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Abstract:

Ocean iron fertilization is currently discussed as a potential measure to mitigate climate change by enhancing oceanic CO_2 uptake. Its mitigation potential is not yet well explored, and carbon offsets generated through iron fertilization activities could currently not be traded on regulated carbon markets. Still, commercial interests in ocean iron fertilization already exist, which underlines the need to investigate a possible regulatory framework for it. To this end, I first discuss important basic aspects of ocean iron fertilization, namely its scientific background, quantitative potential, side effects, and costs. In a second step, I review regulatory aspects connected to ocean iron fertilization, like its legal status and open access issues. Moreover, I analyze how the regulations for afforestation and reforestation activities within the framework of the Kyoto Clean Development Mechanism (CDM) could be applied to ocean iron fertilization. Main findings are that the quantitative potential of ocean iron fertilization is limited, that costs are higher than initially hoped, and that potential adverse side effects are severe. Moreover, the legal status of ocean iron fertilization is currently not well defined, open access might cause inefficiencies, and the CDM regulations could not be easily applied to ocean iron fertilization.

Keywords: Ocean Iron Fertilization, Kyoto Protocol, CDM

JEL classification: D62, K33, Q54, Q58

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1. Introduction

The world is very likely to experience a range of adverse climate change impacts in the coming decades, which underlines the need to investigate measures to mitigate these impacts (*IPCC, 2007a,b*). Ocean iron fertilization is currently discussed as one measure to mitigate climate change. It aims at stimulating phytoplankton growth in certain parts of the ocean by adding iron artificially to the water, thus enhancing oceanic CO_2 uptake and reducing atmospheric CO_2 concentrations (*Denman, 2008; Buesseler et al., 2008*). Ocean iron fertilization belongs to the group of geoengineering options, aiming at mitigating climate change by intentionally altering the environment on a planetary scale.[1] So far, serious research on geoengineering is still in its infancy, but there is an increasing awareness that a serious consideration of such options and involved regulatory and economic aspects is important (*Victor et al., 2009; Barrett, 2007*).

The utilization of ocean iron fertilization, as well as that of other geoengineering options, is highly debated, which is due to the fact that its effects, including intended and unintended ones, are not yet fully understood (*Buesseler et al., 2008; Powell, 2008a*). Still, there are vital commercial interests that favour using ocean iron fertilization in order to sequester CO_2, generate carbon offsets, and sell these offsets on carbon markets (*Leinen et al., 2008*). As of today, selling carbon offsets generated through iron fertilization projects would only be possible on voluntary carbon markets, and these carbon offsets could not be used for compliance with the Kyoto Protocol (*Powell, 2008a*). However, continually increasing CO_2 emissions to the atmosphere could raise the pressure to include further sinks into a Post-Kyoto agreement (*Rehdanz et al., 2005*; *Michaelowa et al., 2005*). The sink enhancement activities currently accepted by the Kyoto Protocol are summarized as land use, land use change and forestry or LULUCF projects (*UNFCCC, 2005b*). The understanding of these activities had been poor for a long time too, before they were finally integrated into the Kyoto regulations. So, given the commercial interests that foster employing ocean iron fertilization on larger scales, it is necessary to investigate its potential as a climate change mitigation option as well as regulatory issues connected to its utilization.

Recently, there have been a few contributions discussing regulatory aspects connected to ocean iron fertilization. *Freestone and Rayfuse (2008)* analyze the legal status of iron fertilization activities and touch upon problems that would arise if such activities were implemented into the framework of the Kyoto Clean Development Mechanism (CDM). However, they only identify critical issues connected to the application of the CDM

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[1] *Keith (2000)* provides a comprehensive treatment of possible geoengineering options.

regulatory framework to ocean iron fertilization but do not analyze these issues systematically. The same holds for *Powell (2008e)* and *Sagarin et al. (2007)*, who identify issues that would have to be addressed, but do not offer a deeper analysis of a possible regulatory framework for iron fertilization activities.

In addition to these contributions, the company Climos has established a voluntary Code of Conduct, presenting issues that would need to be taken into account when implementing iron fertilization projects (*Climos, 2007*). Furthermore, *Leinen (2008)* offers an analysis of how carbon offsets from iron fertilization projects could be created and treated against the background of the current CDM regulations. However, *Leinen (2008)* does not take into account all important aspects. In this paper, I provide a more detailed and far-reaching analysis of a possible regulatory framework for iron fertilization activities and give a comprehensive framework for assessing ocean iron fertilization. In Section 2, I discuss important basic aspects of ocean iron fertilization, namely its scientific background, quantitative potential, side effects, and costs. In Section 3, I proceed to important regulatory aspects, including legislation, externalities and open access. Moreover, I analyze how the current regulations for afforestation and reforestation projects within the Kyoto CDM framework could be applied to ocean iron fertilization before concluding in Section 4.

2. CO_2-Sequestration by Ocean Iron Fertilization

2.1 Scientific Background

The idea to fertilize the ocean with iron dates back to 1990, when John Martin first published the so-called Iron Hypothesis, suggesting that iron could be the limiting factor for photosynthesis in some parts of the ocean, where the concentration of macronutrients is high but where the concentration of chlorophyll is low (*Martin, 1990*). This is the case for the sub-arctic North Pacific, the eastern equatorial Pacific, and, most importantly, for the Southern (Antarctic) Ocean. Adding iron to the surface water in these ocean regions increases the amount of CO_2 used by phytoplankton for photosynthesis and stored in the resulting biomass. Part of this biomass will then sink from the surface to the deep ocean or even to the ocean ground, which could qualify as carbon sequestration (*Denman, 2008*).

