Kiel
Working Papers

Kiel Institute
for the World Economy

Economic prospects of ocean iron fertilization in an international carbon market

by Wilfried Rickels, Katrin Rehdanz and Andreas Oschlies

No. 1573| December 2009

Web: www.ifw-kiel.de

Kiel Institute for the World Economy, Düsternbrooker Weg 120, 24105 Kiel, Germany

Kiel Working Paper No. 1573 | December 2009

Economic prospects of ocean iron fertilization in an international carbon market *

Wilfried Rickels, Katrin Rehdanz, Andreas Oschlies

To stay within the 2°C temperature increase target for climate change calls for ambitious emission reduction targets already for the 2012-2020 compliance period. Cost-efficiency is a crucial criterion for the enforcement of such ambitious targets, requiring analyses of all possible abatement options. Among others, enhancing the oceanic carbon sink by ocean iron fertilization (OIF) could be such an option. In our analysis we consider short-term large-scale OIF modeling experiments for a Post-Kyoto compliance problem to assess the economic prospects of OIF. Our analysis reveals that the critical unit costs per net ton of CO2 sequestered by OIF are in a range of 22 to 28 USD (price level 2000) assuming that the current limitations regarding the use of carbon credits generated in low cost countries and from forestation is completely relaxed. The critical unit costs are determined as those that would make an emitter indifferent between various abatement options. We are also able to show that already seven years of OIF in the area of 30° south provide the same amount of credits equivalent to a global forestation project for the duration of 20 years. Over all and from economic perspective, our results indicate that OIF can be considered as an additional abatement option, but, further research, especially on adverse side effects, is needed.

Keywords: climate change, sink enhancement, ocean iron fertilization, CO_2 market, emission trading

JEL classification: Q52, Q54

Wilfried Rickels
Kiel Institute for the World Economy
24105 Kiel, Germany
E-mail: wilfried.rickels@ifw-kiel.de

Katrin Rehdanz
Kiel Institute for the World Economy
24105 Kiel, Germany
E-mail: katrin.rehdanz@ifw-kiel.de

Andreas Oschlies
IFM-Geomar, Leibniz Institute of Marine Sciences
24105 Kiel, Germany
E-mail: aoschlies@ifm-geomar.de

* The DFG provided financial support through
the Excellence Initiative Future Ocean. The usual caveats apply

---

1 Introduction

Regarding the world's fast declining carbon emission budget for staying within the 2° temperature increase target, all options including carbon sink enhancement options to mitigate climate change need to be considered. Enhancing the carbon sinks allows reducing atmospheric carbon concentration directly by removing past emissions and, therefore, extending the world's carbon emission budget. The terrestrial carbon sink can be enhanced by means of forestry activities, the oceanic sink can be enhanced by means of iron fertilization. Even though limited in total volume, forestry activities are already included in the present climate agreement (UNFCCC, 2003). A release of these limitations is debated for a Post-Kyoto climate agreement (e.g., Eliasch, 2008). Iron fertilization measures are still in the research stage and some small-scale in situ experiments have been carried out with varying results on the effectiveness of ocean iron fertilization (OIF). For an overview see for example Oschlies et al. (2009); Aumont and Bopp (2006). Large-scale projects to explore the geoengineering potential are currently not considered, in particular due to the uncertain effectiveness and side effects (e.g., Strong et al., 2009). We challenge this view but think that further research on the geoengineering potential of OIF is necessary.

Even courageous climate policy may run the risk that catastrophic climate change takes place. If this risk increases, geoengineering becomes an option of last resort and needs therefore to be explored in time. However, exploring the potential of OIF requires not just considering its effectiveness, but as well its efficiency. Therefore, we address in this paper the economic aspects of OIF for a climate agreement like the Kyoto Protocol. We consider short-term, but large-scale OIF model experiments for the duration of 1, 7, and 10 years for a Post-Kyoto climate agreement and derive criteria to assess the efficiency of OIF as a geoengineering option. Including OIF in a Post-Kyoto climate agreement would have implications for the distribution of welfare. Therefore, we also seek to determine the distributional aspects that are involved by including carbon credits from OIF. To our knowledge, this has not been done before.

In major regions of the ocean, the Eastern Equatorial Pacific, the North Pacific, and in particular vast areas of the Southern Ocean, macronutrients, such as phosphate and nitrate, are present at high concentrations under conditions that would seem ideal for total depletion of these macronutrients by phytoplankton growth (Sarmiento and Gruber, 2006). Instead, these regions show rather low phytoplankton growth, named thereby as high nutrient low chlorophyll (HNLC) regions. Besides some other limiting factors, silicon limitation north of the Polar Front and light limitation south of the Polar Front (Aumont and Bopp, 2006), limited iron concentration has been proposed as the main reason for the existence of HNLC regions (Martin, 1990). The limitation of phytoplankton growth by iron has been demonstrated by mesocale iron fertilization experiments in all major HNLC regions (Boyd et al., 2007). Despite large variations in the magnitude of the response in phytoplankton growth, all experiments showed a substantial increase in chlorophyll and a strong decrease in surface pCO_2 (de Baar et al., 2005). Modeling studies have shown that iron fertilization in the tropical Pacific has only very limited and short-lived impact on the net oceanic CO_2 uptake because the macronutrients drawn down locally by the addition of iron will be lacking elsewhere (Gnanadesikan et al., 2003). The case is different in the Southern Ocean where surface waters are currently subducted into the ocean interior before macronutrients are exhausted. Here, iron fertilization has the potential to further draw down the levels of surface macronutrients without depleting nutrient levels in adjacent surface waters further downstream. Earlier modeling studies have suggested that iron fertilization in the Southern Ocean might lead to a net reduction of atmospheric CO_2, with estimates varying considerably from some 70 to 160 Gt C (Aumont and Bopp, 2006; Sarmiento and Orr, 1991). Even though the range indicates the uncertainty about the effectiveness of OIF, the lower estimate for the cumulative uptake of about 70 Gt C is far from being negligible and approximately corresponds to a "stabilization wedge" introduced by Pacala and Socolow (2004). Nevertheless, the effectiveness of OIF is questioned because unintended side effects, like an enhanced production of nitrous oxide (N_2O) and methane (CH_4) might occur (Denman, 2008; Gnanadesikan et al., 2003). These negative side effects have not been observed during patch OIF experiments but uncertainty remains about these effects regarding large-scale OIF projects (Royal Society, 2009).

Enhancing terrestrial carbon sinks by forestry activities has entered the Kyoto Protocol, but its potential is not that certain as well. For example, van Kooten and Sohngen (2007) show that there is great inconsistency across forestry activity studies in how carbon uptake and costs are measured, so that costs of creating carbon credits through forestry vary widely. Another relevant issue for determining the effectiveness of a project is leakage, which is often ignored in bottom-up forestry activities analysis (van Kooten and Sohngen, 2007). Forest management regimes such as drainage might lead to higher emissions of other GHGs, in particular CH_4 and N_2O (Ellis, 2001). Estimates of leakage for forestry projects vary widely between 5 percent to 93 percent (Murray, 2003). Consequently, van Kooten and Sohngen (2007) argue, that the widely held notion that forestry activities are a low-cost means for reducing atmospheric CO_2 (Noble et al., 2000) needs to be reassessed.

While there is a large literature on economic prospects of forestry activities, there are few studies on economic prospects of OIF in general and on the effects of including OIF into an international climate regime in particular. To our knowledge, the rare exemptions are Sagarin et al. (2007), Leinen (2008), and Bertram (in press). Sagarin et al. (2007) provide a non-technical overview about the scientific, legal, and economic issues related to OIF. Leinen (2008) discusses the requirements that carbon markets put on the generation of carbon credits by OIF and argues that the potential commercial interest about OIF could stipulate and fund further OIF experiments. Bertram (in press) reviews basic aspects of OIF as well, but with a more detailed focus on the legal status, open access issues and how the regulation for afforestation and reforestation activities under the Clean Development Mechanism (CDM) of the Kyoto Protocol could be applied to OIF. In her overview, even though non-technical, she concludes that the quantitative potential of OIF is limited, that costs are higher than initially hoped, and that potential adverse side effects are severe. However, all three studies discuss OIF more in general, but neither in light of an explicit reduction target for 2020 nor regarding the question what would be possible carbon price or distributional effects of the inclusion of OIF within a Post-Kyoto climate agreement.

In this paper, we consider large-scale but short-term OIF realized within an international project as part of a Post-Kyoto climate agreement. The agreement covers countries with positive carbon emission reductions targets (Annex1 countries), countries with negative carbon emission reduction targets (HotAir countries), and countries without carbon emission reduction targets (CDM countries). We model a static compliance problem for the countries with a basic CO_2 market for the next commitment period (2012-2020), including domestic carbon emission reductions and emissions permit trading. It might not be likely that OIF is implemented in the next commitment period. Nevertheless, we choose 2012-2020 since data on economic activity, which is essential for our analysis, is more readily available for the next few years compared to later periods. Also, our analysis serves as a first test, if OIF can at all play a role in mitigating climate change compared to existing options.

