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Ocean iron fertilization: Why further research is needed*

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Despite large uncertainties in the fertilization efficiency, natural iron fertilization studies and some of the purposeful iron enrichment studies have demonstrated that Southern Ocean iron fertilization can lead to a significant export of carbon from the sea surface to the ocean interior. From an economic perspective the potential of OIF is far from negligible in relation to other abatement options. Comparing the range of cost estimates to the range of estimates for forestation projects they are in the same order of magnitude, but OIF could provide more carbon credits even if high discount rates are used to account for potential leakage and non-permanence. However, the uncertainty about undesired adverse effects of purposeful iron fertilization on marine ecosystems and biogeochemistry has led to attempts to ban commercial and, to some extent, scientific experiments aimed at a better understanding of the processes involved, effectively precluding further consideration of this mitigation option. As regards the perspective of public international law, the pertinent agreements dealing with the protection of the marine environment indicate that OIF is to be considered as lawful if and to the extent to which it represents legitimate scientific research. In this respect, the precautionary principle can be used to balance the risks arising out of scientific OIF activities for the marine environment with the potential advantages relevant to the objectives of the climate change regime. As scientific OIF experiments involve only comparatively small negative impacts within a limited marine area, further scientific research must be permitted to explore the carbon sequestration potential of OIF in order to either reject this concept or integrate it into the flexible mechanisms contained in the Kyoto Protocol.

Keywords: climate change, geoengineering, ocean iron fertilization, international carbon market, public international law, precautionary principle

JEL classification: K33, Q51, Q54, Q56

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1 Introduction

Today, most countries have accepted a 2°C temperature increase above preindustrial levels as maximum tolerable limit for global warming. An exceedance probability of below 20 percent for this limit implies an emission budget of less than 250 GtC from 2000 until 2049, of which more than one third has already been emitted by now. Extrapolating the current global CO_2 emissions this budget will only last until 2024 (Meinshausen et al., 2009). These numbers emphasize that all options including geoengineering options need to be considered to mitigate climate change (Buesseler et al., 2008). Geoengineering options include the enhancement of natural carbon sinks to reduce atmospheric carbon concentration by removing past emissions and, thereby, extending the remaining carbon emission budget. The terrestrial carbon sink can be enhanced by means of forestation, the oceanic sink can be enhanced by means of iron fertilization. Doubts have been expressed about the potential of mitigating climate change by sink enhancement due to its partially temporary characteristics (Kirschbaum, 2006; Meinshausen and Hare, 2000). Nevertheless, terrestrial vegetation sinks have entered the Kyoto Protocol (2303 UNTS 148 – KP) as offsets for anthropogenic greenhouse gas emissions, but ocean sinks have not.

The potential of ocean iron fertilization (OIF) to enhance the oceanic carbon sink is questioned in particular due to its uncertain efficacy and side effects. This has led some authors to conclude that research and in particular large-scale experiments on OIF should not be further pursued (e.g. Strong et al., 2009). We challenge this view and think that further research about the geoengineering potential of OIF is, indeed, necessary. Even courageous climate polices may run the risk that catastrophic climate change takes place, although expected to happen with a low probability. If this risk increases, OIF may become one of the options of last resort and needs to be explored in a timely manner (Kousky et al., 2009). Therefore, it is important to analyze the potential of OIF on the basis of a comprehensive approach, which brings together the perspectives of science, economics and law.

In general there are few studies considering OIF in the context of an international climate agreement. To our knowledge, the rare exemptions are Sagarin et al. (2007), Leinen (2008), and Bertram (in press), providing non-technical overviews about the scientific, legal, and economic issues related to OIF, and the requirements that carbon markets put on the generation of carbon credits by OIF. While all three studies discuss OIF in general, neither provides an explicit application of accounting methods to OIF nor the inclusion of OIF carbon credits within a global climate agreement. The perspective of public international law has so far only been the subject of three studies by LaMotte (2009), Rayfuse et al. (2008) and Rayfuse and Freestone (2009), and has been examined in an opinion on the legality of the LOHAFEX marine research experiment recently submitted by Proelss (2009).

In the following we start by briefly reviewing the potential of OIF from an oceanographic perspective, we then proceed and summarize findings of our analysis that investigates the economic potential of OIF in the context of an international climate agreement (Oschlies et al., 2009; Rickels et al., 2009a,b). Thereafter, we examine what public international law says today on the issue of OIF and what it should say in future. We think that OIF, if considered an option to mitigate climate change, would have to be carried out under the auspices of the international legal framework.