However, not all the carbon taken up by phytoplankton will be exported to and sequestered in the deep ocean. Instead, a large fraction of it will get back to the atmosphere within short time scales due to remineralization or the respiration and excretion of the higher animals that eat phytoplankton. More than 50 % of the exported organic carbon is already remineralized during the first 100 meters of sinking. Further on, only about 2 to 25 % of the carbon reaches depths of 100 to 500 meters and only 1 to 15 % of the carbon sinks below 500 meters (*Powell,* *2008a*). Consequently, carbon sequestration is less than export and depends on the depth that will be deep enough to keep the carbon away from the surface ocean for a sufficiently long time, e.g. for a hundred years.[2] Moreover, this depth varies and depends on several factors including ocean currents, temperature, weather conditions, lateral patch dilution and grazing activity. In addition, it will also have to be investigated how much carbon ocean iron fertilization will actually draw down from the atmosphere into the ocean to assess its potential to reduce atmospheric CO_2 concentrations (*De Baar et al., 2005, 2008*).

2.2 Quantitative Potential

Different types of studies, including ship-based experiments, modeling studies, and the observation of local natural fertilization events, have made unequivocally clear that iron addition leads to enhanced photosynthetic activity. But the extent of carbon export and sequestration is hard to measure and the observed results vary greatly (*Powell, 2008d*).

During the ship-based patch fertilization experiments, observed carbon export ranged from zero to 27% of primary production. The CO_2 gas flux from the air to the sea was on average 3% of primary production. But as the CO_2 concentrations between air and sea only equilibrate slowly, oceanic CO_2 uptake could have continued after the short experimental observation time, which only was several weeks (*De Baar et al., 2005; Boyd et al., 2007*). Observed export efficiencies to the depth of 100m ranged from zero up to 6,648 mol carbon per mol iron. This implies that one ton of iron added to the water could remove between zero and more than 1,400 tons of carbon from the surface ocean to the depth of a hundred meters. Export efficiencies to the depth of 250 m would be roughly half of these amounts and even less for depths below 500 m (*De Baar et al., 2008*).

A modeling study simulating patch fertilization events in the eastern equatorial Pacific suggests that the cumulative sequestration potential of patch fertilization could be at most some ten million tons of carbon for a hundred years. In this context, patch fertilization means fertilizing an ocean area measuring a few hundred kilometers per side for approximately one month. In contrast to this, recent model simulations suggest that the potential of large-scale iron fertilization, which would continuously deplete all macronutrients in the global ocean, could be 26 to 70 gigatons of carbon (Gt C) for the same time horizon (*Denman, 2008; Gnanadesikan et al., 2003*).

[2] A hundred years is the time horizon the Kyoto Protocol (*UNFCCC, 1997*) adopted for the calculation of global warming potentials, so that this time horizon could be considered to be equivalent to permanent carbon sequestration.

To assess the potential of ocean iron fertilization, one has to recall the scope of anthropogenic CO_2 emissions, which amounted to 7.8 Gt C in 2005 and could reach up to 37 Gt C by the year 2100. Cumulated CO_2 emissions until the year 2100 might well be in the range of 770 to 2,540 Gt C (*IPCC, 2007a*). Consequently, no single mitigation strategy alone has the potential to guarantee a stabilization of atmospheric CO_2 concentrations. But large-scale ocean iron fertilization could contribute a significant share to a portfolio of mitigation options aiming for stringent stabilization targets. Patch fertilization on the other hand, which is probably more realistic and feasible, would only have a relatively small impact. Still, future research may explore ways to enhance sequestration efficiencies and thus the quantitative potential of ocean iron fertilization (*De Baar et al., 2008*). What is more, compared to existing climate targets laid down in the Kyoto Protocol, which sum up to a joint reduction effort of at most 0.25 Gt C (*UNFCCC, 2008*), the potential of ocean iron fertilization would be considerable.

2.3 Side Effects

However, besides its positive potential to sequester CO_2, ocean iron fertilization might also bring about a couple of adverse and unintended side effects. For example, ocean iron fertilization could influence food web dynamics because phytoplankton is at the bottom of the food chain. While this could cause positive effects, e.g. on overfished fish stocks, it could also cause negative effects, e.g. on the development of toxic algal blooms. Moreover, the remineralization of the sinking organic matter could lead to anoxia in the subsurface ocean due to large-scale ocean iron fertilization. Indirect side effects of ocean iron fertilization could furthermore include nutrient depletion and lower primary production downstream of the fertilization site, an enhanced production of the forceful greenhouse gases nitrous oxide (N_2O) and methane (CH_4), increased ocean acidity and altered physical properties of the ocean (*Denman, 2008; Powell, 2008c; Gnanadesikan et al., 2003*).

But when considering the possible adverse side effects of ocean iron fertilization, one also has to keep in mind that these effects are scale and time dependent. No harmful negative effects have been observed during the patch fertilization experiments. Still, such effects might occur if iron fertilization experiments were scaled up with respect to the amount of iron added to the water, the size of the fertilization site, and the time horizon of the experiment (*Powell, 2008c*).