The paper is structured as follows. Section 2 presents the carbon market. The abatement cost functions for reducing carbon emission domestically are calibrated with the computable general equilibrium model DART (Klepper et al., 2003). Since abatement costs derived from top-down models tend to provide lower cost estimates, we include an alternative approach based on empirical data (Tol, 2005). The analysis proceeds by extending the carbon market (Section 2.1) to allow for carbon credits from forestry activity (Section 2.2). The provision of carbon credits from forestry activity is based on an application of the global timber model of Sohngen and Mendelsohn (2003) by Hertel et al. (2009). In Section 2.3 we explain our scenarios regarding limitations on emissions permit trading in general and on carbon credits from forestry activity in particular. Extending the carbon market to OIF (Section 2.4), we use the short-term OIF model experiments presented in Oschlies et al. (2009). In these experiments, the phytoplankton growth rate is increased in the Southern Ocean (south of 30°) for the duration of 1, 7, and 10 years, respectively. Two different growth rates are assumed, representing a high and low level of effectiveness of iron fertilization. Generating carbon credits for OIF is based on three different accounting methods taken from Rickels et al. (2009).

In Section 3, we determine the critical unit costs and the critical discount factors for OIF. These are the costs and discount factors that indicate if OIF would be competitive to forestry or CDM activities. In Section 4 we consider distributional aspects related to OIF. We investigate who would gain or loose if carbon credits from OIF could be used for compliance. In the final Section 5, we compare the critical unit costs to cost estimates in the literature, including cost estimates for forestry activities. We compare as well the critical discount factors to those of Rickels et al. (2009) and discuss the implications regarding the distributional aspects.

2 The carbon market

2.1 The carbon market without forestation and OIF

Assessing the potential of OIF in a Post-Kyoto climate regime requires a carbon market. We model the 2020 compliance problem, restricted to carbon emissions.[1] Achieving a given emission cap, A, requires for a given country to reduce its business as usual emission, E, by the amount R so that $E - R \leq A$. The costs of this action are measured by the abatement cost function, $AC(R)$, and amount to $AC(E - A)$. To reduce costs we allow for emissions permit trading, denoting the net number of permits traded by P. Consequently, the countries face the problem of determining the optimal amount of domestic emission reduction, R^*, and the optimal amount of permits traded, P^*, so that the sum of abatement costs and emission trading costs or gains is minimized. Denoting the

---

[1] From now on we denote carbon emissions just as emissions.

permit price by π and indexing the countries by i, the optimization problem for the each country becomes:

$$\begin{aligned} \min_{R_i,P_i} C_i &= AC_i(R_i) + \pi P_i, && (1) \\ & \text{s.t.} \quad E_i - R_i - P_i \leq A_i, && (2) \\ & \text{s.t.} \quad 0 \leq R_i \leq E_i && (3) \end{aligned}$$

Note, a positive value for P_i indicates a permits buying country and a negative value a selling country. Solving the optimization problem, we obtained for an interior solution, $0 < R_i^* < E_i$, the well-known efficiency result. Marginal abatement costs are equal to the permit price over all countries:

$$AC'(R_i^*) = \pi. \tag{4}$$

The optimal amount of emission reduction becomes a function of the permit price, $R_i^*(\pi)$. The optimal permit price is determined by the overall compliance condition that the sum of individual emission reduction has to be sufficient to fulfil the sum of the individual carbon emission caps:

$$\sum_i^n E_i - \sum_i^n R_i^*(\pi^*) = \sum_i^n A_i. \tag{5}$$

For the determination of the emission caps, A_i, we define a Reference Emission Target for 2020 relative to 2005. The EU made a firm independent commitment to reduce its emissions at least by 20 percent by 2020 relative to 1990, but by 30 percent if an international agreement on emission reduction will be adopted (European Union, 2009a, Art. 3). If countries have announced various targets, we choose the higher one. If Annex I countries have not announced any targets, we choose the emission target from the Garnaut Climate Change Review final report which corresponds to the EU 30 percent target (Garnaut, 2008), except for the Hot Air countries Russia and Ukraine. Here we assume an emission target that ensures no increase over their current BAU emission projections for 2020 (Anger et al., 2009).[2] Based on their large potential to generate emission reduction credits via CDM, we include China, India, and countries in Latin America as CDM countries. For those we assume that no emission target exists. Consequently, we have three groups of countries, Annex I countries with positive reductions targets (Annex1), Annex I countries with negative reductions targets (HotAir), and countries with no reduction targets (CDM). For Annex1 countries the individual emissions reduction targets for 2020 relative to 2005 add up to a 27.5 percent, including HotAir and CDM countries the overall reduction target decreases to 21.7 percent and -5.4 percent, respectively. A detailed description of the determination of the emission caps for the various countries is presented in Appendix A. Individual emission targets are shown in column 3 in Table A.2.

For the determination of the abatement cost functions, $AC(R_i)$, we follow a top-down approach, based on the computable general equilibrium model DART, calibrated to the GTAP-7 database (Narayanan and Walmsley, 2008). The DART (Dynamic Applied Regional Trade) model is a multi-

---

[2] Note, by doing so we still obtain a stricter reduction than we would by taking their historical 1990 emission as target.

region, multi-sector recursive dynamic CGE model of the world economy aimed to analyze climate policies. For a more detailed description of the model see Klepper et al. (2003). The DART version we use, entails 12 world regions. For nine of these regions we calculate abatement cost functions, namely the Annex1 regions, Western Europe (WEU), Eastern Europe (EEU), United States (US), Japan (JPN)[3] and the group of Australia, New Zealand, Canada (OAB), for the HotAir region, the Former Soviet Union (FSU), and for the CDM regions, China (CPA), India (IND), and Latin America (LAM).

We calculate the abatement cost functions based on the emission targets for Annex1 and HotAir countries from our Reference Emission Target for 2020. For CDM countries these targets are equal to their 2020 BAU emission levels. For the region under consideration, we start with a baseline run without emission target and increase the emission target stepwise, observing the change in GDP compared to the first baseline run to obtain the relative costs. For a detailed description of this approach, see Klepper and Peterson (2006b). We fit two analytical functional forms to the observed relative costs:

$$\begin{aligned} \text{Function 1:}\quad 1-\frac{GDP_{red_i}}{GDP_{base_i}} &= \alpha_{1i}R_i^2, \\ \text{Function 2:}\quad 1-\frac{GDP_{red_i}}{GDP_{base_i}} &= \beta_{1i}*R_i+\beta_{2i}*R_i^2. \end{aligned} \tag{6}$$

For each region the resulting parameters for both functions as well as for the adjusted R^2 can be found in Appendix A in Table A.1. To obtain country-specific abatement cost functions for the DART regions that contain several countries, we follow the approach by Tol (2005) and assume a 10 percent spread in relative costs between the country with the highest carbon intensity (CO_2/GDP) and the country with the lowest carbon intensity for a 10 percent reduction. By using the minimum, maximum and average carbon intensity of each region, we adjust the parameters α_{1i} for Function 1 and β_{1i} for Function 2 to obtain country-specific abatement cost functions.

There is some evidence that abatement cost estimates obtained from top-down models like the DART model tend to provide lower cost estimates than cost estimates obtained from bottom-up models (Wing, 2006). Top-down models allow for more possibilities of economic adjustment than bottom-up models and provide better estimates of medium-term cost while bottom-up models provide better estimates of short-term costs (Gallagher, 2008). To take this into account, we include a third abatement cost function, which has the same functional form as Function 1, but parameter values are taken from Tol (2005), who calibrates the parameters to the abatement cost overview by Hourcade et al. (1996). We denote this abatement cost function as Function 3. The country-specific parameter values for the three functional forms, Function 1, Function 2, and Function 3, are shown in columns 4 to 7 in Appendix A in Table A.2.

2.2 Extending the carbon market for carbon credits from forestation

To include forestation in our carbon market, we use the results presented in Hertel et al. (2009), because neither the DART model (Klepper et al., 2003) nor the calibrated model of Tol (2005) do model the forestry sector explicitly. Hertel et al. (2009) applies the global timber model of

---

[3] For Japan, we calculate the abatement cost function based on the equivalent variation instead of GDP to obtain a monotonically increasing abatement cost function.

Sohngen and Mendelsohn (2003; 2007). The global timber model is a partial equilibrium, dynamic optimization model of global timber markets, which maximizes the net present value of consumer surplus in timber markets, taking into account the costs of managing, harvesting, and holding forests. The model determines the optimal age of harvesting trees, the quantity harvested, the area of land converted to agriculture, and timber management (Hertel et al., 2009). If for landowners a carbon rental fee for every additional ton of carbon stored in each year is introduced, the value of forest land increases and landowners respond by converting other land into forests, increasing rotation length, and increasing management intensity (Sohngen and Mendelsohn, 2003). The additional cumulative amount of carbon sequestered is obtained by comparing the situation with a carbon rental fee to a situation with no fee. Hertel et al. (2009) obtain the annual sequestration potential from the global timber model by calculating the annual equivalent amount of carbon in response to the carbon rental fee based on a 20 year projection of carbon storage. The annual equivalent amount is derived from the present value carbon equivalent, using a discount rate of 5 percent.

Using these results, we extend our model by including a forestry sector for each country which responds with carbon sequestration to the prevailing carbon price, $F_i(\pi)$. We assume that the contribution of the forestry sector to GDP is negligible, so that the objective function in the abatement cost minimization problem of a country, (1), does not change, but the first constraint, (2), does:

$$E_i - R_i - P_i - F(\pi) \leq A_i, \tag{7}$$

and so does the optimal permit price, because the overall compliance condition changes:

$$\sum_i^n E_i - \sum_i^n R_i^*(\pi^*) - \sum_i^n F_i(\pi^*) = \sum_i^n A_i. \tag{8}$$

Note, that F_i is not marked with an asterisk, because the carbon sequestration response of the forestry sector enters as an optimized function into the model.

