7**	**-2746.8**	**-7884**	**-19817.5**	**-9732.9**	**-21749**

Note: Negative compliance costs represent net economic benefits

Table 5 Carbon prices by credit type and scenario (€2005 per ton of CO_2)

Region \ Scenario	BASE CASE	REDD	REDD_ MAC	REDD_ MAC+	REDD EXP	REDD_ MAC EXP	REDD_ MAC+ EXP
International permit price	15.7	8.6	6.7	10.4	15.7	12.6	18.4
CDM price	15.7	8.6	6.7	10.4	15.7	12.6	18.4
REDD price		8.6	6.7	10.4	15.7	12.6	18.4

Table 6 Market volumes of CDM and REDD credits (Mt CO_2)

Region \ Scenario	BASE CASE	REDD	REDD_ MAC	REDD_ MAC+	REDD EXP	REDD_ MAC EXP	REDD_ MAC+ EXP
CDM market volume	1618	840	635.	1048	1618	1287	1880
REDD market volume		1463	1857	1066	2021.2	2635	1519

Table 7 Core and expanded Annex I emission reduction commitments by region and scenario (commitments in % vs. BAU emissions in 2020)

Scenario / *Region*	CDM	REDD EXP
EU-27	27.2	44.1
Canada	23.2	37.6
Japan	6.4	10.4
Former Sov. Un.	0.0	0.0
Pacific OECD	25.5	41.4
United States	24.8	40.1
Annex I regions	**19.9**	**32.3**
Relative expansion of commitment	0%	62%

3.4 Comparison to other modelling

Several other studies have modelled the impact of REDD on emissions markets. In this section we compare our results to three other studies.

Anger and Sathaye (2008) utilised a similar methodology to that employed in this study. Several assumptions differed, however, including the use of less stringent emissions reductions commitments. As both studies utilised identical marginal abatement cost functions for REDD supply, CDM supply, and domestic abatement, we are able to compare the study results on an "apples to apples" basis.

In Anger and Sathaye less stringent emissions requirements led to an international carbon permit price of € 13.2 in 2020 under a scenario similar to the base case in our study which yielded a international permit price of € 15.7, indicating a price increase of approximately € 2.5 due to more stringent conditions.

While the previous work by Anger and Sathaye did not investigate the role of restrictions of REDD credit demand and supply, it did model an international carbon price for unlimited REDD access of between € 7.2 and € 7.6 in 2020 depending on transaction cost assumptions. This compares with the REDD scenario in our study which resulted in an international carbon price of € 8.6. Furthermore, Anger and Sathaye did not investigate uncertainties in REDD marginal abatement costs.

The Eliasch Review modelling (Eliasch, 2008) results focus on the year 2030, and suggest that REDD could represent emissions reductions of 2.6 $GtCO_2$ per year by that date, approximately 75 percent of which would be financed through markets. Unlike in this study, their employed policy scenarios focus on individual emissions trading schemes, such as the EU ETS, instead of governmental emissions trading. Moreover, the Eliasch Review only assessed variations of REDD demand restrictions (i.e. supplementarity). Like the modelling in this paper, increased commitment levels are explored in tandem with supplementarity restrictions. The supplementarity restrictions in the Eliasch modelling apply to CDM as well as REDD units, a difference from the approach taken in our paper. Under most of the scenarios modelled for Eliasch, the overall price impact of introducing REDD units is moderate with the interaction between supplementarity and the CDM supply functions apparently responsible for most price changes (Eliasch, 2008).

Modelling for the Eliasch Review (Eliasch, 2008) was conducted using the United Kingdom Office of Climate Change Global Carbon Finance Model (GLOCAF) model. While GLOCAF uses different marginal abatement cost functions than employed in this report, the Eliasch Review's modelling, similar to ours, did utilise GCOMAP to simulate the supply of REDD based mitigation. Updated (2008) GCOMAP values, however, were used. Updates included revised carbon densities and land use opportunity costs (Sathaye et al., 2008).