2 Ocean iron fertilization: the oceanographic perspective

Beginning with the experimental work of Martin and Fitzwater (1988), iron has been recognized for more than two decades as important micronutrient regulating marine productivity and associated biogeochemistry over large ocean areas. This insight immediately led Gribbin (1988) to the suggestion that adding iron compounds to the ocean might present a practicable “technological fix” to remove carbon dioxide from the atmosphere. Meanwhile, a number of in-situ OIF experiments have confirmed that phytoplankton growth is limited by iron in the three major High Nutrient Low Chlorophyll (HNLC) regions, i.e., the Southern Ocean (Boyd et al., 2000), the eastern equatorial Pacific (Martin et al., 1994), and the subarctic North Pacific (Tsuda et al., 2003). All experiments have revealed a significant increase in phytoplankton biomass and an associated decrease in the partial pressure of CO_2 (pCO_2) in the surface water, with enhanced particle export being observed at the end of one experiment (Bishop et al, 2004). However, the experiments conducted so far did not primarily address carbon sequestration, but instead were aimed at a more genuine scientific understanding of the role of iron in marine ecology and biogeochemistry. Such an understanding is required, e.g., to better assess impacts of past and likely future changes in iron supply by dust or icebergs. Time and space scales of the experiments carried out so far have precluded a clear assessment of the export and fate of the extra carbon fixed as a result of the fertilization.

Clear observational evidence for an iron-induced enhancement of carbon export has been obtained from programs targeting natural OIF at the Kerguelen plateau and Crozet Islands in the Southern Ocean. At both sites, seasonal export fluxes were found to be more than three times higher than in adjacent non-fertilized regions (Blain et al., 2007; Pollard et al., 2009). Both estimates differ, however, in the inferred ratio of carbon export to iron supply by an order of magnitude. The reason for this difference is no yet understood and requires further study (Pollard et al., 2009).

To what extent the enhanced export of particulate carbon leads to a net drawdown of atmospheric CO_2 depends on the fertilization region. Model studies suggest that the carbon sequestration potential of OIF is essentially limited to the Southern Ocean, with very limited impact in the HNLC regions of the equatorial or subpolar North Pacific (Sarmiento and Orr, 1991; Gnanadesikan et al., 2003; Aumont and Bopp, 2006). Information on magnitude of the CO_2 sequestration potential of large-scale OIF comes from a combination of numerical ocean models and paleo records: Continental Antarctic ice core data of dust and of atmospheric CO_2 across glacial-interglacial cycles (Watson et al., 2000) and compilations of Southern Ocean sea-floor sediment records (Kohfeld et al., 2005) suggest that enhanced glacial atmospheric iron supply led to a carbon sequestration of about 100 GtC. A caveat is that this atmospheric CO_2 drawdown took several thousand years. On the other hand, it is not known to what extent the glacial dust supply was sufficient to fully relieve Southern Ocean iron limitation.

Estimates of the sequestration potential of large-scale iron fertilization on centennial time scales, so far, essentially rely on numerical modeling studies. These have suggested that large-scale Southern Ocean iron fertilization may sequester some 70 to 180 GtC within hundred years (e.g., Sarmiento and Orr, 1991; Aumont and Bopp, 2006). Even the lower end of the large range is far from negligible and amounts to about one “stabilization wedge” as introduced by Pacala and Socolow (2004).

Besides observational and theoretical evidence for a non-negligible carbon sequestration potential, there is also evidence for significant perturbations of marine biogeochemistry and ecology by large-scale OIF. In fact, some alteration of the function of pelagic ecosystems is the very objective of carbon sequestration by OIF. Any assessment of OIF therefore has to account for both intended and unintended consequences (Cullen and Boyd, 2008). Unintended consequences identified so far include a downstream reduction of nutrients and productivity (Gnanadesikan et al., 2003), expansion of anoxic areas (Sarmiento and Orr, 1991), increased production of the greenhouse gas nitrous oxide (Jin and Gruber, 2003), and changes in species composition (Chisholm and Morel, 1991). Interestingly, a model study of Southern Ocean OIF shows that volumes of low oxygen waters and associated production of N_2O may eventually decrease in response to downstream reduction in nutrients fueling production above the tropical oxygen minimum zones (Oschlies et al., 2009). Further study is needed to obtain a robust assessment of the currently known potential consequences and to evaluate these against the potential consequences of leaving the CO_2 in the atmosphere. While we acknowledge that Garrett Hardin’s first law of ecology, “we can never do merely one thing” (Hardin, 1985), does apply to iron fertilization, we have to bear in mind that it applies equally well to emitting CO_2 into the atmosphere.