2.4 Cost Estimates

Early estimates for the costs of ocean iron fertilization were very low so that it appeared to be quite a cheap way to reduce atmospheric CO_2 concentrations. For example, *Markels and*

Barber (2001) estimated a price of 1.1 to 2.2 USD per t CO_2 sequestered. With less optimistic and more realistic assumptions regarding the sequestration efficiency of ocean iron fertilization, costs are more likely to be between 8 and 80 USD per t CO_2 sequestered (*Boyd, 2008*). Still, these cost estimates are based on the sequestration efficiency ratios observed during the patch fertilization experiments, which in turn are quite uncertain and vary over one order of magnitude. Consequently, also *IPCC (2007b)* points out that there are no reliable cost estimates available for ocean iron fertilization as a mitigation option.

Moreover, the few cost estimates that are available only include the direct costs of the fertilization activity (*Boyd, 2008*), which would constitute private costs for a project initiator. Further private costs, which would have to be considered, are the costs for monitoring and verification as well as the costs that would occur if there was an outgassing of other greenhouse gases such as N_2O or CH_4, offsetting the initial CO_2 sequestration and implying deductions from the amount of carbon offsets to be generated. In addition to these private costs, external costs may occur due to potential negative downstream effects, e.g. on fisheries, or other unintended side effects, which would imply higher social costs. All these additional cost factors imply that any cost estimate just based on export or sequestration efficiency ratios will probably underestimate true costs. And as potential side effects are hard to predict and measure, costs are even harder to be estimated.

A comparative assessment of ocean iron fertilization in comparison with other mitigation strategies would also need to include the ratio of estimated costs to arising risks. *Boyd (2008)* classifies ocean iron fertilization as a medium-risk, medium-cost mitigation strategy and states that other strategies with lower risks may have lower costs as well. In addition to this, the potential profitability of ocean iron fertilization could be assessed by considering the market price for CO_2 emission allowances, e.g. within the EU Emission Trading System (ETS). Throughout the first three quarters of 2008, the price for an EU allowance covering the emission of one ton of CO_2 was between 20 and 30 Euros, which could make ocean iron fertilization profitable given the possibility to sell carbon offsets on this market. In the first quarter of 2009, the CO_2 price dropped to below 10 Euros, which would imply a lower profitability of iron fertilization activities. To assess future prospects for the application of ocean iron fertilization it would of course be necessary to take into account future expected CO_2 prices and future climate policies influencing these prices.

3. Regulatory Aspects of Ocean Iron Fertilization

3.1 Ocean Iron Fertilization and International Law

One of the most crucial factors influencing a possible regulatory framework for ocean iron fertilization is that it would predominantly take place on the high seas, where no national jurisdiction applies. Consequently, ocean iron fertilization would fall under international law. As of today, it falls into a legal grey area and is neither bindingly prohibited nor regulated. However, dumping activities which are against the principles of the United Nations Convention on the Law of the Seas (UNCLOS), the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention or LC) or the London Protocol (LP) and which could harm the marine environment or marine living resources are banned under international maritime law. This could also apply to iron fertilization, taking into account its potential harmful side effects (*Freestone and Rayfuse, 2008*).

Consequently, there is a vital need to establish an internationally agreed legal framework, including permitting, best practice, and monitoring requirements as well as liability regulations for iron fertilization activities. Moreover, it will have to be clarified how to link international agreements such as the Kyoto Protocol or a successor agreement, the LC/LP and the UNCLOS. But even if all these issues will have been addressed, an effective enforcement of the provisions still cannot be guaranteed because no international organization is responsible for their enforcement. Instead, this responsibility rests with the flag and port states that are members to the Conventions. This leaves the possibility to circumvent effective regulation and enforcement by flying a so-called flag of convenience and loading vessels in states that are no members to the LC/LP (*Freestone and Rayfuse, 2008*).

Based on these findings, one could conclude that the responsibility for establishing and enforcing regulatory oversight over iron fertilization activities would better be transferred to an international institution instead of leaving it to member states. This international institution would then be responsible for permitting all iron fertilization projects, thereby ensuring that all projects meet the same agreed requirements and standards. Like this, only one institution would have to acquire the needed know-how about ocean iron fertilization and to build up the capacities to assess proposed iron fertilization projects. In addition, the international institution would be able to coordinate different fertilization activities. Moreover, one would also eliminate the possibility to circumvent effective regulation as all iron fertilization activities, no matter under which flag a project vessel sails, would be subject to the same permission process. In this context, it may be reasonable to entitle the International Maritime Organization (IMO) or a special committee under its umbrella to be responsible for dealing with ocean iron fertilization, in particular because the Parties to the LC/LP have already started addressing iron fertilization activities.

The Parties to the LC/LP consider iron fertilization to be dumping because it is contrary to the aims of the Conventions. In a non-binding resolution put forward under the umbrella of the IMO in October 2008, they therefore state that ocean iron fertilization should not be carried out except for careful scientific research, which in turn should be subject to member state permission on a case-by-case basis (*IMO, 2008*). The process of addressing ocean iron fertilization continued in February 2009 with the first meeting of the Intersessional Technical Working Group on Ocean Fertilization, which is instructed to develop an assessment framework for ocean fertilization and to summarize the current state of knowledge about it. During this first meeting, some Parties proposed to include a condition that would prohibit any commercial use of iron fertilization into the assessment framework. However, the working group did not adopt this proposal. Consequently, the question if ocean iron fertilization should be eligible for a commercial use still has to be answered by the Parties to the Conventions (*IMO, 2009*). So, even now that the Parties to the LC/LP have started addressing iron fertilization activities, there still remains the need to develop a broad and internationally agreed legal framework for such activities.