Based on the global carbon supply schemes for the US, China, and the rest of the world taken from Hertel et al. (2009) we estimate simple linear forest sequestration supply functions, $F_i(\pi) = f_i * \pi$. We use the share of additional carbon stored without the US and China presented in Sohngen and Mendelsohn (2007) to divide the forest supply function of the rest of the world to less aggregated regions. We use the share of forest area from FAO (2009) to further divide the forrest supply curve of the remaining aggregated regions Europe, Central America, South America, and Oceania to the country level. The results are shown in Appendix A in column 8 in Table A.2. Column 9 in this table shows the current annual limits for sequestration by forestation for each Annex1 and HotAir country under the Kyoto Protocol, $\bar{F}_i$ (UNFCCC, 2001). We assume that for CDM countries no limits for sequestration by forestation exist.

2.3 Scenarios for the carbon market with forestation

Under the Kyoto Protocol the exchange of carbon credits with CDM and HotAir countries is limited as well as the use of domestically generated carbon credits from forestation.[4] For a given emission

---

[4] In our carbon market, we do not distinguish between domestic emission permits (e.g. Assigned Amounts) and carbon credits from CDM (CER).

reduction target, increasing the exchange of credits with CDM and HotAir countries or allowing for more carbon credits from forestation leads to declining abatement costs, lower permit prices and smaller amounts of domestic emssion reduction, R_i, in Annex1 countries. This is as expected. Following the announcements for a Post-Kyoto climate agreement, a scenario with trade but limitations using CDM carbon credits, permits generated in HotAir countries, or credits from domestic forestation projects for compliance seems most likely (e.g., European Union, 2009a, Art. 32). We take this into account and distinguish between scenarios for emission trading and the exchange of carbon credits generated outside of Annex1 (CDM and HotAir countries) as well as between scnearios including carbon credits from domestic forestation projects (Table 1). We define the Scenario $LimitCDMLimitForest$ as our Reference Scenario, where the volume of trade with CDM and HotAir countries is limited to 10 percent and the inclusion of carbon credits from forestation is limited by Annex Z (UNFCCC, 2001, Art. 3.4).

Table 1: Scenarios for emission trading and inclusion of forestation

	Emission trading restricted to Annex1	Emission trading including CDM and HotAir up to 10 percent of Annex1 reduction targets	Emission trading without limitations for CDM and HotAir countries
no forestation $F_i(\pi) = 0$	$Trade$ $NoForest$	$LimitCDM$ $NoForest$	$FullCDM$ $NoForest$
limited forestation (Annex Z) $F_i(\pi) = f_i\pi$ if $f_i\pi < \bar{F}_i$ $F_i(\pi) = \bar{F}_i\pi$ if $f_i\pi \geq \bar{F}_i$	$Trade$ $LimitForest$	$LimitCDM$ $LimitForest$ (Reference Scenario)	$FullCDM$ $LimitForest$
unlimited forestation $F_i(\pi) = f_i\pi$	$Trade$ $FullForest$	$LimitCDM$ $FullForest$	$FullCDM$ $FullForest$

2.4 Extending the carbon market to carbon credits from OIF

We assume that carbon sequestration by OIF is realized within an international project as part of a Post-Kyoto climate agreement, because without international coordination its usage would be inefficiently low and it would be more difficult to establish a mechanism that addresses side effects (Kousky et al., 2009). Consequently, determining the optimal amount of OIF does not enter the individual country's objective function, but releases the overall reduction cap. We denote the number of carbon credits obtained from OIF used for compliance with I and the costs of OIF with $C(I)$. Determining the optimal amount of OIF from a social planer's perspective, requires that marginal costs of the various abatement options are equalized, which implies $\pi = C'(I^*)$.[5] The optimal use of OIF becomes a function of the permit price, $I^*(\pi)$, so that the overall compliance condition with forestation and OIF becomes:

$$\sum_i^n E_i - \sum_i^n R_i^*(\pi^*) - \sum_i^n F_i(\pi^*) - I^*(\pi^*) = \sum_i^n A_i. \tag{9}$$

---

[5] Note, if large-scale OIF would be performed by a company or one country, the optimization would require to take into account the price effect of OIF. OIF would been provided according to $\pi'(I)I + \pi(I) = C'(I)$, resulting in a lower amount of OIF than optimal from a social planers perspective, $I < I^*$.

For a quantitative assessment we use information on the modeled OIF experiments reported in Oschlies et al. (2009). In that paper a number of scenarios are presented. OIF is realized by increasing the phytoplankton growth rate in the Southern Ocean (south of 30°) for 1, 7, 10, 50, and 100 years, assuming the IPCC SRES A1 emission scenario. The maximum phytoplankton growth rate is increased from 0.13 per day at 0° C to either 0.26 or 10.0, respectively. The first growth rate corresponds to a scenario with low effectiveness (fertilization effectiveness low), while the second corresponds to a scenario with high effectiveness of iron fertilization (fertilization effectiveness high). The model outcome is summarized by the annual global oceanic carbon uptake and the annual global atmospheric carbon removal over 100 years for each experiment for both growth rates.[6] The oceanic carbon uptake is always larger than the atmospheric carbon removal, indicating that oceanic carbon uptake is a composite of atmospheric and terrestrial carbon. In this paper we consider only the short-term OIF model experiments, 1, 7, and 10 years, to which we refer as Experiments 1 to 3. We exclude the results of the long-term experiments (50 and 100 years respectively) assuming that short-term experiments represent a more realistic alternative to existing enhancement projects. Also, the potential negative side effects are presumably much lower compared to long-term OIF.

For the inclusion of OIF into a global carbon market, carbon credits have to be assigned to the carbon fluxes induced by OIF. In Rickels et al. (2009) various accounting methods are discussed and applied, using the model OIF experiments. Four carbon accounting methods exist that assign permanent carbon credits: the net method, the average method, the discount method, and the equivalence method. Two carbon accounting methods exist that assign temporary carbon credits: the shorttemp method and the longtemp method. One carbon accounting method exists that assigns permanent and as well temporary carbon credits: the mixed method. Temporary carbon credits used for compliance have to be replaced at some point in time, permanent carbon credits not.

In our analysis we focus on accounting methods that assign permanent carbon credits, because we consider only a short-term compliance problem for the period 2012 to 2020. Issuing temporary credits would require that possible replacement issues in later compliance periods are taken into account which would unnecessarily complicate an actual implementation. In our analysis we choose two accounting methods: the net method and the discount method. We choose the net method because it is implicitly applied in most OIF modeling studies. It measures the overall effect of OIF for a given period of time, generally 100 years (Rickels et al., 2009), no matter when the carbon fluxes take place within that period. We choose the discount method, because it is generally applied when calculating carbon credits from forestation (see Section 2.2). The discount method weights the carbon fluxes in early years higher than in later years. We ignore the average method in our analysis, because it leads to results between those of the net and the discount method. We ignore the equivalence method, because it is discussed rather controversially in the literature (e.g., Dornburg and Marland, 2008). Additionally, with the equivalence method issuing credits spreads over a relatively long time period and is, therefore, less attractive from an economic perspective. For further details see Rickels et al. (2009).

For comparison, we include one accounting method that assigns temporary carbon credits. We choose the shorttemp method, because it provides the largest amount of carbon credits in the first

---

[6] For other emission scenarios the uptakes might be slightly lower due to a lower concentration gradient between atmospheric and oceanic carbon or slightly higher due to a reduced temperature feedback.

commitment period if applied to short-term OIF. As indicated above, these carbon credits have to be replaced in the following commitment period and are, therefore, of lower value compared to than permanent credits. We do not discuss this issue in detail.

To allow a direct comparison with the amount of carbon credits generated by forestation all three methods are applied to oceanic carbon uptake. Table 2 shows the corresponding amounts of carbon credits for a single year in the first compliance period 2012-2020. To obtain the amount for a single year, the cumulative amount for the whole period is equally distributed over the 8 years. Note, in comparison to Table 1 presented in Rickels et al. (2009) carbon credits are measured in Gt CO_2. For the discount method we apply a social rate of time preference (SRTP) of 5 percent taken from (Hertel et al., 2008), where it is applied to determine the amount of carbon credits from forestation (Section 2.2).

Table 2: Annual OIF carbon credits in 2012-2020 in Gt CO_2

Accounting method	Exp 1: 1 year OIF		Exp 2: 7 years OIF		Exp 3: 10 years OIF	
	fertilization effectiveness		fertilization effectiveness		fertilization effectiveness	
	high	low	high	low	high	low
net	1.5252	0.2812	6.2108	1.1451	8.2261	1.6168
discount	3.1491	0.4993	10.4365	2.6642	12.8699	3.4945
shorttemp	3.6917	0.5528	14.7575	4.3879	16.0308	5.1848

Source: Rickels et al. (2009)

Using the OIF model experiments, I is not a continuous function and no reliable estimates for $C(I)$ exists (Barker et al., 2007; Bertram, in press). To solve this problem, we turn the question around and seek to determine a critical cost level for OIF. The critical cost level makes an emitter indifferent between the different abatement options. We assume that the costs for OIF can be expressed by a simple linear function, $C(I) = c_I I$, implying that marginal costs are equal to unit costs.[7] In order to determine the critical costs, we calculate an upper and lower level for the critical unit costs of OIF realized as in the model experiments. The upper level is calculated by observing the permit price in a carbon market where credits from OIF are not traded, π_0^*. Only if $c_I < \pi_0^*$ is fulfilled, OIF can be considered as an abatement option. The lower level is calculated by observing the permit price when credits from OIF can be traded on the market π_1^*. Regarding the lower level, three cases can be distinguished:

Case 1: $\pi_1^* > c_I$ implies that the optimal amount of I should be larger and OIF should be extended,

Case 2: $\pi_1^* = c_I$ implies that the optimal amount of I is provided,

Case 3: $\pi_1^* < c_I$ implies that the optimal amount of I should be smaller and OIF should be reduced.