According to Sathaye, carbon choke prices[10] for Central America, South America, and Southeast Asia declined when compared with the 2006 GCOMAP results, while Africa's prices remained constant. If similar adjustments were made to the modelling completed for this paper, it would be expected that Africa's dominance in REDD credit exports would be somewhat reduced.

The Environmental Defense Fund (EDF) utilised a spreadsheet model to investigate the impact of REDD unit imports on compliance markets in the EU and the United States. Under the EDF's model, the use of REDD credits reduces the permit price by approximately 13 percent, whereas our study suggests a 45 percent decrease in the international permit price. The EDF model assumes unlimited banking of REDD credits (Cabezas and Keohane, 2008).

4. Implications for negotiations

Our results show that Annex I emissions reduction commitments can increase to close to the range recommended by the IPCC at carbon price levels that would prevail with access to the CDM only, if Annex I Parties have unrestricted access to REDD units for meeting their commitments. However, Annex I compliance costs would increase significantly as a result of the substantial transfer of funding to tropical forest countries through the purchase of REDD units. Compliance costs could, of course, be limited with less ambitious expansions of Annex I targets.

[10] A deforestation carbon choke price is the price at which at which the carbon price is sufficient to halt deforestation.

This raises an essential issue for the post-2012 negotiations: are Annex I Parties willing to increase their commitments (and financial transfers to developing countries) while absorbing substantial increases in compliance costs? Unrestricted access to REDD coupled with Annex I targets that reflect this large source of emission reductions would provide significant benefits in terms of increased mitigation and potential poverty alleviation. However, Annex I Parties may not be willing to agree to the increased costs (or the level of commitments) without corresponding concessions from developing countries.

Another reason why Annex I Parties may be concerned about the potential value of transfers to tropical forest nations with expanded commitments is that large transfers of resources are also sought to deal with developing country issues such as adaptation, capacity building and technology transfer.

Further, because many tropical forest nations are low income countries, if the value of REDD unit sales is as large as modelled, it would represent a substantial proportion of these nations' economies. In some cases, the economic effect could be akin to the discovery of major mineral deposits, with the associated advantages and disadvantages of such large and sudden financial windfalls.

Annex I Parties' willingness to confer such transfers of wealth on these countries is likely to be limited. This may lead to proposals for supply or, more probably, demand restrictions for REDD units, which would limit both the transfers to tropical forest countries and Annex I compliance costs. However, this would also reduce the volume of mitigation.

5. Limitations

Since the modelling presented in this report was commissioned, an updated version of the GCOMAP forestry model has become available (Sathaye, et al., 2007). It would be useful to re-examine the findings of this report using updated inputs. It may also be useful, from a comparison perspective, to utilise alternative REDD MAC functions available in the literature.

The modelling used for this report is a partial equilibrium model which provides a snapshot of the implications of a particular scenario at a given point in time. The model does not identify the feedback effects (e.g. on land use and food prices) that would be expected to occur with the alterations to financial flows resulting from the scenarios examined in this report. Expanding the simulation through application of a general equilibrium model would aid in the investigation of these feedback effects in greater detail.

6. Conclusion

Without alterations to Annex I commitments, our modelling indicates the unrestricted introduction of REDD units in to the post-Kyoto international emissions market may approximately halve the international price of carbon in 2020. While this reduction leads to substantial compliance cost savings for developed countries in the short term, the incentives for increased domestic abatement are decreased in the medium term and development of clean infrastructure and technologies may be delayed.

Another potential barrier to unrestricted integration could include opposition from CDM supplying nations, who our modelling shows stand to lose a large portion of their net economic benefit from the CDM compared to the base case if there are no restrictions on developed country access to, or use of, REDD. Some developed countries may also oppose the significant wealth transfers to non-Annex I nations, when these nations are not subject to emission reduction commitments.