3 Ocean Iron fertilization: the economic perspective

To explore the economic potential of OIF in the context of an international treaty on climate change requires first answers to the following questions: How many carbon credits are generated, how are they assigned, and can they be used for compliance. The Kyoto Protocol (KP) established such criteria for Clean Development Mechanism (CDM) and Joint Implementation (JI) projects. The projects have to be measured by an approved methodology, the storage has to be additional, the credits have to be verified by a third party, the storage has to be permanent, and the number of carbon credits has to take into account leakage (Grubb et al., 1999). Leinen (2008) discusses the fulfillment of these criteria for carbon sink enhancement through OIF. Following her line of reasoning, the criteria regarding methodology and additionality are easily fulfilled by OIF. The criterion of verification by a third party does apply in particular to projects between single firms or single countries in the context of CDM and JI. We consider large-scale OIF, realized within an international project as an element of an international Post-Kyoto climate regime. Without international coordination the use of OIF would be inefficiently low. Also, it would be more difficult to establish mechanisms that address adverse side effects in an adequate way (Kousky et al., 2009). The remaining two criteria are the requirement of taking into account the issue of permanence and leakage. The degree of fulfillment of both criteria determines the number of carbon credits assigned to the sink enhancement project.

Addressing the issue of permanence first, for terrestrial sinks various carbon accounting methodologies have been proposed to assess the value of different temporary storage projects (e.g. Dutschke, 2002; Fearnside et al., 2000; Fearnsinde, 2002; Marland et al., 2001; Moura-Costa and Wilson, 2000). A common assumption within these approaches is to assess permanence over the time period of 100 years, following the IPCC's definition of permanence for sequestration projects (UNFCCC, 1997).[1] Four carbon accounting methods exist that assign permanent carbon credits: the net method, the average storage method, the discounting method, and the equivalence method (permanent methods). The net method, for example, measures the overall effect of OIF for a given period of time, generally 100 years no matter when the carbon fluxes take place within that period. Two carbon accounting methods exist that assign temporary carbon credits: the short-term method and the long-term method (temporary methods). Another 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. Under the KP two

[1] The choice of 100 years is not based on scientific rationale but was rather policy driven (Leinen, 2008).

of the above assignment options are applied, the permanent and the temporary method. Terrestrial sink enhancement projects can generate temporary carbon credits only. Papers discussing the effectiveness of OIF implicitly apply the net method.

Rickels et al. (2009a) discuss all these accounting methods and apply them to OIF. The results indicate that overall, and from an economic perspective, the short-term method is most appropriate for temporary OIF. Based on this method the largest amount of carbon credits is provided at an early state. Also, the fraction which is permanently provided until the end of the crediting period is larger compared to the other methods. The equivalence method, for example, is less attractive due to the equivalence factor which leads to a spread of credits over a much longer time horizon than other methods. These methods are also referred to as ton-year accounting schemes. From an environmental perspective, the short-term method seems most appropriate as well as the effect of OIF is at least neutral. No additional carbon emissions will be released, because all credits have to be replaced at some point in time. As a substantial fraction of carbon is stored permanently, the method leads to net carbon reductions.

Addressing the issue of leakage, all potential offsets have to be taken into account to obtain the net amount of carbon credits. Potential offsets arise due to carbon emission outside the enhancement region and due to changes in emissions of other greenhouse gases than carbon. In the context of OIF additional emissions of N_2O are particularly important and need to be considered (Oschlies et al. 2009). A third potential offset that has to be considered when relating sink enhancement and carbon storage projects to changes in atmospheric CO_2 is the source of the stored carbon. Storage projects that change the path of future atmospheric CO_2 concentrations also change the fluxes between the atmosphere and the terrestrial and oceanic reservoirs as these respond to changed atmospheric pCO_2. In consequence, carbon is not only removed from the atmosphere but as well from other sinks (Oschlies et al., 2009).

To account for leakage the analysis by Rickels et al. (2009a) uses global data on oceanic carbon uptake instead of local data and introduces discount factors. The discount factor deducts the gross amount of carbon credits to a net amount which then can be used for compliance. To offset N_2O emissions the average discount factor ranges between 5.6 and 10.1 percent for the various accounting methods analyzed. However, the upper and lower bounds for discount factors vary between the various accounting methods and the various experiments, ranging overall from 0.23 to 13.26 percent. These ranges indicate that the potential of OIF cannot be determined with great accuracy. However, within an international treaty, like the KP, a discount rate could be chosen that is significantly large to compensate for this lack of knowledge and to take into account uncertainties. Considering offsets by other greenhouse gases as well as carbon emissions from ship operations, Rickels et al. (2009a) suggest an upper bound of 15 percent for the discount factor. Applying this discount factor to the net method, they find a range of 0.4 to 2.2 GtC for annual oceanic carbon uptake for OIF in the Southern Ocean, if OIF is implemented for 10 years. Increasing the duration of implementation to 100 years, the range narrows to 0.5 to 1.4 GtC. In the model of Oschlies et. al. (2009), about 90 percent of the carbon sequestered in the ocean as result of OIF originates from the atmosphere (and the rest from the terrestrial vegetation). This percentage is higher than the airborne fraction of anthropogenic CO_2 emissions which, for the period 2010-2110, amounts to about 60 percent in the model (Oschlies et al., 2009, Rickels et al., 2009).