Depending on our scenario, we obtain different prices for the upper level, π_0^*. Limitations on the use of credits generated outside the Annex1 countries (in CDM and HotAir countries) or by domestic forestation are based on the belief that they should only be used to supplement domestic action. Without these limitations permit prices would be lower, restraining technological change towards a

---

[7] Considering a potential range for carbon credits generated by OIF, $I \epsilon \{I_{min}, I_{max}\}$, the characteristics of large-scale OIF imply that $I_{min} >> 0$. The costs of OIF will be dependent on the overall project scale and not on the marginal unit of carbon sequestered.

low-carbon economy in the Annex1 countries. Including OIF in a Post-Kyoto agreement would have the same effect. Consequently, it seems more likely that limitations on existing abatement options will be loosened before a new uncertain abatement option like OIF will be introduced. To calculate the lower level, π_1^*, we exclude carbon credits from OIF and choose $\pi_0^*(FullCDMFullForest)$ instead. We argue, that including OIF should at least generate the same efficiency gains as extending existing options, like unlimited trade with CDM and HotAir countries and unlimited carbon credits from forestation.

To account for leakage, we distinguish between I_{gross} and I_{net} by introducing a discount factor.[8] Only the net amount of carbon credits, I_{net} can be used for compliance, whereby the deducted carbon credits should cover possible leakage. The discount factor captures leakage arising from changes in emissions of other GHGs than carbon. Spatial leakage of carbon is already taken into account by using global data for oceanic carbon uptake instead of local data just for the enhancement region. Since little is known about the extend of leakage we determine maximum discount factors for OIF by comparing the gross amount of carbon credits, I_{gross}, with three critical amounts. We calculate the first critical amount as the average amount of carbon credits necessary to observe the same decrease in permit price as by switching from scenarios with $NoForest$ to scenarios with $FullForest$. We calculate the second critical amount as the average amount of carbon credits necessary to observe the same decrease in permit price as by switching from scenarios with $Trade$ to scenarios with $FullCDM$. We calculate the third critical amount as the amount of carbon credits necessary to observe the same decrease in permit price as by switching from Scenario $LimitCDMLimitForest$ to the Scenario $FullCDMFullForest$. The first and second critical amounts have straightforward interpretations. They ensure an equivalence of OIF to forestation and CDM projects respecively. The third critical amount describes an actual policy option, because it implies switching from our Reference Scenario to a scenario, which allows compliance at lowest cost (equivalence policy).

3 Critical unit costs and discount factors for OIF

Prices and costs for the various scenarios are measured in USD for the price level of 2000. Data on GDP (for 2005) and population (for 2005 to 2020) were taken from the World Resource Institute. Data on emissions (measured in CO_2) was provided by the IEA (2007). The data for emissions and GDP were projected to 2020 using information on the average annual percent change for the period 2005 to 2020 (IEA, 2007; OECD, 2008, respectively). Emission reduction targets are those discussed in Section 2.1.

Table 3 shows the permit prices and the total costs for compliance in 2020 for our three functional forms as well as the various scenarios.[9] Carbon credits from OIF are not considered here. Our calibrated functions, Function 1 and Function 2, provide results in the same order of magnitude. Only for the scenarios including $FullCDM$ (last three scenarios in the table), Function 2 provides significantly lower total costs than Function 1.[10] The reason is that Function 2 has a stronger

---

[8] Note, the discount factor shall not be confused with the discount rate in the corresponding accounting method.

[9] In addition, we calculated the permit prices and total costs for scenarios where the CDM volume is restricted to 20 percent and 30 percent of Annex1 countries targets, respectively. As expected, the results indicate that permit prices and total costs are declining for an increasing volume of CDM. The overall results are the same.

[10] Function 2 provides moderately lower cost estimates than Function 1, except for two scenarios: $TradeFullForest$

Table 3: Abatement costs and permit prices

Scenario	Function 1		Function 2		Function 3	
	permit price USD tCO$_2$	total costs 10^9 USD	permit price USD tCO$_2$	total costs 10^9 USD	permit price USD tCO$_2$	total costs 10^9 USD
Trade NoForest	141	292	106	271	248	515
Trade LimitForest	133	261	102	247	234	459
Trade FullForest	104	159	89	181	153	195
LimitCDM NoForest	127	235	98	221	223	437
LimitCDM LimitForest	119	209	95	209	209	367
LimitCDM FullForest	94	129	83	151	138	158
FullCDM NoForest	29	60	35	40	40	83
FullCDM LimitForest	23	37	24	16	30	45
FullCDM FullForest	22	34	23	13	28	39

curvature in particular for CDM and HotAir countries compared to Function 1 (see Table A.1 and A.2 in the Appendix). Consequently, the unlimited use of carbon credits from CDM and HotAir countries leads to low reduction targets and reduces the total costs, but the marginal costs and therefore the permit price are higher. This effect, lower total costs but a higher permit price, is damped for scenarios including *FullCDM*, because the solutions for Function 2 are restricted. For rather low permit prices, negative reduction shares would occur for some countries. To avoid that the reduction share is set equal to zero, implying a restricted solution for these countries.[11]

Function 3 provides much higher permit prices for scenarios with *Trade* and with *LimitCDM*, but only slightly higher permit prices for scenarios with *FullCDM*, compared to Functions 1 and 2. The reason is that Function 3 is originally calibrated to lower emissions reduction targets compared to our Reference Emission Targets. In scenarios with *FullCDM*, the realized reductions are much lower so that Function 3 provides similar results compared to the other two functions. Except for scenarios with *FullForest* Function 3 leads to much higher total costs. The reason is that due to the high permit price many carbon credits are provided by forestation, $F(\pi)$, which has no influence on GDP (see Section 2.2).

In the following, we focus on Function 1, since Function 2 provides similar results, but includes restricted solutions for scenarios with *FullCDM*. Function 3 overestimates the permit price for all scenarios except for those with *FullCDM* and overestimates total costs for all scenarios except the ones with *FullCDM* and *FullForest*.

In a next step we apply Function 1 to calculate the three critical amounts as discussed above.

---

and *LimitCDMFullForest*. This can be explained by the fact that due to the higher permit price for Function 1, more carbon credits are provided by forestation in scenarios with *FullForest*. The underlying changes in the forestry sector, e.g. adjusting the provision of carbon credits, are assumed to have no influence on GDP (see Section 2.2).

[11] 5 countries in Scenario *FullCDMNoForest*, 7 countries in Scenario *FullCDMLimitForest*, and 9 countries in Scenario *FullCDMFullForest*.

The critical amounts guarantee the decrease in permit prices to different scenario levels. The critical amounts are 944 Mt CO_2 (equivalent forestation), 3274 Mt CO_2 (equivalent CDM), and 2924 Mt CO_2 (equivalent policy). We compare these amounts to the various amounts of annual carbon credits obtained from the three OIF model experiments in Table 2. If the amount of carbon credits generated by OIF exceeds a critical amount, we calculate discount factors which imply equivalence otherwise we set the discount factors to zero. The results are presented in Table 4. Note, a discount factor of zero does not imply that carbon credits from OIF can only be used if the realized discount factor is zero. A zero discount factor implies that the amount of carbon credits from OIF is not equivalent to the corresponding critical amount.

Table 4: Maximum possible discount factors

		Equivalence Forestation 944 10^6 tCO_2		Equivalence CDM 3274 10^6 tCO_2		Equivalence Policy 2924 10^6 tCO_2	
		fertilization effectiveness		fertilization effectiveness		fertilization effectiveness	
		high	low	high	low	high	low
Exp 1: 1 year OIF	net	0.3808	0	0	0	0	0
	discount	0.7001	0	0	0	0.0716	0
	shorttemp	0.7442	0	0.1132	0	0.2081	0
Exp 2: 7 years OIF	net	0.8480	0.1753	0.4729	0	0.5293	0
	discount	0.9095	0.6455	0.6863	0	0.7199	0
	shorttemp	0.9360	0.7848	0.7782	0.2539	0.8019	0.3337
Exp 3: 10 years OIF	net	0.8852	0.4159	0.6020	0	0.6446	0
	discount	0.9266	0.7298	0.7456	0.0632	0.7728	0.1634
	shorttemp	0.9411	0.8179	0.7958	0.3686	0.8176	0.4361

4 Distributional prospects of OIF

Transferring the social planers solution to the international project level requires the distribution of potential profits from OIF to the country level. This can be realized by either distributing the potential profits or the carbon credits to the countries based on some allocation formula. The allocation formula influences the individual countries' costs but not the overall optimality condition. To provide an example of the distributional consequences, we include OIF in our Reference Scenario, *LimitCDMLimitForest*. We assume that OIF provides net credits equal to the third critical amount (equivalence policy), 2924 Mt CO_2, and that the unit costs, c_I, are equal to $\pi(FullCDMFullForest)$, 22 USD. It implies that including OIF would have the same effect as loosening existing limits on carbon credits from CDM and domestic forestation. Additionally, it implies that OIF does not provide any extra profits, because the unit costs are equal to the prevailing permit price. The OIF carbon credits are either sold on the market or allocated to the countries. If allocated to the countries, we assume that only countries with positive emissions reduction targets can receive OIF credits. There are several possibilities to define and combine allocation criteria. We assume an allocation of carbon credits to countries with binding emission targets (Annex1) based on population, but allocation of payment based either on CO_2 emissions or GDP (all in 2005). This implies that the more populated a country is compared to others the higher is it's share in the initial allocation. The richer a country is or the more it contributes to global warming the greater is