Demand-side and supply-side restrictions on the import of REDD units into compliance markets can support prices somewhat, but would fail to encourage further progress toward more ambitious GHG reduction goals by simultaneously restricting economic efficiency. While demand-side restrictions will please the cost conscious in developed countries, maintaining a reasonably high international price of carbon while enabling REDD units to be acquired at a mere third of that price may cause disaffection among supplying nations.

As negotiators prepare for Copenhagen 2009, consideration should be given to another option: expanding commitments beyond what Annex I Parties may currently be contemplating. The cost savings to Annex I Parties which would occur with REDD integration could justifiably be reinvested in deeper commitments.

In investigating a scenario which could fully mitigate the concerns over lost CDM income and a dampening of the international carbon price signal, we describe an option which is calibrated to yield a carbon price similar to what occurs in the base case. While the additional 60 percent reduction from core commitments[11] for Annex I is ambitious, it takes full advantage of the efficiency gains of intersectoral trading between domestic Annex I, CDM, and REDD emissions reductions. The result is GHG mitigation which approaches the lower end of the IPCC range of a 25-40 percent reduction in emissions

[11] Our base case assumed aggregate reductions (includes US) of 20 percent from 2020 BAU (-10 percent vs. 1990) levels while our expanded commitments scenario results in reductions of 32 percent from 2020 BAU (-24 percent vs. 1990). The base case reductions are at the upper end of the 550ppm CO2e reduction scenario, and best represent a level of effort in line with no action to depart from baseline by non-Annex I nations.

allowances to Annex I nations compared to 1990 levels to stabilise atmospheric carbon at 450ppm CO_2e (Gupta *et al*, 2007).

The total costs for such expanded commitments are high. Annex I compliance costs increase approximately 85 percent with additional reductions of this magnitude. Transfer payments from Annex I to CDM and REDD nations increase to a level two-and-a-half times that with core commitments. Clearly, lower expansions of Annex I targets could be established at constant compliance costs.

The opportunities presented are significant; however caution is required when considering the results of modelling efforts in general. While adequate for comparing alternative policy scenarios, our model is not deterministic and does not aim at predicting prices explicitly. Updating this model with improved understanding of forest and domestic abatement costs will further improve its currency, but factors such as technological change or feedback-effects on non- CO_2 markets are beyond this study.

While the modelling in this paper illustrates the benefits and costs of incorporating REDD into international carbon markets, whether a viable REDD supply will actually materialise still remains uncertain at the time of writing. Significant concerns around the permanence of mitigation and the environmental integrity of REDD units will need to be successfully addressed in the design of a REDD regime. Even once these issues have been addressed, natural factors and market conditions will impact the supply of REDD units.

This study shows that if these issues are addressed, REDD provides a large opportunity for both economic efficiency gains and significant future emission reductions for combating global climate change.

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Appendix A Modelling of REDD carbon market interactions

In order to quantify the carbon market impacts of reducing deforestation we employ a numerical multi-country, two-sector partial equilibrium model of the global carbon market (Anger and Sathaye, 2008; Anger, 2008). The simulation model represents the parallel structure of the future carbon market for (i) international emissions trading among sectors covered by the EU Emissions Trading Scheme and emerging non-EU schemes as well as (ii) international emissions trading among post-Kyoto governments in 2020, and accounts for emissions reductions via the Clean Development Mechanism (CDM). The modelling framework features explicit marginal abatement cost functions based on energy-system data and is calibrated to represent the carbon market under a post-Kyoto agreement in the year 2020. Furthermore, marginal abatement cost functions for REDD are implemented into the model by covering tropical rainforest areas as explicit model regions. Within this model framework, developing countries may export emissions reduction credits from reducing deforestation to industrialised world regions via the global carbon market.

In the economic model, two classes of conditions characterize the (competitive) equilibrium for the model: zero profit conditions and market clearance conditions. The model is programmed with the software GAMS (General Algebraic Modelling System) and solved using the PATH solver. In the simulation model, alternative emission reduction commitments for industrialised countries, as well as alternative access restrictions to REDD credit imports and limitations of REDD credit supply can be analyzed.