3.2 Ocean Iron Fertilization, External Effects, and Open Access

As can be seen from the previous section, there is no legally binding regulation of iron fertilization activities in place. So, given that it would predominantly take place on the high seas, where no national jurisdiction applies, it could in principle be carried out by everybody and to an arbitrary extent. Put differently, one can say that as of today there are no private property rights assigned for using ocean iron fertilization on the high seas.

Consequently, the possibility to generate carbon offsets through iron fertilization activities could be considered to represent a renewable open access resource, meeting the criteria of non-excludability and rivalry. The use of ocean iron fertilization can be considered to be non-excludable as long as there are no effective ways to prevent somebody from carrying out these activities, which would be the case without any enforceable legislation in place. Moreover, the use of ocean iron fertilization can be considered to be rivalrous because once somebody has added iron to the water in order to enhance photosynthesis and phytoplankton growth, macronutrients will be extracted from the water and these macronutrients will no longer be available for other iron fertilization projects. On the other hand, the resource can be considered to be renewable, because nutrients in the surface ocean will be replenished naturally over time, for example by the upwelling of nutrient-enriched deep waters.

This open access setting, where many profit-maximizing companies seek to generate carbon offsets out of iron fertilization activities, leads to the conclusion that iron fertilization could be overly used in a non-efficient way with the consequence of welfare losses. This results from the following reasoning: Nutrients would at present be used to a higher extent than would socially be desirable because every single profit-maximizing agent would carry out iron fertilization activities as long as benefits exceed costs and a positive profit could be generated. External costs of future nutrient stocks which are too low and imply lower possibilities to generate carbon offsets in the future would not be considered by these agents.

This effect would be enhanced by further negative externalities, which might occur due to adverse side effects of the fertilization activity. These adverse side effects may e.g. include decreasing fish stocks due to nutrient depletion, which would lead to even higher external costs. But none of these external costs would have to be carried by the profit-maximizing economic agents as long as they only have to pay for the actual fertilization process and as long as there is no regulatory framework in place. So, these economic agents would not carry all social costs and their private decisions would induce welfare losses for the society. So, with open access issues and considerable externalities being present, a careful regulation and restriction of iron fertilization activities, employing taxes or volume restrictions, would be necessary, not only from an ecological but also from an economic point of view.

Iron fertilization might have the potential to reduce climate change impacts and thus to generate a social benefit. On the other hand, possible negative external effects of its use may not be forgotten when assessing its potential, and the corresponding costs would have to be added to occurring sequestration costs. Possible negative external effects would be accounted for e.g. by the imposition of a tax so that private companies would have to bear all social costs for their actions. If these costs get too high, the incentive to carry out iron fertilization for commercial purposes would vanish automatically. In equilibrium, marginal social costs would be equal to marginal social benefits, so that ocean iron fertilization would be used in a way to maximize net benefits for the society. These net benefits can be described as the avoided climate change impacts, achieved at lower costs than might have been the case without the possibility to use iron fertilization and taking into account its potential negative side effects. Of course, in reality there is no perfect information about the damage iron fertilization may cause, so that it would also be necessary to consider the effects of uncertainty and possible threshold effects when regulating the use of ocean iron fertilization as a mitigation option. Moreover, this also underlines the necessity to establish permitting requirements and project standards in order to minimize negative side effects of iron fertilization activities.

3.3 Ocean Iron Fertilization and the Kyoto Clean Development Mechanism

As the legal status of ocean iron fertilization is not yet clearly defined, the possibility remains to implement iron fertilization projects and to try to sell carbon offsets for the CO_2 removed from the atmosphere, which creates a profit incentive for its commercial use. However, carbon markets are fragmented and the different market segments have different regulations referring to the inclusion of project-based carbon offsets. Currently, carbon offsets from iron fertilization projects could not be traded on regulated carbon markets such as the EU ETS or the Chicago Climate Exchange (CCX), but only on the rapidly increasing market for voluntary over-the-counter (OTC) transactions (*Powell, 2008a*). In this market segment, project-based carbon offsets can be traded by individuals or companies, who do not face own emission constraints but nevertheless wish to engage in carbon trading. However, public perception and third party verification have become increasingly important on voluntary carbon markets due to concerns about the quality of the traded carbon offsets, for example with respect to additionality, permanence and verification (*Hamilton et al., 2008*).

This underlines that the generation of carbon offsets through iron fertilization activities would have to be subject to certain regulatory requirements, both for trading on regulated and voluntary carbon markets. The CDM standard plays a major role for carbon removal projects, not only on regulated but also on voluntary carbon markets, so that an analysis of the CDM requirements and their compatibility with iron fertilization activities is an important issue.[3] In this context, the regulation of afforestation and reforestation activities within the CDM framework is chosen as a benchmark, because they are the only sink enhancement activities currently allowed within the CDM framework.[4] As ocean iron fertilization also constitutes a sink enhancement option for mitigating climate change, though aiming at enhancing ocean sinks and not land sinks, the regulation of these activities would probably have to feature similar properties. So, building on the existing similarities between the two sink enhancement options and keeping in mind the particularities of ocean iron fertilization, I analyze if and how the currently existing CDM regulations for afforestation and reforestation activities could be applied to ocean iron fertilization.