Table 5: Distributional effects of including OIF into the Reference Scenario (constant 2000 USD)

Top 8 Payers (absolute)	**Total costs** 10^9 USD Reference Scenario (LimitCDM10 LimitForest no OIF)	Change in **total costs** compared to Reference Scenario (in percent)			
		FullCDM FullForest (no OIF)	LimitCDM10 LimitForest		
			OIF via market	OIF via distribution population/CO_2	OIF via distribution population/GDP
	permit price 119 USD tCO_2	permit price 22 USD tCO_2			
United States	147.76	-71.52	-71.52	-63.74	-67.00
Germany	18.44	-68.52	-68.52	-74.08	-72.29
Japan	16.09	-73.61	-73.61	-84.95	-51.67
UK	14.92	-73.70	-73.70	-80.95	-73.94
France	10.54	-74.41	-74.41	-92.27	-79.45
Italy	10.21	-69.32	-69.04	-82.57	-79.81
Australia	9.02	-70.79	-62.92	-55.30	-65.13
Spain	6.50	-65.84	-65.47	-80.73	-83.82
Top 8 Receivers (absolute)	**Total profits**	Change in **total profits** compared to Reference Scenario (in percent)			
China	27.48	-24.69	-82.02		
Russia	6.11	24.23	-79.44		
India	5.73	-20.47	-81.92		
Brazil	4.36	31.00	-81.92		
Ukraine	1.71	-1.41	-82.53		
Venezuela	0.72	6.34	-81.92		
Colombia	0.58	27.80	-81.92		
Mexico	0.53	-30.34	-82.90		

its contribution to pay for OIF. Note, if allocation and payment of carbon credits are based on the same criteria, the market solution would be retained. We compare the distributional consequences to those observed by switching from the Reference Scenario, *LimitCDMLimitForest*, to the Scenario *FullCDMFullForest* (equivalence policy).

Table 5 shows the results of including OIF carbon credits into the Reference Scenario for the eight countries with the highest (all Annex1 countries) and the lowest abatement costs (all CDM or HotAir countries). The results are based on our Reference Emission Target for the year 2020. Table A.3 in the Appendix provides the results for all countries.

The calculation shows that countries with high abatement costs (Top Payers) are rather indifferent between the option of switching from the Reference Scenario to the Scenario *FullCDMFullForest* (third column) and the option of including OIF into the Reference Scenario (column four to six). Both options result in lower permit prices and a larger total amount of carbon credits available, in lower domestic emission reductions and larger amounts of carbon credits purchased for compliance. However, depending on the allocation rule chosen, moderate differences can be observed. The decrease in costs ranges from 65 to 74 percent for the first option and from 52 to 92 percent for the second option. For some countries payment based on CO_2 emissions is more beneficial compared to a rule based on GDP (e.g. Japan and France). For other countries the opposite is true (e.g. United

States and Australia). However, in general the costs decrease roughly in the same order of magnitude, which is rather straightforward, because we include OIF such that equivalence in volume and permit price effect is assured in comparison to switching from Scenario $LimitCDMLimitForest$ to Scenario $FullCDMFullForest$.

The calculation shows as well that countries with low abatement costs (Top Receivers) are not indifferent between the two options. Under the first option, switching from the Reference Scenario to Scenario $FullCDMFullForest$ (third column), the profits either increase (e.g. Brasil and Columbia) or decrease (e.g. Mexico and China). For countries with decreasing profits, the effect of the increase in the amount of carbon credits sold on the market (volume effect) is overcompensated by the effect of the decrease in permit price (price effect). For example, China doubles its carbon credits sale from 227 Mt CO_2 to 504 Mt CO_2, whereas the permit prices decreased by a factor six from 119 USD to 22.92 USD, loosing overall 25 percent. For countries with increasing profits, the overall negative effect of carbon credits sale is compensated by the positive effect from additional sale of forestry credits (forestation effect). For example, Brazil doubles its sale of forestry carbon credits from 36 Mt CO_2 to 72 Mt CO_2, gaining overall 31 percent. Under the second option, including OIF carbon credits, the profits for all eight countries decrease by about 80 percent (fourth column). It does not matter, if OIF carbon credits are sold on the market or if the allocation is based on some allocation rule, because none of these countries are considered in the allocation since they have no binding emissions reduction targets. When including OIF carbon credits, the price effect remains the same, but is not compensated by the volume effect or forestation effect.

Table 6: Reduction targets 2020

Climate Regime		OIF 10^6 tCO_2	reduction target 2020 rel. 2005 in percent
BAU	without OIF	0	-24.7
Reference emission target	without OIF	0	-5.4
	OIF equiv. forestation	944	-0.9
	OIF equiv. Policy	2924	8.3
	OIF equiv. CDM	3274	10.0
	OIF max	11583	48.8

Considering the choice between the option of relaxing existing limitations and the option of including OIF, we expect the first option to be chosen for several reasons. The underlying regulation requirements are already in place and potential side effects are better explored. Realizing both options, relaxing existing limitations and including OIF, would decrease the permit price below $\pi(FullCDMFullForest)$ and would therefore decrease the incentives for switching to a low carbon economy further. To avoid a decline in prices and to enable more ambitious emissions reduction targets we turn the question around and calculate how the overall emission reduction target would change if the permit price $\pi(FullCDMFullForest)$ is maintained while carbon credits from OIF are included.

Table 6 shows the various emissions reduction targets with and without the Reference Emission Target and with and without the inclusion of OIF. The emission targets are for 2020, relative to 2005. For the countries included in our analysis, the business as usual situation (BAU) without any emissions reduction targets implies an increase in emissions by 24.7 percent. Realizing our Reference Emission Target, which does not include CDM countries, still implies an increase in emissions by 5.4 percent. Maintaining the permit price $\pi(FullCDMFullForest)$ and including OIF at an amount equivalent to forestation (first critical amount), the overall emission target can be intensified, but would still lead to an increase in emissions of 0.9 percent. Maintaining the permit price $\pi(FullCDMFullForest)$ and including OIF at an amount equivalent to the current policy option (second critical amount), the overall reduction target gets stricter and reaches 8.3 percent. Overall emission reduction increases to 10.0 percent, if OIF is included at an amount equivalent to CDM (third critical amount). Including the maximum amount of permanent carbon credits from OIF by realizing Experiment 3 (10 years OIF), using a social rate of time preference of 5 percent, assuming a high level of fertilization effectiveness and a discount factor for offsets of 9.0 percent,[12] results in an overall emission reduction of 48.8 percent.

5 Discussion and conclusion

Our main objective was to determine critical costs and maximum discount factors for OIF to be equivalent to existing abatement options. In our analysis we did not follow a bottom-up engineering approach, but turned the question around and started from a top-down market approach based on results of three modeled OIF experiments. For the determination of the critical costs we considered the permit price in various scenarios for a 2020 compliance problem. The permit prices obtained from our calibrated functions, Function 1 and Function 2, were comparable to previous studies (e.g., Anger et al., 2009; Klepper and Peterson, 2006a), whereas the obtained permit prices for the various scenarios with Function 3, based on Tol (2005), provided much higher permit prices. We chose the Scenario $LimitCDM10LimitForest$ to determine the upper level of the critical costs as it represents the current status of climate policy for the next commitment period. We chose the Scenario $FullCDMFullForest$ to determine the lower level of the critical costs, because this is the climate policy which achieves a given emission reduction target with existing abatement options at lowest costs.

In our analysis critical unit cost for the upper level were ranging from 95 to 119 USD per t CO_2 (Scenario $LimitCDMLimitForest$), or even up to 209 considering Function 3 as well. For the lower level values were ranging from 22 to 23 USD per t CO_2 (Scenario $FullCDMFullForest$), or even up to 28 again considering Function 3. We argued, that the upper level of our estimates indicates, if OIF could be considered an abatement option at all. The lower level of our estimates indicates, if OIF would be comparable to existing abatement options. Using recent sequestration efficiency ratios from patch OIF experiments, Boyd (2008) estimates that the costs are between 8 and 80 USD per t CO2 sequestered. Although, these cost estimates might be not be representive for large-scale OIF (Bertram, in press), the upper and lower level of those estimates are below the corresponding range of the upper and lower level of our estimates.

To determine maximum discount factors to account for leakage we compared the amounts of OIF carbon credits for the various experiments and the various issue options to the critical amounts obtained when relaxing the limitations regarding carbon credits from trade with HotAir and CDM countries as well as from forestation. If fertilization effectiveness was high, OIF with a duration of

---

[12] Rickels et al. (2009) suggest an average discount factor of 9.0 percent to cover offsets due to emissions of other GHG than carbon as well as carbon emissions due to operation. This discount factor should not be confused with the social rate of time preference, applied in the accounting method named discount.

only one year provided annual credits in the commitment period 2012-2020 which allowed discount factors between 38 (net method) and 70 percent (discount method) to be still equivalent to the annual effect of forestation. If the fertilization effectiveness was low, the duration of OIF extended to seven years to maintain equivalence. The corresponding maximum tolerable discount factors are between 17 (net method) and 64 percent (discount method). Note, the annual amounts of carbon credits from forestation are based on global forestation projects for the duration of 20 years based on the discount method. Regarding the uncertainty about the growth rates of phytoplankton, we conclude that seven years of OIF seem sufficient to obtain an amount of annually carbon credits in the 2012-2020 commitment period which is a) equal to that provided by forestation and b) allow maximum discount factor which sufficiently exceed the upper range of 15 percent estimated by Rickels et al. (2009) to account for leakage.