In comparison to OIF, enhancing terrestrial carbon sinks by forestry activities has entered the KP as offsets for anthropogenic carbon emissions but the potential is uncertain as well. In a recent study, the annual potential of global forestry activities, including reforestation, forest management, expanded use of forest products, and reduced deforestation, for carbon uptake is estimated between 0.4 to 0.8 GtC until 2030 assuming carbon prices between 20 and 100 USD per ton CO_2 (Nabuurs et al. 2007, Canadell and Raupach 2008). The share of reforestation is approximately one-third (Nabuurs et al. 2007). Extending the time horizon to 2100, the range for reforestation enlarges and amounts to an annual carbon uptake of 0.2 to 1.1 GtC (Sathaye et al., 2006; Sohngen and Sedjo, 2006; Strengers et al., 2006). These numbers indicate that the potential of forestation cannot be determined with that great accuracy as well. Van Kooten and Sohngen (2007) show that there is a great inconsistency across forestry activity studies in how carbon uptake and costs are measured, so that costs of creating carbon credits through forestry activities vary widely. They conclude that the widely held notion that these activities are a low-cost means for reducing atmospheric CO_2 (Noble et al., 2000) needs to be reassessed.

As discussed above, 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 greenhouse gases, in particular CH_4 and N_2O (Ellis, 2001). Estimates for forestry projects vary widely between 5 to 93 percent (Murray, 2003). Leakage also arises, if the stored carbon in forest is intendedly or unintendedly released. In particular the unintended release due to naturally occurring events like fires, pest, droughts or hurricanes imposes a risk on long-term storage prospects (Royal Society, 2001). The likelihood of such naturally occurring risks may increase in the future due to global warming and would make terrestrial carbon sinks less attractive (Ellis, 2001).

Using recent sequestration efficiency ratios from patch OIF experiments, Boyd (2008) estimates that the costs are between 8 and 80 USD per t CO_2 sequestered. For large-scale OIF no cost estimates exist. However, OIF will not be used if costs exceed the benefits as a mitigation option. Regarding the still existing uncertainty regarding volume of and costs for OIF, Rickels et al. (2009b) turn the question around and seek to determine the critical costs levels and the critical amounts for carbon credits from OIF that indicate if OIF would be competitive to forestry or CDM activities. Applying short-term OIF model experiments for the duration of 1, 7, and 10 years they obtain critical unit cost for the upper level between 95 to 119 USD per t CO_2 and between 22 to 23 USD per t CO_2 for the lower level. The upper level of the estimates indicates, if OIF could be considered an abatement option at all compared to the current status of climate policy including existing abatement option. For the lower level it is assumed that the current limitations regarding the use of carbon credits generated in low cost countries is completely relaxed. The lower level of the estimates, therefore indicates, if OIF would be comparable to options which achieve a given emission reduction target at lowest costs. 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.

Comparing this range of cost estimates to those of Boyd (2008) for patch OIF experiments indicates that the upper and lower level of those estimates are below the corresponding range of the upper and lower level of the estimates of Rickels et al. (2009b). However, it must be noted that these cost estimates might not be representative for large-scale OIF (Bertram, in press). Comparing the range of cost estimates to the range of estimates for forestation projects, they are in the same order of magnitude. However, OIF may well provide more carbon credits. Rickels et al. (2009b) show that seven years of large-scale OIF in the area of 30° South can provide the same amount of credits equivalent to a global forestation project for the duration of 20 years.

Therefore, we conclude, that current knowledge regarding the potential as well as the costs does not allow excluding OIF as possible an abatement option in the future.