[3] The CDM within the Kyoto framework allows Annex 1 countries to carry out emission reduction or removal projects in Non-Annex 1 countries for compliance with their own emission reduction targets. For detailed information on the CDM and the regulation of afforestation and reforestation activities within the CDM framework see *UNFCCC (2001, 2005a)*.

[4] Currently, it is also discussed to include avoided deforestation into a successor agreement to the Kyoto Protocol. The corresponding initiative under the umbrella of the UNFCCC is called Reducing Emissions from Deforestation in Developing Countries (REDD).

Project Site Boundary

One basic issue applying to afforestation and reforestation projects under the CDM is the importance of the project site boundary. This boundary is central for defining e.g. additionality, baselines and leakage and is thus needed to calculate the net anthropogenic greenhouse gas removals by sinks that will be attributable to a project (*UNFCCC, 2005a*). The problem that would arise if ocean iron fertilization was carried out, is that it would be very difficult to determine a certain bounded project area in advance of the project`s implementation. The reason for this is that even a relatively small patch of fertilized water will be rapidly diluted and dispersed. As a result, the eventual size of algal blooms from small iron addition experiments can reach up to 1,000 square kilometers or more. Furthermore, the patch can extend to a depth of a hundred meters or more and even drift hundreds of kilometers from the starting position. The scope and direction of patch dilution thereby crucially depends on local ocean currents (*De Baar et al., 2005; Powell, 2008b*).

But even though it might be quite difficult to define a project site boundary for iron fertilization activities due to patch dilution, the concept could be used nevertheless and modeling studies could help to define a suitable boundary. This would imply a conservative way to estimate greenhouse gas removals attributable to a certain iron fertilization project, because removals occurring outside of the boundary could not be counted for issuing carbon offsets. Thus, the whole amount of greenhouse gas removals would not be overestimated. Another possibility would be to give up the concept of a clearly defined project site. But this would require a whole new framework and would complicate the attribution of greenhouse gas removals and emissions once several iron fertilization activities take place at the same time in the same environment.

Additionality and Baselines

Additionality is another important concept within the CDM framework, which was introduced to the Kyoto Protocol in order to prevent projects that would have been implemented anyway from being rewarded by the possibility to create carbon offsets (*UNFCCC, 1997*). This is important because it is the aim of the Kyoto Protocol to bring about real greenhouse gas emission reductions, which exceed those of a business-as-usual or baseline scenario with no CDM in place. The concept of additionality can be divided into financial and environmental additionality. Financial additionality of a project refers to the question if investment in a certain CDM project would have taken place without the possibility to gain offsets under the CDM. Environmental additionality in turn does not refer to a yes-or-no question like financial additionality does, but it answers the question to what extent actual emissions with the project are below baseline emissions (*Baumert, 1999*).

The demonstration of additionality within the CDM framework is quite complex and includes aspects of both financial and environmental additionality. To prove the additionality of a sink enhancement project, alternative land-use scenarios have to be identified and analyzed by carrying out a barrier analysis, an investment analysis, and a common practice analysis (*CDM-Executive Board, 2007*). The purpose of this complicated procedure is to find out if there are other usage scenarios for the project site that are not prevented by any barriers and which of these alternative scenarios would constitute the baseline scenario.

In the case of ocean iron fertilization, proponents argue that these activities would per se be additional because the possibility to sell carbon offsets is the only reason for commercial funding of such activities. What is more, carbon mitigation would be the primary reason for iron fertilization to be contemplated, and additionality would be given if an iron fertilization project was not carried out in order to satisfy any other economic benefit or policy requirement (*Leinen, 2008; Climos, 2007*). However, this reasoning only refers to financial additionality and does not account for setting up a baseline to define environmental additionality. If a framework similar to that of the CDM was used, additionality and baselines would both have to be determined by comparing the proposed activity with other "ocean use scenarios". These scenarios would at least have to include the pre-project use of the ocean and the iron fertilization activity without being eligible for the creation of CERs. One could then build a framework similar to that for proposed afforestation and reforestation activities under the CDM in order to assess the additionality of the project and define the corresponding baseline.

In this framework, this procedure could only be simplified if there were no reasonable alternatives for using the ocean in the region considered for iron fertilization. In this case, there would only remain two alternatives, either not using the specified regions at all or carrying out iron fertilization, while the latter would only be profitable given the possibility to create carbon offsets. In addition to this, ocean iron fertilization must not constitute a common practice, which is the case as it is not carried out today except for few scientific experiments. If these conditions held, one could conclude that iron fertilization activities could usually be considered to be additional and not request any further project-based assessment of additionality. This would reduce transaction costs and certainly facilitate the implementation of iron fertilization projects.

In such a case, the baseline would be given by the pre-project state of the ocean and the absence of any iron fertilization activity. The environmental additionality of a certain project activity and the amount of creditable carbon offsets would then be determined by comparing actual to baseline greenhouse gas emissions or removals. In this context, the problem remains how to estimate baseline emissions and removals accurately. This underlines the need for adequate baseline methodologies in order to ensure the credibility of greenhouse gas removals and comparability between several projects, so that the quality of the generated carbon offsets will be guaranteed.