Accounting for the forestry sector in tropical regions

In order to represent the response of the forestry sector to changes in future carbon prices, we use data from 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 consider the role of institutional barriers for crediting carbon abatement from reducing deforestation we account for transaction costs of forestry projects and programs (hereafter also referred to as projects, 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.

Proposals for the inclusion of REDD credits in international carbon markets have included provisions for project based crediting and for national-level crediting. Under national level crediting, individual nations take the lead in reducing national deforestation by aggregating projects at the domestic level and introducing policies and measures. While GCOMAP explicitly models projects, we generalise the resultant regional marginal abatement cost curves to represent regional aggregations of national level crediting cost functions.

This assumption introduces additional uncertainties to the forestry model. The imposition of policies and measures raises the prospect of land use choices which are sub-optimal from the perspective of the land user. Additionally, central government management of a REDD regime may introduce additional transaction costs or may, alternately, reduce overall transaction costs. In order to ensure that the model results are robust in the face of such variation, a sensitivity analysis is conducted to demonstrate the impact of a broad range of REDD cost structures.

Modelling the global carbon market including reduced deforestation

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), the core model 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. For this study, we focus on the carbon market for post-Kyoto governments. 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 base year 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. Table 8 in Appendix A shows the resulting least-square estimates of MAC coefficients by region and sector in 2020.

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 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. 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 industrialised model regions via the global carbon market. Table 9 in Appendix A presents the estimated marginal abatement cost coefficients for avoided deforestation for the four tropical regions in 2020.

Appendix B Marginal abatement cost functions

Table 8 Marginal abatement cost coefficients for conventional abatement options (€2005)

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

Region	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
Eastern 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 9 Marginal abatement cost coefficients for reduced deforestation (€2005)

Region	$\beta_{1,r}$	$\beta_{2,r}$	$\beta_{3,r}$
Africa	0.01807	-0.00011	0.00000
South-East Asia	0.20949	-0.00095	0.00002
Central America	0.23116	-0.00114	0.00002
South America	0.02841	-0.00002	0.00000

Appendix C Quantitative simulation results

Table 10 Total compliance costs by region and scenario (million €2005)

Region \ *Scenario*	IET	CDM	REDD	REDD_ SUP	REDD_ DEM	REDD_ MAC	REDD_ MAC	REDD EXP	REDD_ SUP EXP	REDD_ DEM EXP	REDD_ MAC EXP	REDD_ MAC+ EXP
EU-27	34708.6	17874.3	10415.2	14667.4	12380.5	8300.4	12476.4	30633.1	22007.7	18927.3	25018.7	35338.9
Canada	2630.4	1659.1	1027.2	1398.8	1157.7	831.8	1211	3013.9	2097.7	1770.9	2495.5	3437.5
Japan	624.6	724.9	495.6	640.6	512.2	410.7	570.3	1452.3	960.2	784.8	1227.5	1626.1
Former Sov. Un.	-14198	-3308.6	-1173.6	-2248.4	-2228.6	-768.3	-1650	-3297.4	-3308.5	-3308.6	-2273.5	-4298.3
Pacific OECD	2067.1	1499.6	898.1	1250.5	1052.5	717.9	1071.1	2606.2	1858	1590.7	2147.5	2973.5
United States	28428.5	19195.1	11977.6	16264	13479.4	9697.1	14108.4	34843.3	24261.3	20486.2	28927.9	39622.6
Annex I regions	**54261.2**	**37644.4**	**23640.1**	**31972.9**	**26353.7**	**19189.6**	**27787.2**	**69251.4**	**47876.4**	**40251.3**	**57543.6**	**78700.3**
Brazil		-40.1	-11.7	-25.3	-25.1	-7.1	-17.6	-40	-40.1	-40.1	-25.6	-54.9
China		-11353	-3231.1	-7116.9	-7040.3	-1939.4	-4885.4	-11307.8	-11353	-11353	-7214.5	-15513.4
South Korea		-412.4	-119.9	-259.8	-257	-72.8	-179.6	-410.8	-412.4	-412.4	-263.3	-564.2
Mexico		-495.2	-184.9	-342.3	-339.4	-124.1	-255.1	-493.6	-495.2	-495.2	-346	-636.8
India		-1496.8	-416	-921.4	-911.2	-250.5	-629.2	-1490.4	-1496.8	-1496.8	-934.3	-2093.5
CDM regions		**-13797.5**	**-3963.6**	**-8665.7**	**-8573**	**-2393.9**	**-5966.9**	**-13742.6**	**-13797.5**	**-13797.5**	**-8783.7**	**-18862.8**
Africa			-5136.8	-2917	-718.7	-2505.2	-6124.7	-14113.1	-3790.7	-718.7	-8805.8	-16213.2
South-East Asia			-180.4	-389.8	-38.9	-13.8	-193.9	-617.6	-617.3	-38.9	-58.3	-610.6
Central America			-162.7	-276.9	-35.1	-24.9	-171.3	-556.8	-374.7	-35.1	-95.1	-539.1
South America			-1323.8	-2394.6	-285.5	-202.9	-1393.7	-4530	-3275.1	-285.5	-773.7	-4386.1
REDD regions			**-6803.7**	**-5978.3**	**-1078.2**	**-2746.8**	**-7883.6**	**-19817.5**	**-8057.8**	**-1078.2**	**-9732.9**	**-21749**