4 Ocean Iron fertilization: the public international law perspective

The preceding economic analysis has shown that the comparison to efficiency criteria established by existing abatement options and in particular by existing sink enhancement options does not allow for an exclusion of OIF as possible abatement option. Consequently, the inclusion of OIF activities in future global or regional emissions trading schemes could result in considerable economic benefits. This conclusion renders calls for prohibiting or restricting any such activity under public international law in need of justification. While the 1992 Rio Declaration on Environment and Development (ILM 31 [1992], 874) states that "[i]n order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it", it is implicitly acknowledged in the very same Principle 4 of the Declaration that economic development, indeed, constitutes one of the three central pillars (the other two being environmental protection and intergenerational justice) on which the concept of sustainable development is founded. Thus, economic aspects should at least be taken into account (even though not necessarily given priority) whenever a certain activity is assessed by the competent fora in respect of whether it should be accepted or not.

Notwithstanding the fact that the concept of sustainable development is, by itself, not a binding principle of international law but a political key concept that aims at providing a framework for decision making processes both on the national and international plane (see, e.g., Beaucamp, 2002: 109), the need to consider the economic impacts of OIF arises from the scientific uncertainty connected with its potentially negative effects on the marine environment, the novel character of the underlying legal questions as well as the epochal challenge posed by global warming. However, as will be shown in the following, current developments in international relations seem to point at the opposite direction, i.e., the imposition of a complete moratorium on OIF. Discussions recently held within one of the competent international bodies on a catalogue of numerous and strict criteria which should be fulfilled prior to the commencement of scientific OIF experiments suggest that the concern voiced here might, ultimately, also apply to fundamental scientific research. If lack of a scientific basis on which to justify a certain potentially harmful activity is used to strengthen the case against scientific research on the very same subject matter, though, it is difficult to argue that such a course of conduct is sustainable. From a legal perspective, it is submitted that these developments are not based on an adequate reading of the precautionary principle. It will be argued here that such a reading does not address the issue of potential negative impacts on the marine environment in an isolated manner, but is rather based on the understanding that these impacts must, again, be weighed in light of the global challenges deriving from climate change.

4.1 Relevant international agreements

If one, in a first step, examines the rules of public international law applicable to OIF, it is generally accepted that whenever a question affecting the oceans is to be answered, the 1982 United Nations Convention on the Law of the Sea (1833 UNTS 3 – UNCLOS) should be referred to first. This framework treaty, a “constitution of the seas”, was concluded according to its preamble with the objective “to promote [...] the study, protection and preservation of the marine environment”, as specified by part XII of the Convention. In consideration that OIF conducted in certain marine areas could constitute “dumping”, Art. 210 UNCLOS is the initially relevant protectionary norm. Its paragraph 1 requires the contracting parties “[to] adopt laws and regulations to prevent, reduce and control pollution of the marine environment by dumping”. The reference to “global rules and standards” contained in this norm is generally understood as a reference to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 1972 (London Convention – LC) and the Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 1996 (London Protocol – LP), which replaces the LC for its contracting parties, which are specifically applicable to pollution by dumping (LaMotte, 2009).

The concept of “dumping” is defined in Art. III (1)(a) LC and Art. 1 No. 4.1.1 LP (as well as in Art. 1 (5)(a) UNCLOS) as follows:

> “(i) any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures at sea;
>
> (ii) any deliberate disposal at sea of vessels, aircraft, platforms or other man-made structures at sea.”

Even if iron filings introduced into the marine environment were not classified as “wastes”, they would still be classified as “other matter”. Since they will remain in the ocean, “disposal” appears to be occurring (Rayfuse et al., 2008; Freestone and Rayfuse, 2008). However, this alone does not lead to the conclusion that OIF constitutes “dumping”. Art. III (1)(b)(ii) LC and Art. 1 (4) No. 2.2 LP (as well as Art. 1 (5)(b)(ii)) UNCLOS) contain an exception, under which

> “‘Dumping’ does not include: […] (ii) placement of matter for a purpose other than the mere disposal thereof, provided that such placement is not contrary to the aims of this Convention.”

Accordingly, the placement of iron filings for purposes other than mere disposal should not be seen as dumping, provided it is not contrary to the objectives of the LC and the LP. Since the goal of OIF is the stimulation of the primary production of phytoplankton in order to scientifically examine this process and its consequences with a view to potential increases in the uptake of CO_2, an objective other than the mere disposal of iron filings is being pursued.