Measurement Monitoring, and Verification

The issuance of carbon offsets within the CDM framework takes place based on measurable and verifiable changes in carbon stocks (*UNFCCC, 2005a*). Consequently, methodologies for the measurement, monitoring and verification of iron fertilization activities would have to be set up, just as for afforestation and reforestation activities under the CDM today. The regulation of the monitoring of these afforestation and reforestation CDM projects by the UNFCCC is guided by a number of publications by the Intergovernmental Panel on Climate Change (e.g. *IPCC, 2000*), which provide the necessary scientific and technical background. Carrying over this approach to the regulation of iron fertilization activities, the cooperation of ocean scientists would be required in order to work out a set of criteria which will have to be measured and monitored as well as adequate methods to achieve this aim.

Cullen and Boyd (2008) offer an overview over the aspects that need to be monitored while carrying out iron fertilization projects. Greenhouse gases which would have to be included are CO_2, N_2O and CH_4. Moreover, the data to be measured and monitored would at least have to include CO_2 drawdown from the atmosphere and carbon export to the deep ocean but also oxygen or nutrient depletion in the deep sea or in upwelling regions downstream of the project site as well as downstream environmental impacts on food web dynamics or possibly occurring unpredictable side effects.

There are a couple of techniques which may be used for measuring these aspects, but, nevertheless, the precise measurement of air sea gas exchange, carbon export, and especially carbon sequestration still is difficult. Measurement, monitoring and verification are further complicated by the fact that side effects could affect the global ocean, and maybe they would not occur until in a few decades. A combined approach, using models in addition to experimental observations, could help in this respect, but there still remains considerable uncertainty connected to the adequacy and use of such models, especially because the models are used against the background of a changing climate system, which affects the oceans as well (*Watson et al., 2008; Cullen and Boyd, 2008*).

Consequently, baseline and monitoring methodologies would have to be worked out, laying down a formulae-based framework for how to calculate greenhouse gas removals from the atmosphere and how to use models to support these calculations (*Leinen, 2008*). In addition, these methodologies would have to make sure that all direct and indirect effects can be attributed to a certain ocean iron fertilization activity. Moreover, the methodologies would have to be approved of by the EB, it should be possible to suggest new methodologies to the EB, and their approval should follow the same rigorous decision process than that for existing CDM methodologies. In connection to monitoring, it would be important that the monitoring plans established by the project participants are reviewed and updated regularly. Furthermore, measurement, monitoring and verification might have to continue even after the project activity as such is finished to ensure the long-term success of the carbon sequestration.

In addition to these findings, it has to be pointed out that the possibility to verify carbon removals by iron fertilization activities will be more limited than for afforestation and reforestation activities, because there is no real project-site that can be visited. Still, independent third parties would have the possibility to carry out own ship-board observations and measurements, they could interview project participants and test the monitoring equipment, and they could review documented data and measurements taken by the project participants. Verification requirements would thus have to be adjusted for iron fertilization activities compared to CDM afforestation and reforestation projects.

Non-permanence

Another issue that has to be kept in mind is the potential non-permanence of the carbon storage. This issue came up when the inclusion of sink enhancement activities into the CDM framework was discussed against the background of the Kyoto requirement to create long-term benefits related to the mitigation of climate change. The inclusion of such sink enhancement projects had been controversial because carbon storage in the terrestrial biosphere is reversible, for example due to fires, pests or anthropogenic activities like deforestation and logging. So, carbon additionally stored through a CDM project might be reemitted during the duration of the project. Furthermore, there are no guarantees that the carbon stays in the terrestrial biosphere indefinitely, once the project is finished (*Maréchal and Hecq, 2006*).

Leinen (2008) takes up the issue of non-permanence by exploring the 100-year-standard adopted by the UNFCCC for calculating the global warming potentials of all greenhouse gases. Consequently, carbon sequestration could be considered to be permanent within the Kyoto framework if the carbon was stored for at least 100 years (*UNFCCC, 1997*). In such a framework, permanent carbon offsets would be issued if a storage period of a hundred years was guaranteed. However, afforestation and reforestation projects under the CDM are treated differently. Accounting for the issuance of Certified Emission Reductions (CERs) connected to afforestation and reforestation activities has to be based on verifiable carbon stock changes within the project site boundary, and expiring carbon offsets will be issued for verifiable increases in the amounts of carbon stored in the biomass (*UNFCCC, 2005a*).

There are two types of expiring offsets that may be issued for a CDM afforestation or reforestation activity and address the problem of non-permanence: Temporary CERs (tCERs) and long-term CERs (lCERs). TCERs are issued once during a commitment period according to the verified amount of net anthropogenic greenhouse gas removals achieved by the project since its start and expire after one commitment period. If net anthropogenic greenhouse gas removals have decreased since the last certification, only a smaller amount of tCERs will be newly issued, which takes adequate account of the non-permanent storage time. LCERs are issued once during a commitment period according to the verified increases of net anthropogenic greenhouse gas removals achieved since the last certification of lCERs. If verification discovers a reversal, i.e. a net decrease of greenhouse gas removal since the last certification date, a certain amount of lCERs will have to be invalidated (*UNFCCC, 2005a*).