Table 11   Emission reductions by region and scenario (% of BaU emissions)

Region \ Scenario	IET	CDM	REDD	REDD_SUP	REDD_DEM	REDD EXP	REDD_SUP EXP	REDD_DEM EXP
EU-27	15.2	7.2	4	5.8	5.8	7.2	7.2	7.2
Canada	20.4	10.6	6.3	8.8	8.7	10.6	10.6	10.6
Japan	8.8	4.5	2.7	3.8	3.7	4.5	4.5	4.5
Former Sov. Un.	22.1	12.8	8.6	11	11	12.8	12.8	12.8
Pacific OECD	27.9	9.5	4.3	6.9	6.9	9.5	9.5	9.5
United States	23.9	11.9	6.6	9.6	9.5	11.8	11.9	11.9
Brazil	0	0.5	0.3	0.4	0.4	0.5	0.5	0.5
China	0	20.6	10.7	16.3	16.2	20.6	20.6	20.6
South Korea	0	5.7	3	4.5	4.5	5.7	5.7	5.7
Mexico	0	6.4	4.3	5.5	5.5	6.4	6.4	6.4
India	0	6.1	3	4.6	4.6	6.1	6.1	6.1
Africa	0	0	77.9	19.3	34.3	94.9	19.3	34.3
South-East Asia	0	0	10.7	15.8	4.9	20	19.3	4.9
Central America	0	0	22.5	19.3	10.3	42.2	19.3	10.3
South America	0	0	20.4	19.3	9.3	38.2	19.3	9.3

Table 12 Carbon prices by credit type and scenario (€2005 per ton of CO_2)

Scenario / *Type*	IET	CDM	REDD	REDD_ SUP	REDD_ DEM	REDD_ MAC	REDD_ MAC	REDD EXP	REDD_ SUP EXP	REDD_ DEM EXP	REDD_ MAC EXP	REDD_ MAC+ EXP
International permit price	37.9	15.7	8.6	12.5	12.5	6.7	10.4	15.7	15.7	15.7	12.6	18.4
CDM price	0	15.7	8.6	12.5	12.5	6.7	10.4	15.7	15.7	15.7	12.6	18.4
REDD price	0	0	8.6	12.5	4	6.7	10.4	15.7	15.7	4	12.6	18.4

Table 13 Market volumes of CDM and REDD credits (Mt CO_2)