Rickels et al. (2009) conclude that from an environmental and economic perspective an accounting method that assigns short-term temporary carbon credits seems most appropriate for short-term OIF. In our study we focused on permanent methods to avoid taking into account replacement issues which arise when issuing temporary carbon credits. Nevertheless, applying this accounting method we obtained for a fertilization period of 7 years sufficient amounts of carbon credits, which allowed for discount factors above 15 percent for all three critical amounts regardless of the effectiveness of OIF.

In the IPCC Fourth Assessment Report the annual carbon sequestration potential by reforestation is estimated between 0.44 and 0.88 Gt CO_2 until 2030 assuming a CO_2 price range of 20 to 100 USD. Including in addition to reforestation forest carbon density management, expanded use of forest products, and in particular reduced deforestation, the range is estimated to be 1.47 to 2.93 Gt CO_2 (Nabuurs et al., 2007; Government of Canada, Minister of Environment, 2008). In our analysis based on the study of Hertel el al. (2009), we estimated the annual potential of forestry projects at 0.944 Gt CO_2 (equivalence forestation). The number is slightly above those for reforestation projects but lower compared to the potential when including all kind of forestry activities. However, both critical amounts, equivalence policy and equivalence CDM, exceeded the range for all forestry activities, so that implementing OIF for 7 years and applying the shorttemp method, which assigns temporary carbon credits, would have a larger effect than the effect of all forestry activities together for a period of 30 years.

Assessments of forestry activities often neglect the issue of leakage (van Kooten and Sohngen, 2007). Forest management regimes such as drainage might lead to higher emissions of other GHGs, in particular CH_4 and N_2O (Ellis, 2001). Estimates for leakage regarding forestry projects vary widely: between 5 to 93 percent (Murray, 2003). A leakage factor of 25 percent, for example, would increase costs by one-third (Boyland, 2006). Leakage also arises, if the stored carbon in forests is intended or unintendedly released. In particular the unintended release due to naturally occurring events like fires, pests, droughts or hurricanes imposes a risk on long-term storage prospects (Royal Society, 2001). The likelihood of such naturally occurring events may increase in the future due to global warming and would make terrestrial carbon sinks less attractive (Ellis, 2001).

In our analysis, we considered distributional aspects of OIF as well. We included OIF into our Reference Scenario *LimitCDMLimitForest* by allocating OIF carbon credits to countries with positive reduction targets and compared the effects for the countries with the highest and lowest abatement costs to the situation of switching from our Reference Scenario to the Scenario $FullCDMFullForest$. The results revealed that including OIF might provide new incentives for the negotiation process of a Post-Kyoto climate agreement. Considering the choice between the option of switching the scenarios and the option of including OIF, countries with high abatement costs are expected to be more or less indifferent based on our calculation. Countries with low abatement costs and therefore sellers of carbon credits are expected to favor the first option based on our calculation. Even though not all selling countries gained under the first option, they were still better off compared to the second option. Therefore, one could consider a third option with $FullCDM$, $FullForest$, and OIF, but in which CDM and HotAir countries are included in the allocation of OIF, if they would accept emissions reduction targets in a future commitment period. The costs of countries with high abatement costs did not change so much with respect to the various allocation formula, but the cost of countries with low abatement costs would. OIF carbon credits were assigned according to population, but had to be paid according to GDP or CO_2 emissions. Annex1 countries are rather similar in the relations of population to GDP as well as to CO_2 emissions, but CDM and HotAir countries differ significantly. Therefore, an allocation formula could be designed as an additional option that provides incentives to CDM and HotAir countries to accept emissions reduction targets, while assuring that Annex1 countries are indifferent between the different options.

Realizing this third option requires to intensify the overall emission reduction target, because otherwise the permit price would decline further. Based on our calculations, including the maximum amount of permanent carbon credits from OIF (fertilization duration of 10 years, effectiveness high, discount factor for offset 9 percent), allowed an overall emission reduction target of 48.8 percent for 2020, whereas our Reference Emission Reduction Scenario implied an overall increase in emissions of 5.4 percent. The calculation was based on the assumption, that the permit price $\pi(FullCDMFullForest)$ is maintained. Consequently, including OIF might not just provide new incentives for the negotiation process for further climate agreements but allows for a negotiation of more ambitious emissions reduction targets in the future.

In this study, we did not consider if and how the modeled OIF experiments could be realized in the Southern Ocean, which remains a crucial aspect of OIF to be considered as an abatement option. It should be noted as well, that we considered a static 2020 compliance problem. Implementing OIF will generate carbon credits for several years within one commitment period or even spread over different commitment periods. Therefore, the costs of OIF should be compared with a time series of permit prices to incorporate the dynamic effects of the carbon market. Nevertheless, our study is in line with assessments of other abatement options, which concentrate as well on a given compliance year, (e.g. Anger et al., 2009) for the assessment of reducing emissions from deforestation and degradation. Additionally, economic data necessary for the conduct of our analysis is more readily available for the next commitment period. We focused on, so far, neglected aspects in the discussion about OIF: the conditions placed by a market for OIF to be considered as an abatement option in a Post-Kyoto climate regime. Our results provide information on critical unit costs and feasible discount factors for OIF which led us to the conclusion that based on current knowledge OIF cannot be excluded from the list of potential abatement options. Further, we showed that OIF provides new incentives for the negotiation of a Post-Kyoto climate agreement. Therefore, further research regarding its sequestration efficiency and its side effects, but as well regarding its distributional and its dynamic aspects is necessary.

References

Anger, N., Erich, A. D., Livengood, 2009. Interactions of reduced deforestation and the carbon market: The role of market regulations and future commitments. Discussion Paper 09-001, ZEW - Centre for European Economic Research.

Aumont, O., Bopp, L., 2006. Globalizing results from ocean in situ iron fertilization studies. Global Biogeochemical Cycles 20, doi:10.1029/2005GB002591.

Barker, T., Bashmakov, I., Alharthi, A., Amann, M., Cifuentes, L., Drexhage, J., Duan, M., Edenhofer, O., Flannery, B., Grubb, M., M. Hoogwijk, F. I. I., Jepma, C. J., Pizer, W., Yamaji, K., 2007. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Ch. Mitigation from a cross-sectoral perspective, pp. 619–690.

Bertram, C., in press. Ocean iron fertilization in the context of the Kyoto protocol and the post-Kyoto process. Energy Policy, doi:10.1016/j.enpol.2009.10.065.

Boyd, P. W., 2008. Implications of large-scale iron fertilization of the oceans. introduction and synthesis. Marine Ecology Progress Series 364, 213–218.

Boyd, P. W., Jickells, T., Law, C. S., et al., 2007. Mesoscale iron enrichment experiments 1993-2005: Synthesis and future directions. Science 315, 612–617.

Boyland, M., 2006. The economics of using forests to increase carbon storage. Canadian Journal of Forestry Research 36, 2223–2234.

de Baar et al., H., 2005. Synthesis of iron fertilization experiments: From the iron age in the age of enlightment. Journal of Geophysical Research 110, doi:10.1029/2004JC002601.

Denman, K. L., 2008. Climate change, ocean processes and ocean iron fertilization. Marine Ecology Progress Series 364, 219–225.

Dornburg, V., Marland, G., March 2008. Temporary storage of carbon in the biosphere does have value for climate change mitigation: a response to the paper by miko kirschbaum. Mitigation and Adaptation Strategies for Global Change 13 (3), 211–217.

Eliasch, J., 2008. Climate change: financing global forests: The Eliasch Review. United Kingdom Office of Climate Change.

Ellis, J., 2001. Forestry projects: Permanence, credit accounting and lifetime. Information Paper COm/ENV/EPOC/IEA/SLT(2001)11, OECD Environment Directorate and International Energy Agency.

European Union, 2009a. Directive 2009/29/EC of the European Parliament and of the Council amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Comunity. Tech. rep.

European Union, 2009b. Decision No 406/2009/EC of the European Parliament and of the Council on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020. Tech. rep.

FAO, 2009. State of the World Forests 2009. FAO, Rome.

Fukuda, Y., 9 June 2008. Japan as a low-carbon society, speech by H.E. Mr Yasuo Fukuda, Prime Minister at the Japan Press Club.

Gallagher, E., 2008. The Gallagher Review of the indirect effects of biofuels production. Tech. rep., Renewable Fuels Agency.

Garnaut, R., 2008. The Garnaut Climate Change Review: Final Report. Cambridge University Press, Melbourne.

Gnanadesikan, A., Sarmiento, J., Slater, R., 2003. Effects of patchy ocean iron fertilization on atmospheric carbon dioxide and biological production. Global Biogeochemical Cycles 17 (1050), doi:10.1029/2002GB001940.

Government of Canada, Minister of Environment, 2008. Turning the Corner: Regulatory Framework for Industrial Greenhouse Gas Emissions.

Hertel, T. W., Lee, H.-L., Ross, S. K., Sohngen, B., 2008. Modeling land-use related greenhouse gas sources and sinks and their mitigation potential. GTAP Working Paper 44, Center for Global Trade Analysis, Purdue University.