This approach implies that carbon storage through CDM afforestation or reforestation projects is always considered to be temporal, even though the carbon might stay stored for a long time after the end of the project lifetime. This is because the temporary offsets have to be replaced by permanent ones at the latest after 60 years, when the crediting period of the project is over. The rationale for this is that no legal liability mechanisms are in place that would govern the responsibility for carbon releases after the end of the crediting period (*Pedroni, 2005*).

In the context of ocean iron fertilization, a reversal of greenhouse gas removals would be possible due to an outgassing of CO_2 or an enhanced production of N_2O and CH_4. This non-permanent storage could be accounted for by issuing expiring offsets as under the CDM. However, this approach will only be appropriate if net greenhouse gas removals always remain positive.[5] If, over time and after the end of the project`s crediting period, net anthropogenic greenhouse gas removals become negative, nobody will be held responsible for this net outgassing. Consequently, one would have to think of establishing liability regulations for a potential non-permanence of the greenhouse gas removals due to outgassing after the end of the crediting period of the project. This would require ongoing monitoring and

[5] See *Pedroni (2005)* for a detailed discussion of the inconsistent treatment of permanent project emissions, which are treated as being temporary within the current CDM framework of expiring carbon offsets.

verification beyond the project life time and the use of modeling studies as described above or other mechanisms to ensure liability for a reversal of greenhouse gas removals.

This leads to another issue, which refers to the liability for unintended adverse side effects, occurring either during the project lifetime or afterwards. In theory there are two different approaches to regulate risky economic activities: ex-ante regulation, e.g. by setting standards, or ex-post regulation through liability laws.[6] In the case of iron fertilization, it could be useful to use both, in order to ensure that, on the one hand, certain minimum standards and valid permitting requirements for iron fertilization activities are in place, and to ensure that, on the other hand, unintended side effects will be covered.

Leakage

Leakage is another important issue included in the CDM regulations for afforestation and reforestation projects. In this context, leakage refers to increasing greenhouse gas emissions which occur outside of the project site boundary but which are attributable to a certain project activity. Occurring leakage will have to be accounted for when calculating the amount of carbon offsets to be issued for a project activity by subtracting the corresponding amounts from actual net greenhouse gas removals (*UNFCCC, 2005a*).

Leakage effects can be divided into four different groups. The first group of leakage can be described as ecological leakage, which can occur if greenhouse gas fluxes within the ecosystem in the surroundings of the project site are altered due to the project activity. A second group of leakage refers to life-cycle shifting of emissions, which emerges if project activities increase emissions upstream or downstream of the project. An example would be enhanced emissions from the use of machinery connected to afforestation or reforestation projects. A third group of leakage covers emissions from the displacement or relocation of activities. The last group of leakage effects encompasses market leakage, which occurs if the project activity changes the relationship between supply and demand on local, regional or global commodity markets and if the resulting price changes induce increased greenhouse gas emissions elsewhere (*Schwarze et al., 2002*).

In the context of iron fertilization activities, CO_2 emissions generated by the use of vessels and aircrafts in connection with a certain project activity would have to be taken into account. Moreover, the upwelling of CO_2 remote from the project site, decreased carbon export downstream of the project site due to nutrient depletion, and an increased production of N_2O and CH_4 remote from the project site would have to be considered (*Leinen, 2008*). But these

6 See *Kolstad et al. (1990)* or *Shavell (1984)* for a deeper discussion of ex-ante safety regulation and ex-post liability.

issues only cover life-cycle shifting of emissions and ecological leakage. With respect to emissions from the relocation of activities, there does not seem to be a great problem connected to iron fertilization activities. This is because ocean iron fertilization would predominantly take place in the Southern Antarctic Ocean, where competing usages, which are mutually exclusive with iron fertilization activities, probably do not exist. Consequently, leakage due to activity displacement would not be of great significance for iron fertilization activities.

In addition to these three leakage groups, market leakage effects with regard to iron ore markets would also have to be taken into account. Iron fertilization activities could considerably influence these markets if the amounts of iron needed were high compared to overall trading volumes. Given that during the mesoscale iron addition experiments only up to three tons of iron were needed, it seems unlikely that patch fertilization or single iron fertilization projects would significantly influence demand and supply patterns and thus the price of iron on global markets.[7] However, large-scale iron fertilization would require millions of tons of iron per year and might thus result in market effects. And even if global markets were not affected, it could still be that regional or local markets would be affected. But to analyze these effects, a detailed market analysis for iron and iron sulphate, which is used for fertilizing the ocean, would be required. Furthermore, leakage will only occur if market distortions lead to higher emissions outside the project boundary, which would also have to be analyzed.

At this point, the dimension of the project site and the needed monitoring scale becomes important again. If one sets up a certain project site boundary, though this might be difficult, only carbon removals that occur inside this boundary can be considered for issuing CERs. However, ecological leakage can happen far from the project site, so that monitoring would have to cover the global ocean. If one refrains from using a project site or considers the global ocean to be the project site, leakage as defined under the CDM will not be an issue anymore, but baselines, additionality, monitoring and verification would all have to be designed on a global scale. This seems to be difficult and connected to even more uncertainties. What is more, this approach would be further complicated once several iron fertilization activities take place simultaneously, which would make it even more difficult to attribute greenhouse gas removals and emissions to single fertilization projects.