Scenario / *Market*	IET	CDM	REDD	REDD_ SUP	REDD_ DEM	REDD_ MAC	REDD_ MAC+	REDD EXP	REDD_ SUP EXP	REDD_ DEM EXP	REDD_ MAC EXP	REDD_ MAC+ EXP
CDM market volume	0	1618.3	839.8	1277.9	1271	635	1048	1615	1618.1	1617.8	1287	1880
REDD market volume	0	0	1462.9	636.3	650.1	1857	1066	2021.2	650	649.7	2635	1519

Table 14 Net CDM credit exports (exports less imports, Mt CO_2)

Scenario / *Region*	IET	CDM	REDD	REDD_SUP	REDD_DEM	REDD EXP	REDD_SUP EXP	REDD_DEM EXP
Brazil	0	4.5	2.3	3.6	3.6	4.5	4.5	4.5
China	0	1338.3	693	1059.3	1053.4	1335.8	1338.3	1338.3
South Korea	0	48.9	25.5	38.5	38.3	48.8	48.9	48.9
Mexico	0	47	31.8	40.7	40.5	47	47	47
India	0	179.1	87.2	136.1	135.2	178.7	179.1	179.1
Annex I regions	**0**	**-1618.3**	**-839.8**	**-1277.9**	**-1271**	**-1615**	**-1618.1**	**-1617.8**

Table 15 Net REDD credit exports (exports less imports, Mt CO_2)

Scenario / *Region*	IET	CDM	REDD	REDD_ SUP	REDD_ DEM	REDD_ MAC	REDD_ MAC+	REDD EXP	REDD_ SUP EXP	REDD_ DEM EXP	REDD_ MAC EXP	REDD_ MAC+ EXP
Africa	0	0	1097.5	271.9	482.6	1275.9	847	1336.9	271.9	482.6	1526.6	1126.5
South-East Asia	0	0	40.7	60.3	18.6	64.8	24.4	76.2	73.6	18.6	123.3	43.8
Central America	0	0	35.5	30.4	16.3	56.6	21.3	66.6	30.4	16.3	107.8	38.2
South America	0	0	289	274	132.5	460.3	173.6	541.5	274	132.5	877.2	310.8
Annex I regions	**0**	**0**	**-1462.9**	**-636.3**	**-650.1**	**-1857.6**	**1066.3**	**-2021.2**	**-650**	**-649.7**	**-2634.9**	**-1519.3**

Table 16 Core and expanded Annex I emission reduction commitments by region and scenario (commitments in % vs. BAU emissions in 2020)

Scenario / *Region*	CDM	REDD EXP	REDD_SUP EXP	REDD_DEM EXP
EU-27	27.2	44.1	32.6	32.6
Canada	23.2	37.6	27.8	27.8
Japan	6.4	10.4	7.7	7.7
Former Sov. Un.	0.0	0.0	0.0	0.0
Pacific OECD	25.5	41.4	30.6	30.6
United States	24.8	40.1	29.7	29.7
Annex I regions	**19.9**	**32.3**	**23.9**	**23.9**
Relative expansion of commitment	0%	62%	20%	20%

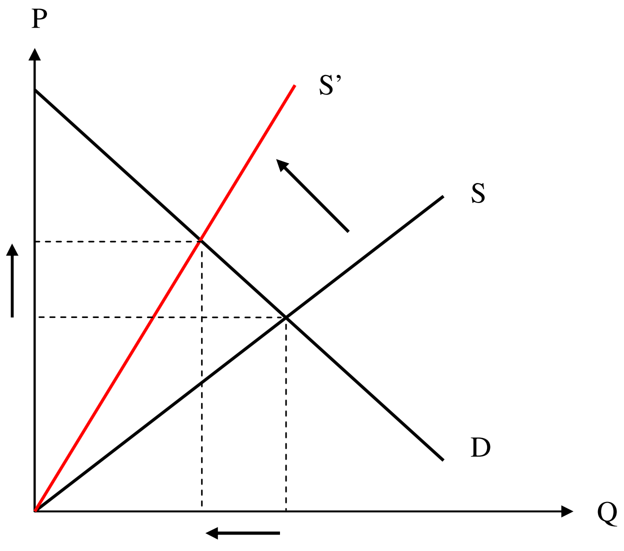
Appendix D Economic intuition

This section aims to explain the theoretical economic intuition of carbon-market impacts associated with our alternative policy scenarios described in the previous section. We start by analyzing the role of higher marginal costs for REDD as well as market regulations in a world of core emission reduction commitments of Annex I countries. Subsequently, we assess the implications of expanding these commitment levels.