The question remains whether OIF activities are contrary to the aims of the LC and the LP. The purpose of these treaties is to prevent the pollution of the oceans through the dumping of wastes and other substances. Thus, a contradiction to the objectives of the Conventions would seem to exist when the substances introduced have a potentially damaging effect on human health, living resources and/or marine life (see Art. I LC; Art. 2 in connection with Art. 1.6.10 LP). As shown above, it is currently not possible to rule out negative consequences of OIF for marine life or for human beings (Chisholm et al., 2001; Denman, 2008; Lampitt et al., 2008). Having said that, it should not be ignored that the main purpose of OIF experiments is not, at least not foremost, the mere stimulation of primary production in the ocean, but, instead, to investigate a potential stimulation of phytoplankton blooms under specific conditions and their consequences, as well as to achieve a more general understanding of the role of iron in marine ecology and biogeochemistry. This conclusion strongly militates in favor of accepting that not *all* scientific OIF experiments are contrary to the aims of the LC and the LP.

In this respect, one must note that the issue relevant here is also addressed by other international treaties, which potentially overlap with the aforementioned law of the sea instruments. In particular, reference to the primary agreement relevant to climate change, the 1992 United Nations Framework Convention on Climate Change (1771 UNTS 107 – UNFCCC) and its 1997 KP, is mandatory. The ultimate aim of the UNFCCC is to achieve a stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (Art. 2 UNFCCC), but it contains only comparatively weak obligations of mainly procedural nature such as, e.g., the duty to gather and share information on greenhouse gas emissions, national policies and best practices. In contrast, the KP obliges the industrialized States (Annex I States) to ensure that their greenhouse gas emissions do not exceed their individually assigned limitation and reduction commitments inscribed in Annex B. It is generally recognized that the ocean is a natural CO_2 sink in terms of the KP. Against this background, one might well ask whether an isolated interpretation of the aims of the LC and LP might, ultimately, not result in a contradiction with the objectives of the climate change regime.

Having said that, the KP calls on its parties to implement policies and measures “taking into account its commitments under relevant international environmental agreements” (Art. 2 (1) lit. a (ii) KP). One of the key international instruments in this respect is the Convention on Biological Diversity (1760 UNTS 79 – CBD). The Convention addresses the protection and sustainable use of biological diversity with regard to habitats, species and genetic resources “from all sources including, inter alia, terrestrial, *marine* and other aquatic ecosystems and the ecological complexes of which they are a part” (Art. 2). Since the protection standards contained therein not only apply to the marine biodiversity of areas within the limits of national jurisdiction, but also to processes and activities carried out under the jurisdiction or control of the States parties within the area of their national jurisdiction as well as beyond the limits of national jurisdiction (Art. 4), the CBD has a role to play in light of the potentially negative impacts of OIF on marine ecosystems. On the other hand, Art. 22 (2) CBD, which serves as a derogation norm in the relationship between the CBD and other multilateral treaties, expressly recognizes that the CBD, in regard to the protection of the marine environment, must be interpreted in agreement with the rights and obligations of States in accordance with the international law of the sea. Against this background, it cannot be unambiguously concluded from the texts of the pertinent conventions whether all OIF activities, including scientific experiments, are contrary to the objective of safeguarding the general duty to protect the marine environment.

4.2 Current developments

This state of unclarity has recently led several of the competent international fora to address the issue relevant here. As regards the legality of OIF activities under the CBD, the 9th Conference of the Parties (COP) to the Convention adopted Decision IX/16 on "Biodiversity and Climate Change" in May 2008, whose relevant part reads:

> "4. *Bearing in mind* the ongoing scientific and legal analysis occurring under the auspices of the London Convention (1972) and the 1996 London Protocol, *requests* Parties and *urges* other Governments, in accordance with the precautionary approach, to ensure that ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities [...]; with the exception of small scale scientific research studies within coastal waters."

Since small scale scientific research studies within coastal waters are not suitable for such experiments (Denman, 2008; Lampitt et al., 2008; Sarmiento and Gruber, 2002), Decision IX/16 amounts, in substance, to a moratorium on OIF activities, including scientific experiments.

About half a year before, the Meeting of the Parties (MOP) to the LC and the LP released a Statement of Concern regarding OIF. In this document, it was stated that

> "recognizing that it was within the purview of each State to consider proposals on a case-by-case basis in accordance with the London Convention and Protocol, urged States to use the utmost caution when considering proposals for large-scale ocean fertilization operations. The governing bodies took the view that, given the present

> state of knowledge regarding ocean fertilization, such large-scale operations were currently not justified."

One year later, in November 2008 (i.e., after the adoption of CBD Decision IX/16), the same body adopted Resolution LC-LP.1 (2008) on the regulation of OIF. According to paragraph 8 of this document, OIF activities are contrary to the objectives of the London regime if and to the extent to which they cannot be qualified as legitimate scientific research:

> "AGREE that, given the present state of knowledge, ocean fertilization activities other than legitimate scientific research should not be allowed. To this end, such other activities should be considered as contrary to the aims of the Convention and Protocol and not currently qualify for any exemption from the definition of dumping in Article III.1(b) of the Convention and Article 1.4.2 of the Protocol".