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7 Annual extraction of iron ore amounts to around 1.8 billion tons, of which approximately 98% are used for the production of steel (*Weinberg, 2008*).

Measures to counteract leakage would above all require a careful site selection. Modeling studies could help find ocean regions with favourable conditions, where currents are such that an early upwelling in other ocean regions or enhanced greenhouse gas releases to the atmosphere is less likely (*Watson et al., 2008*). But however well the site might be chosen, monitoring would always have to consider the global ocean to detect all sources of ecological leakage. If this kind of monitoring seems practically infeasible, one could also reduce the amount of CERs to be issued according to expected leakage rates. But this approach could result in arbitrary deductions from earned carbon offsets or would require a better understanding of the effects of iron fertilization in order to quantify realistic deduction rates. Besides these project-based measures, one could also cap the number and scope of allowed iron fertilization projects on the macro-level, as has already been suggested when outlining the issue of open access in the context of iron fertilization.

Reporting Requirements

The current regulatory framework of the CDM comprises rigorous reporting requirements (*UNFCCC, 2001, 2005a*). These, though creating high transaction costs, can be seen as a measure to establish transparency and credibility regarding CDM projects, which would also be important for iron fertilization activities. First, reporting would be necessary to enable a valid verification of the actual greenhouse gas removals as well as of the monitoring procedures of the project initiator. In addition to this, the publishing of the project reports could enable the public to convince itself of the validity of the achieved greenhouse gas removals. In this context, an assessment of the potential environmental impacts and a monitoring of their occurrence should also be guaranteed.

Host Party Approval and Sustainability

There are two more basic requirements within the CDM framework, which include that projects have to bring about a benefit for the host country`s sustainable development and that they have to be approved of by the host Party. Neither would be possible for iron fertilization activities because they would take place on the high seas and far from any country (*Freestone and Rayfuse, 2008*).

But the need for a host Party to approve of iron fertilization projects could simply be dropped, due to the remaining controls by investor Parties, the Designated Operational Entity (DOE) and the Executive Board (EB), which are specified in the CDM regulatory framework (*UNFCCC, 2001, 2005a*). As mentioned above, another way to deal with this issue would be to ask an independent third party to be responsible for project approval. This would ensure that international standards and provisions for iron fertilization activities would be met.

Another consequence of these basic requirements is that iron fertilization projects would counter at least one of the main goals of the CDM as it exists today: fostering sustainability. However, it is debatable if this aim can be achieved at all simultaneously with the aim of cost-effectiveness, and even the currently existing CDM projects do not necessarily bring about benefits for the host country`s sustainable development (*Holm Olsen, 2007*). Furthermore, one would first have to find an adequate definition for sustainability. As a consequence, this issue could serve as a chance to think of decoupling the two aims of sustainability and cost-effectiveness and allowing for projects that do not support a country`s sustainable development but do bring about cost-effective ways to reduce net anthropogenic CO_2 emissions.

4 Conclusions and Future Outlook

Ocean iron fertilization has been suggested as one measure to contribute to climate change mitigation. However, the quantitative potential especially of patch fertilization seems to be rather limited. Only large-scale fertilization could contribute significantly to reaching stringent global climate targets. But large-scale ocean iron fertilization does not seem realistic at present, e.g. due to logistic constraints. Furthermore, there are large uncertainties connected to the potential negative side effects of ocean iron fertilization. In addition, iron fertilization seems to be more costly than initially hoped, and the uncertainties about its costs remain high. Consequently, it might well be the case that other options to mitigate climate change are cheaper and/or connected to fewer risks.

The substantial uncertainties connected to ocean iron fertilization and its effectiveness have led to the insight that more research will be required until ocean iron fertilization could be used commercially or on larger scales (*Buesseler et al., 2008; Leinen, 2008*). If ocean iron fertilization would one day be used as a climate change mitigation option, carbon offsets generated by such projects might be sold on global carbon markets, which would require several regulatory issues to be addressed. The current legal status of ocean iron fertilization and the open access issue underline that international permitting requirements and liability regulations for these activities are necessary. Furthermore, CDM regulations could not be easily applied to ocean iron fertilization due to the particularities of the latter. Some of the CDM regulations, like those concerning additionality and baselines, could be used with modifications, but some others, like host Party approval or the goal of fostering a country`s sustainable development, would have to be dropped or regulated in a different way.

Moreover, measures to address non-permanence and leakage would have to be adjusted to iron fertilization activities. But this could also be seen as a chance to streamline the existing CDM regulations and set up new mechanisms.

The most problematic issue in connection with creating carbon offsets through iron fertilization projects is likely to be the difficult measurement, monitoring and verification, which could also alleviate the credibility of such projects and lead to increasing public concerns. Reporting in order to create transparency with regard to iron fertilization therefore seems necessary too, not only covering monitoring and verification but also regarding possible environmental impacts.

If a regulatory framework for iron fertilization was set up, it would also make sense to define the provisions in such a way that their extension to further ocean fertilization activities would be possible. For example, there already exist ideas to fertilize ocean regions showing low macronutrient supply and low primary productivity with lacking macronutrients such as nitrate or phosphate (*Gnanadesikan et al., 2003*). This would not fall under ocean iron fertilization as analyzed above but clearly qualifies as a similar activity with the aim to sequester CO_2, which would then also have to be regulated.

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