Core commitments of Annex I countries

First, Figure 12 describes the international market for REDD credits, denoting credit supply with S and credit demand by D, as well as prices for REDD credits by P and quantities by Q. The figure illustrates the effects of doubling marginal abatement cost levels for REDD. It shows that the associated upward tilt of the REDD credit supply curve to the new supply function S′ results in a new market situation with a higher price level and a lower quantity of REDD credits than in the original market equilibrium. Note that the price is, however, less than doubled due to a positive price elasticity of REDD credit demand. This new market situation increases the economic rents (producer surplus) for the suppliers of REDD credits, i.e. tropical rainforest regions, while it decreases the economic rents (consumer surplus) of regions demanding REDD credits, i.e. industrialised countries.

Figure 12 Implications of doubling REDD marginal abatement costs (scenario REDD_MAC)



Second, Figure 13 describes the carbon-market implications of restrictions on the demand for REDD credits. The implementation of a demand limit changes the demand curve to D′, which results in a new market equilibrium with a lower price level and a lower quantity of REDD credits. This new market situation implies diminished economic rents for the supplying tropical rainforest regions and augmented economic rents for purchasing industrialised countries.

Figure 13 Implications of restricting REDD credit demand (scenario REDD_DEM)

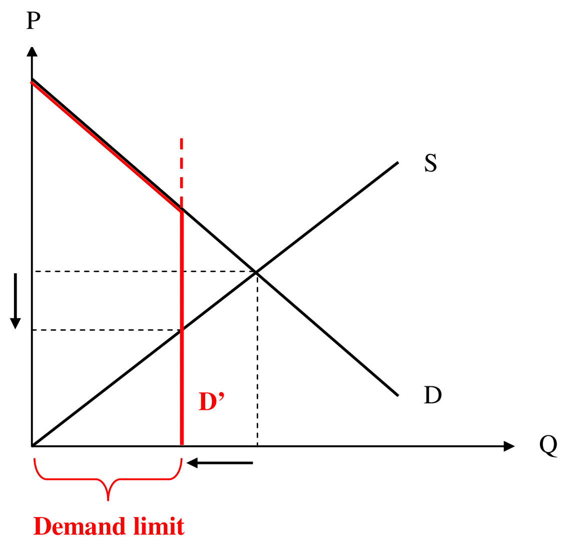
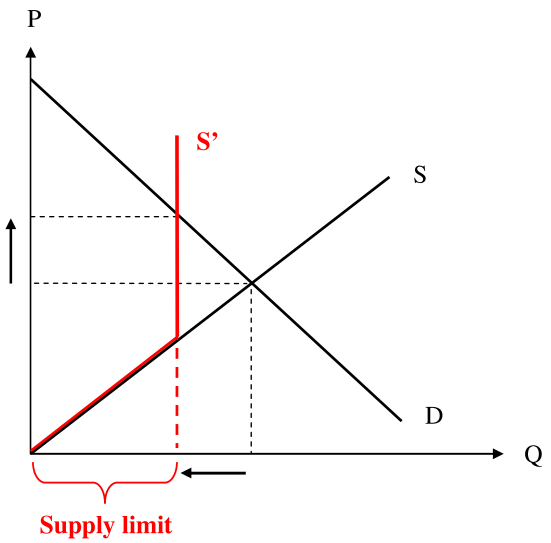


Figure 14 illustrates the consequences of restrictions on the supply of REDD credits. The implementation of a supply limit alters the supply curve to S′, which results in a new market equilibrium with a higher price level and a lower quantity of REDD credits. This new market situation implies higher economic rents of tropical rainforest regions and lower rents of industrialised countries.