It was pointed out by Proelss (2009) that neither the CBD Decision nor the Statement of Concern and the resolution LC-LP.1 are by themselves legally binding. However, since Resolution LC-LP.1 (2008) directly examines the question whether OIF should be categorized as dumping under the LC and LP, it can be referred to as an aid in the interpretation of the scope of the respective Conventions. The conclusion is that *legitimate* OIF experiments cannot be considered as prohibited dumping.

As expressly demanded by Resolution LC-LP.1 (2008), the Scientific Group of the LC and LP is currently working to establish an assessment framework for scientific research involving OIF. The framework which has so far been agreed upon contains a detailed catalogue (approximately 20 pages) of strict criteria to be fulfilled for evaluating whether an OIF experiment constitutes legitimate scientific research in terms of the Resolution. As an initial assessment as well as a detailed risk analysis will be required, effectively realizing an OIF experiment is likely to pose a serious, if not unrealizable, challenge for scientists. Indeed, the course of action taken by the Scientific Group seems to undermine the decision that legitimate scientific research shall be considered as being lawful. Additionally, in light of the economic benefits described above, it is at least doubtful whether any such implementation of Resolution LC-LP.1 (2008) can be held to be sustainable.

4.3 Impact of the precautionary principle

It is submitted that further clarification can be achieved by reference to the precautionary principle. This principle constitutes the common denominator of virtually all of the pertinent legal instruments including the LC and LP, and may, arguably, be used as a balancing tool to measure the environmental benefits arising out of a certain activity against its potentially negative impacts on another part of the environment (Proelss and Krivickaite, 2009).

Additionally, it is commonly held to be one of the cornerstones of the concept of sustainable development (see only Voigt, 2009: 48). While it is true that assessment frameworks constitute one of the means of implementation of the precautionary principle, one might ask whether the catalogue of criteria discussed within the context of the LC and LP is consistent with its requirements.

Notwithstanding a considerable degree of unclarity as to its normative content and validity (Fitzmaurice, 2009: 1 et seq.; Freestone/Hey, 1996; Marr, 2003: 7 et seq.; Wolfrum, 1999), it is well established that Principle 15 of the Rio Declaration contains the most widely known formulation of the precautionary principle:

> “In order to protect the environment, the precautionary approach shall be widely applied by all States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradations”.

By explicitly referring to cost-effective measures, the precautionary principle requires a careful analysis of the economic impacts of a decision (Hasbun, 2009). It does not provide an authorization to act, but shall be considered whenever States exercise their rights and obligations under public international law.

If one attempts to explore the relevance of the precautionary principle in the context at hand, recourse to the differentiation between rules and principles appears to be helpful. Dealing with Hart´s concept of positivistic legal theory, Dworkin developed his famous principle paradigm (Dworkin, 1982: 14 et seq.). According to Hart´s concept of law, legal systems are composed solely by rules (Hart, 1961: 89 et seq.). If a certain situation cannot be judged on the basis of existing rules, the judge has to take a discretionary decision by referring to extra-judicial, often moralistic criteria. This is the point of criticism for Dworkin, who argues that even in such a situation there must be a legally binding standard to be applied by the judge. For Dworkin, this standard becomes manifest in legal principles (Dworkin, 1982: 29). Principles are characterized as “optimizing commands” (Alexy, 2002: 70). They express certain values, but do not require a specific behavior of the respective subject of law. Principles can be realized to varying degrees subject to the legal possibilities, i.e., the extent to which a certain principle can be implemented depends on the existence and scope of competing principles. Thus, the application of legal principles generally results in a fair balance of values. By contrast, rules are structured in the pattern of fact and legal consequence and are applicable in an “all-or-nothing-fashion” (Dworkin, 1982: 24). They are specific in their requirements and consequences. If a rule is valid, it prescribes a definitive legal consequence by permitting, forbidding or commanding something. If it is not valid, it has no influence on the decision.

As regards the precautionary principle, its elements are characterized by a degree of indetermination which precludes an implementation of that principle in an “all-or-nothing-fashion”. It constitutes a “norm of aspiration” rather than a “norm of obligation” (Jackson, 1969: 761). This becomes particularly manifest in the element “lack of full scientific certainty” contained in Principle 15 of the Rio Declaration. It is exactly this vagueness which shows that the precautionary principle must be qualified as a legal principle (Marr, 2003: 13).