Hertel, T. W., Lee, H.-L., Ross, S. K., Sohngen, B., 2009. Economic Analysis of Land Use in Global Climate Change Policy. Routledge, London, Ch. 6, pp. 123–153.

Hourcade, J., Halsneas, K., Jaccard, M., Montgomery, W., Richels, R., , Robinson, J., Shukula, P., Sturm, P., 1996. Climate Change 1995: Economic and Social Dimensions. Contribution of Working Group III to the SAR of IPCC. Cambridge University Press, Cambridge, Ch. A review of mitigation cost studies, pp. 297–366.

IEA, 2007. CO_2 Emissions from Fossil Fuel Combustion 1971-2005, 2007th Edition. IEA, Paris.

Klepper, G., Peterson, S., 2006a. Emission trading, cdm, ji, and more: the climate strategy of the EU. The Energy Journal 27 (2), 1–26.

Klepper, G., Peterson, S., 2006b. Marginal abatement cost curves in general equilibrium: The influence of world energy prices. Resource and Energy Economics 28, 1–23.

Klepper, G., Peterson, S., Springer, K., 2003. DART97: A description of the multi-regional, multi-sectoral trade model for the analysis of climate policies. Kiel Working Paper 1138, Kiel Institute for the World Economy.

Kousky, C., Rostapshova, O., Toman, M., Zeckhauser, R., 2009. Responding to threats of climate change mega-catastrophes. Policy Research Working Paper 5127, The World Bank.

Leinen, M., 2008. Building relationships between sientists and business in ocean iron fertilization. Marine Ecology Progress Series 364, 251–256.

Martin, J. H., 1990. Glacial-interglacial CO_2 change: The iron hypothesis. Paleoceanography 5 (1), 1–13.

Murray, B. C., 2003. Forest in a Market Economy. Kluwer Academic Publishers, Dordrecht, Netherlands, Ch. Economics of Forest Carbon Sequestration, pp. 221–242.

Nabuurs, G. J., Masera, O., Andrasko, K., Benitez-Ponce, P., Boer, R., Dutschke, M., Elsiddig, E., Ford-Robertson, J., Frumhoff, P., Karjalainen, T., Krankina, O., Kurz, W., Matsumoto, M., Oyhantcabal, W., Ravindranath, N., Sanchez, M. S., Zhang, X., 2007. Climate Change: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambrige, New York, Ch. Forestry, pp. 542–584.

Narayanan, G. B., Walmsley, T. L., 2008. Global Trade, Assistance, and Production: The GTAP 7 Data Base. Center for Global Trade Analysis, Purdue University.

Noble, I., Apps, M., Houghton, R., Lashof, D., Makundi, W., Murdiyarso, D., Murray, B., Sombroek, W., Valentian, R., et al, 2000. Land Use, Land Use Change, and Forestry. Cambridge Universtiy Press, Cambridge U.K., Ch. Implications of different definitions and generic issues, pp. 53–166.

OECD, 2008. Environmental Outlook to 2030. OECD, Paris.

Oschlies, A., Rickels, W., Rehdanz, K., 2009. Assement aspects of ocean iron fertilization: leakage and permanence, mimeo.

Pacala, S., Socolow, R., 2004. Stabilization wedges: Solving the climate problem for the next 50 years with current technologies. Science 305 (5686), 968–972.

Rickels, W., Rehdanz, K., Oschlies, A., 2009. Accounting aspects of ocean iron fertilization. Working Paper 1572, Kiel Institute for the World Economy.

Royal Society, 2001. The role of land carbon sinks in mitigating global climate change. Policy Doucment 10/01, 085403561 3, Royal Society.

Royal Society, 2009. Geoengineering the climate: Science, governance and uncertainty. Policy Doucment 10/09, Royal Society.

Sagarin, R., Dawson, M., Karl, D., Michael, A., Murray, B., Orbach, M., Clair, N. S., 2007. Iron fertilization in the ocean for climate mitigation: Legal, economic, and environmental challenges. General technical report, Duke University (NC): Nicholas Institute for Environmental Policy Solutions.

Sarmiento, J., Orr, J., 1991. Three dimensional simulations of the impact of southern ocean nutrient depletion on atmospheric co_2 and ocean chemistry. Limnology and Oceanography 36, 1928–1950.

Sarmiento, J. L., Gruber, N., 2006. Ocean Biogeochemical Dynamics. Princeton University Press.

Schweizerische Eidgenossenschaft, May 6 2009. Faktenblatt 2: Die Eckpunkte des CO_2-Gesetzes. Tech. rep., Bundesamt für Umwelt, Abteilung Klima, Ökonomie, Umweltbeobachtung.

Sohngen, B., Mendelsohn, R., 2003. An optimal control model of forest carbon sequestration. American Journal of Agricultural Economics 85 (2), 448–457.

Sohngen, B., Mendelsohn, R., 2007. A sensitivity analysis of carbon sequestration. In: Schlesinger, M. E., Kheshgi, H. S., Smith, J., de la Chesnaye, F. C., Reilly, J. M., Wilson, T., Kolstad, C. (Eds.), Human-Induced Climate Change: An Interdisciplinary Assessment. Cambridge University Press, Ch. 19, pp. 227–337.

Strong, A., Chisholm, S., Miller, C., Cullen, J., 2009. Ocean fertilization: time to move on. nature 461 (17), 347–348.

Tol, R., 2005. An emission intensity protocol for climate change: an application of FUND. Climate Policy 4, 269–287.

UNFCCC, 2001. Report of the conference of the parties on its seventh session, held at marrakesh from 29 october to 10 november 2001. Fccc/cp/2001/13/add.1, UNFCCC.

UNFCCC, 2003. Modalities and procedures for afforestation and reforestation project activities under the clean development mechanism in the first commitment period of the Kyoto protocol. Fccc/kp/cmp/2005/8/add.1, UNFCCC.

van Kooten, G. C., Sohngen, B., 2007. Economics of forest ecosystem carbon sinks: A review. International Review of Environmental and Resource Economics 1, 237–269.

Wing, I. S., 2006. The synthesis of bottom-up and topn-down approaches to climate policy modelling: Electric power technologies and the cost of of limiting US CO_2 emissions. Energy Policy 34, 3847–3869.

Appendices

A Appendix 1

The country specific emissions reduction targets for the Reference Emission Reduction Target can be found in column 3 in Table A.2. For the calculation of the country specific emission commitments for the EU member states, we use details of the 20 percent target, the reduction commitment of 21 percent by 2020 relative to 2005 for the European Emission Trading Sector (European Union, 2009a, Art. 5) and the individual reduction commitments in Annex IIa by 2020 relative to 2005 for the Non-ETS sector (European Union, 2009b). With these two reduction targets for the ETS sector and the Non-ETS sector for each country, we calculate the total reduction by 2020 relative to 2005, obtaining the country-specific share on the overall reduction for the 20 percent target. Using this country-specific share, we calculate the country-specific reduction target for the 30 percent overall target. For Canada we chose the emission reduction announcement of 20 percent relative to 2006 for the industry sector (Government of Canada, Minister of Environment, 2008). For Japan we choose the emission reduction announcement of 20 percent relative to 2005 indicated in a speech of Prime Minister Fukuda (Fukuda, 9 June 2008). For Switzerland we choose the emission reduction announcement of 30 percent relative to 1990 (Schweizerische Eidgenossenschaft, 2009). For Norway we choose the emission reduction announcement of 30 percent relative to 1990 (Garnaut, 2008). For the US, for Australia, and for New Zealand we choose the emission entitlement allocation from the Garnaut Climate Change Review final report. The reduction target is 28 percent relative to 2000 for the US, and 25 percent relative to 2000 for Australia and New Zealand (Garnaut, 2008, p.209). For Russia and Ukraine we assume an emission target that ensures no increase over their current BAU emission projections for 2020. For Croatia we assume an zero percent emission target relative to 2005 and for Iceland we assume a 30 percent emission target relative to 1990. We convert all emission targets to be based on the reference year 2005.

Table A.1: Estimates for the abatement cost functions

Region	Function 1		Function 2		
	α	adj. R2	β_1	β_2	adj. R2
WEU	0.06438	0.99633	-0.00374	0.07544	0.99832
EEU	0.12604	0.97775	0.02175	0.06177	0.99637
USA	0.08659	0.96463	0.01823	0.03271	0.99165
OAB	0.07746	0.98097	0.01111	0.04462	0.99337
FSU	0.14602	0.97242	-0.03865	0.24742	0.99673
CPA	0.10998	0.98493	-0.02564	0.16672	0.99851
IND	0.06867	0.97600	-0.01980	0.11064	0.99499
LAM	0.07997	0.95598	-0.02498	0.14790	0.99735
JAPAN [a]	0.19466	0.98698	-0.02583	0.27100	0.99812

[a] The estimated parameters for Japan are based on the observed change in the equivalent variation and not on the observed change in GDP.