Figure 14 Implications of restricting REDD credit supply (scenario REDD_SUP)



Expanded commitments of Annex I countries

We will now turn to the carbon-market implications of expanding emission reduction commitments of Annex I countries for the three scenarios presented above. First, Figure

15 assesses the case of doubling marginal abatement cost levels for REDD. It shows that expanding commitment levels (and thereby increasing the demand for emission abatement) induces an upward shift of the REDD credit demand curve to the new demand function D'. This results in a new market situation with a higher price level and a higher quantity of REDD credits, thereby increasing the economic rents of tropical rainforest regions and decreasing those of industrialised countries.

Figure 15 Implications of expanding Annex I commitments in the context of double REDD marginal abatement cost levels (scenario REDD_MAC_EXP)

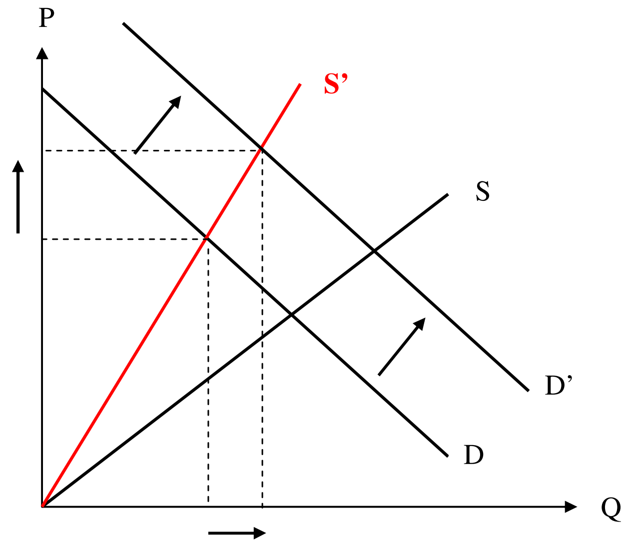
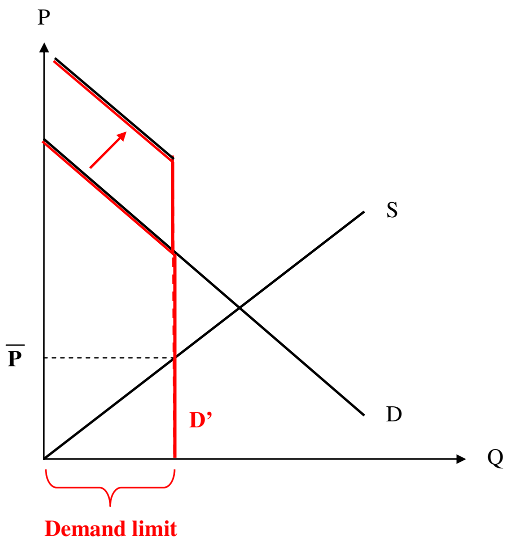


Figure 16 shows that for a carbon market with restrictions on demand for REDD credits, expanding Annex I commitment levels induces an upward shift of the REDD credit demand curve only within the range of the demand limit. As a consequence, the carbon-market equilibrium remains unchanged by the commitment expansion.

Figure 16 Implications of expanding Annex I commitments in the context of restricted REDD credit demand (scenario REDD_DEM_EXP)



Finally, Figure 17 illustrates that in a carbon market with restrictions on the supply of REDD credits, expanding commitments induces an upward shift of the REDD credit demand curve to the new demand function D'. This results in a new market situation with a higher price level but – due to the supply limit – unchanged quantity of REDD credits. Consequently, the economic rents of tropical rainforest regions are augmented, while those of industrialised countries are diminished.

Figure 17 Implications of expanding Annex I commitments in the context of restricted REDD credit supply (scenario REDD_SUP_EXP)