If one applies this classification to the case of OIF, one must note that on the basis of an isolated reading of the relevant provisions of the law of the sea (see Art. 1 (1) No. 4, Art. 194 (1) UNCLOS), the precautionary principle seems to militate in favor of the protection of the marine environment. On the other hand, Art. 3 (3) UNFCCC demands that the lack of full scientific certainty of mitigation measures should not be used as a reason for postponing such measures where there are threats of serious or irreversible damage. Consequently, within the context of global warming the precautionary principle argues for permitting OIF activities. Against this background, and keeping in mind the nature of the precautionary principle as a principle of law, the precautionary principle ought to be used to balance the risks arising out of scientific OIF activities (which are likely to contradict with the aims contained in the CBD) with the potential advantages relevant to the objectives of the UNFCCC and the KP.

If one measures the potential negative impacts of OIF on the marine environment against the global dangers resulting from rising CO_2 concentrations in the atmosphere, it is submitted that a proper application of the precautionary principle can only lead to the conclusion that further scientific research must be permitted to explore the sequestration potential of OIF in order to either reject this concept or integrate it into the flexible mechanisms contained in the KP. This is even more so with a view to the potential economic benefits of OIF examined in this paper. A fortiori, fundamental research on the role of iron in marine ecology and biogeochemistry is to be permitted. In contrast to large-scale and periodic commercial OIF, scientific OIF experiments involve, as far as is known today, only small negative impacts within a very limited marine area. Based on this reasoning, it seems impossible to justify a complete moratorium on OIF including scientific experiments. Having said that, whether or not commercial activities should be permitted by inclusion of OIF in the flexible Kyoto mechanisms depends on the outcome of experiments dealing with the potential negative impacts of OIF on the marine environment.

5 Conclusion

In this paper we have challenged the view that research on OIF should not be further pursued. Neither the scientific nor the economic analysis has resulted in the identification of an exclusion criterion suggesting that OIF should not be considered as a geoengineering option. Consistently, we have demonstrated that public international law does not require the imposition of a complete moratorium on OIF. On the contrary, as far as scientific research experiments are concerned, a proper analysis of the pertinent agreements as well as an adequate reading of the precautionary principle results in a clear presumption in favour of permitting such activities.

Against the background of an ever declining carbon emission budget on the one hand and widespread reluctance to accept meaningful global reduction targets on the other, including OIF into a Post-Kyoto climate agreement might provide new incentives for the negotiation process. Rickels et al. (2009b) show that countries with high abatement costs are expected to be more or less indifferent between the option of extending the share of carbon credits traded with CDM countries and the option of including OIF, presuming that only countries with positive reduction targets are included in the allocation of OIF carbon credits. CDM countries like China are expected to favor the first option. Consequently, a third option could be considered, which realizes both options, extending the share of CDM carbon credits and including OIF, but which allocates OIF carbon credits to CDM countries, if these would accept emission reduction targets in a future commitment period.

However, only discussing OIF as a potential geoengineering option tends to provoke public resistance, which in the case of the German-Indian LOHAFEX experiment resulted in anti-scientists propaganda by individual non-governmental organizations, political struggle between different German government authorities and calls for implementing a complete ban on commercial and, to some extent, scientific experiments. These views and attempts, based on statements about uncertain side effects and consequences, reveal an attitude that emphasizes continuity above alteration.

All of the unintended side effects are generally considered as “adverse” effects. This valuation seems to be based on the conservational view that changing the ocean is generally “bad”. This is in contrast to many terrestrial environments where enhanced food production, forestation or other management activities are often viewed as permissible if not desirable. From a governance point of view, however, ocean resources generally and OIF specifically are not intrinsically different from terrestrial or avian resources and environmental uses (Orbach, 2008). What leads us to treat the oceanic and terrestrial environment differently essentially is a cultural question.

Disregarding our cultural reservation against non-fishery related ocean change, a valuation might be more complicated. For example, how do we value the likeliness of enhanced marine production in the Southern Ocean that may turn out beneficial for many species including the hunted-down whale populations (Smetacek and Naqvi, 2008)? How do we account for the situation that large-scale Southern Ocean OIF might, via downstream reduction of macronutrients, lead to reduced oxygen minimum zones and associated nitrous oxide emissions in the tropical oceans (Oschlies et al., 2009)?

We have to acknowledge that we will never have full knowledge or forethought of all the risks which are associated with OIF – nor of the risks associated with discarding OIF under continuing CO_2 emissions. Given the multi-sectoral and overwhelmingly serious challenges posed by climate change, a truly global phenomenon, as well as the difficulties in achieving wordwide agreement on a sufficient degree of emissions reductions, there is, indeed, no alternative to further explore engineering options such as large-scale OIF.

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