Table A.2: Reduction targets, abatement cost functions and forestation factors and limits

Country	Class	Reduction 2020 rel. to 2005 (in percent)	Function 1	Function 2		Function 3	Foresty factor (Mt CO_2)	Forest limitation Annex Z (Mt CO_2)
			α	β_1	β_2	γ		
Austria	Annex1	29.92	0.06442	-0.00374	0.07544	0.15347	0.03490	2.31021
Belgium	Annex1	29.57	0.06536	-0.00368	0.07544	0.15281	0.00603	0.11001
Denmark	Annex1	31.99	0.06283	-0.00383	0.07544	0.15449	0.00452	0.18335
Finland	Annex1	30.62	0.06469	-0.00372	0.07544	0.15328	0.20330	0.58672
France	Annex1	28.30	0.06305	-0.00382	0.07544	0.15433	0.14054	3.22696
Germany	Annex1	29.65	0.06538	-0.00368	0.07544	0.15280	0.10008	4.54708
Greece	Annex1	27.24	0.06636	-0.00363	0.07544	0.15220	0.03390	0.33003
Iceland	Annex1	39.55	0.06181	-0.00389	0.07544	0.15546	0.00042	0.00000
Ireland	Annex1	31.94	0.06399	-0.00377	0.07544	0.15373	0.00604	0.18335
Italy	Annex1	28.67	0.06522	-0.00369	0.07544	0.15290	0.09017	0.66006
Luxembourg	Annex1	31.73	0.06557	-0.00367	0.07544	0.15267	0.00079	0.03667
Netherlands	Annex1	30.07	0.06538	-0.00368	0.07544	0.15280	0.00330	0.03667
Norway	Annex1	45.00	0.06163	-0.00390	0.07544	0.15570	0.08482	1.46680
Portugal	Annex1	23.55	0.06657	-0.00361	0.07544	0.15208	0.03418	0.80674
Spain	Annex1	27.66	0.06571	-0.00366	0.07544	0.15258	0.16188	2.45689
Sweden	Annex1	30.23	0.06124	-0.00393	0.07544	0.15653	0.24874	2.12686
Switzerland	Annex1	35.76	0.06119	-0.00393	0.07544	0.15700	0.01103	1.83350
United Kingdom	Annex1	29.99	0.06376	-0.00378	0.07544	0.15386	0.02571	1.35679
United States	Annex1	29.44	0.08659	0.01823	0.03271	0.15234	4.26042	102.67600
Australia	Annex1	32.42	0.08097	0.01182	0.04462	0.15057	1.47895	0.00000
Canada	Annex1	19.28	0.07811	0.01124	0.04462	0.15105	2.80229	44.00400
New Zealand	Annex1	30.37	0.07222	0.01006	0.04462	0.15196	0.07508	0.73340
Japan	Annex1	20.00	0.19466	-0.02583	0.27100	0.15475	0.31062	47.67100
Bulgaria	Annex1	23.68	0.13657	0.02408	0.06177	0.14502	0.03275	1.35679
Croatia	Annex1	0.00	0.12237	0.02094	0.06177	0.15037	0.01929	0.00000
Czech Rep	Annex1	23.54	0.13012	0.02265	0.06177	0.14725	0.02393	1.17344
Estonia	Annex1	25.97	0.12915	0.02244	0.06177	0.14764	0.02064	0.36670
Hungary	Annex1	17.06	0.12117	0.02067	0.06177	0.15089	0.01785	1.06343
Latvia	Annex1	12.00	0.11819	0.02001	0.06177	0.15245	0.02657	1.24678
Lithuania	Annex1	15.80	0.12015	0.02044	0.06177	0.15138	0.01897	1.02676
Poland	Annex1	21.60	0.12702	0.02197	0.06177	0.14854	0.08306	3.00694
Romania	Annex1	21.06	0.12931	0.02247	0.06177	0.14757	0.05756	4.03370
Slovakia	Annex1	21.32	0.12544	0.02162	0.06177	0.14919	0.01743	1.83350
Slovenia	Annex1	22.11	0.11905	0.02020	0.06177	0.15194	0.01142	1.32012
Russia	HotAir	-14.38	0.14136	-0.03909	0.24742	0.14189	7.30802	64.64921
Ukraine	HotAir	-17.83	0.15067	-0.03820	0.24742	0.13800	0.08652	4.07037
China	CDM	no	0.10998	-0.02564	0.16672	0.14454	7.43928	no limit
India	CDM	no	0.06867	-0.01980	0.11064	0.14763	2.56048	no limit
Argentina	CDM	no	0.07743	-0.02530	0.14790	0.15268	0.78010	no limit
Bolivia	CDM	no	0.08280	-0.02461	0.14790	0.14836	1.38769	no limit
Brazil	CDM	no	0.07828	-0.02519	0.14790	0.15212	11.28531	no limit
Chile	CDM	no	0.07978	-0.02500	0.14790	0.15127	0.38085	no limit
Colombia	CDM	no	0.07932	-0.02506	0.14790	0.15151	1.43466	no limit
Ecuador	CDM	no	0.08238	-0.02467	0.14790	0.14872	0.25640	no limit
Guatemala	CDM	no	0.07841	-0.02517	0.14790	0.15204	0.58872	no limit
Mexico	CDM	no	0.07901	-0.02510	0.14790	0.15169	0.00000	no limit
Nicaragua	CDM	no	0.08154	-0.02478	0.14790	0.14948	0.77574	no limit
Panama	CDM	no	0.07720	-0.02533	0.14790	0.15284	0.64194	no limit
Paraguay	CDM	no	0.07733	-0.02531	0.14790	0.15275	0.43646	no limit
Peru	CDM	no	0.07729	-0.02532	0.14790	0.15277	0.00161	no limit
Uruguay	CDM	no	0.07509	-0.02560	0.14790	0.15485	0.03558	no limit
Venezuela	CDM	no	0.08178	-0.02474	0.14790	0.14925	1.12719	no limit

Table A.3: Distributional effects of including OIF into the Reference Scenario

Country	Total costs in 10^6 USD (constant 2000 USD)				
	LimitCDM10 LimitForest (no OIF)	FullCDM10 FullForest (no OIF)	LimitCDM10 LimitForest		
			OIF via market	OIF via distribution population/CO_2	OIF via distribution population/GDP
	permit price 119 USD tCO_2	permit price 22 USD tCO_2			
Austria	1794.25	551.54	551.54	425.22	509.07
Belgium	2589.48	799.13	799.62	720.32	718.29
Denmark	1547.85	375.17	375.17	277.06	430.51
Finland	1413.05	317.04	401.83	356.75	389.99
France	10537.23	2696.62	2696.62	814.35	2164.88
Germany	18440.64	5805.50	5805.50	4780.05	5110.54
Greece	1616.62	611.57	620.62	410.92	325.28
Iceland	97.97	21.10	21.30	13.84	27.46
Ireland	1303.90	340.54	340.54	305.19	366.80
Italy	10213.34	3133.55	3162.39	1780.26	2061.78
Luxembourg	280.04	85.84	85.84	116.30	112.14
Netherlands	4354.86	1331.55	1332.33	1247.63	1243.41
Norway	1729.46	362.31	370.91	267.36	515.86
Portugal	675.57	344.61	344.61	-1.78	-58.95
Spain	6498.49	2220.19	2244.10	1252.41	1051.19
Sweden	1523.36	272.70	345.56	31.81	405.46
Switzerland	1713.63	395.42	395.42	154.21	530.66
United Kingdom	14920.24	3924.72	3924.72	2842.32	3888.08
United States	147758.28	42078.18	42078.18	53580.14	48753.94
Australia	9022.80	2635.58	3345.96	4033.61	3146.14
Canada	1472.30	2184.22	2565.83	3392.31	2428.27
New Zealand	885.33	265.68	285.66	206.02	168.63
Japan	16088.57	4245.13	4245.13	2421.31	7775.66
Bulgaria	-362.14	319.74	319.74	63.61	-142.59
Croatia	-7.49	56.82	66.09	-117.82	-173.12
Czech Rep	-92.71	617.72	617.72	585.74	120.43
Estonia	206.51	123.13	125.00	122.52	57.88
Hungary	470.23	251.32	251.32	-94.63	-260.71
Latvia	15.23	31.73	31.73	-78.41	-89.65
Lithuania	184.49	81.87	81.87	-68.51	-100.24
Poland	1133.68	1479.60	1479.60	580.01	-518.36
Romania	381.04	634.56	634.56	-281.12	-648.63
Slovakia	87.42	190.26	190.26	45.23	-97.75
Slovenia	349.08	122.38	122.38	75.40	47.30
Russia	-6105.01	-7584.04	-1255.23	-1255.23	-1255.23
Ukraine	-1707.64	-1683.53	-298.26	-298.26	-298.26
China	-27482.72	-20695.97	-4941.01	-4941.01	-4941.01
India	-5731.23	-4558.27	-1036.33	-1036.33	-1036.33
Argentina	-418.64	-475.40	-75.70	-75.70	-75.70
Bolivia	-516.95	-688.96	-93.48	-93.48	-93.48
Brazil	-4358.00	-5708.81	-788.02	-788.02	-788.02
Chile	-219.19	-242.28	-39.63	-39.63	-39.63
Colombia	-583.99	-746.36	-105.60	-105.60	-105.60
Ecuador	-149.34	-164.33	-27.00	-27.00	-27.00
Guatemala	-218.34	-291.62	-39.48	-39.48	-39.48
Mexico	-527.76	-367.64	-90.27	-90.27	-90.27
Nicaragua	-279.79	-378.81	-50.59	-50.59	-50.59
Panama	-229.75	-312.25	-41.54	-41.54	-41.54
Paraguay	-155.81	-212.03	-28.17	-28.17	-28.17
Peru	-29.32	-20.57	-5.04	-5.04	-5.04
Uruguay	-15.44	-19.17	-2.79	-2.79	-2.79
Venezuela	-721.29	-766.99	-130.43	-130.43	-130.43