Proposal to establish a DFG Priority Programme

Climate Engineering: Risks, Challenges, Opportunities?

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Disciplines: Earth, environmental and social sciences, humanities and law
Funding period and start: 2 x 3 years, start in October 2012**.**

1. Summary

There is growing concern that future reductions in greenhouse-gas emissions may be insufficient to avert dramatic climate change effects. In an attempt to expand the portfolio of options for reducing the risk of dangerous climate change, some scientists have proposed to develop global-scale engineering methods in order to offset some of the effects of greenhouse gas emissions. Methods suggested include an enhanced reflection of solar radiation back into space (e.g., by injecting aerosols into marine clouds or the stratosphere) and the removal of carbon dioxide from the atmosphere (e.g., by enhancing oceanic or terrestrial carbon sinks). Climate Engineering (CE) is defined as such intentional intervention in the environment on a planetary scale. It is a relatively new topic that is rapidly gaining public, scientific, political and even commercial attention. However, a conclusive scientific assessment, characterized by an appropriate disciplinary breadth and depth, of the potential environmental, political and moral risks, challenges and opportunities of CE is lacking. On the one hand, risks and adverse "side" effects might be ignored or underestimated, possibly leading to premature approval and problematic reliance on ineffective options. On the other hand, uncertainty about opportunities possibly opened up by CE may forestall early exploration of technologies that might eventually turn out to be sufficiently reliable and beneficial.

With no rigorous overall assessment of CE available, the deployment of some of the proposed CE schemes may appear relatively simple and cheap compared to ambitious mitigation efforts that are hard to achieve. An engineering and economic perspective that takes only direct deployment costs into account may be an incentive for certain countries, consortia, or even wealthy individuals to push for action. Currently, an appropriate framework of research guidelines, legal regulations and political measures is lacking at both national and international levels. Therefore it is important to assess the potential impacts of CE, to evaluate the legal situation and to consider developing governance structures that can be capable of ensuring that any CE research and potential deployment will be carried out in a transparent, responsible and sustainable manner. This is particularly challenging as CE with its intended and unintended global and long-term impacts gives rise to intricate scientific, ethical, social and political questions and concerns. Altering the climate, whether inadvertently or deliberately, has the potential to affect every person on Earth, in both the present and the future. Is it thus possible to ensure fair participation or an informed consent/dissent of the "test persons" (at least those already alive)? Who would be held responsible if a CE field trial resulted in disastrous unexpected effects, and how could the responsible parties rectify the situation without introducing substantial further risks? Moreover, given our incomplete understanding of natural climate variability, how could cause and effect be attributed? How would CE affect mitigation policies? These are only a few out of many questions that, in our view, highlight gaps in our knowledge and available governance tools, which need thorough consideration already at an early stage of CE research and certainly well before decisions about CE field trials can be made.

The aim of the Priority Programme proposed here is to help reduce the significant uncertainties in our current understanding of the environmental, societal and political risks, challenges and possible opportunities of climate engineering. To this extent, we will investigate the potential impacts and implications of CE in a comprehensive, rigorous and reflective manner. Because of the intricate complexity of the topic, an inherently interdisciplinary approach is needed, which goes well beyond the disciplinary pilot studies that, so far, have mostly concentrated on technical and climatic aspects of CE. Our approach of problem-oriented fundamental research toward CE and its potential implications on nature, society and international relations is, to our knowledge, both unique and timely. Having brought together an interdisciplinary team of experts on CE from the natural and social sciences, humanities and law, we will provide a thorough, critical and well-balanced analysis and assessment of CE across a broad range of scientific, environmental, economic, social, legal, political, ethical and communicative dimensions. On this basis, research carried out by this Priority Programme will enable us to provide much-needed knowledge for creating a framework for the responsible conduct of research on and decision making about CE.

2. State of the art

2.1 The Science of Climate Engineering

Climate engineering is understood as the intentional intervention in the environment on a planetary scale, currently being discussed from the perspective of counteracting the effects of global warming from greenhouse gas emissions. Measures proposed so far cover a large variety of techniques that may be grouped into two main categories (Royal Society, 2009; BMBF scoping study, Rickels et al., 2011): Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR). SRM attempts to increase the amount of solar radiation reflected back into space, for example by changing the reflectivity of the land or ocean surface or of clouds, or by injecting aerosols into the atmosphere. SRM is considered to have the potential for a significant climate response within months, but it does not address elevated CO_2 concentrations. SRM can thus be viewed as an attempt to alleviate the symptoms without addressing the cause of the problem. CDR, on the other hand, is aimed at removing CO_2 from the atmosphere by enhancing biological or chemical processes, such as photosynthetic biomass production, chemical weathering of rocks, or specially-designed industrial air-capture facilities combined with storage of the sequestered carbon in suitable marine or geological reservoirs. While CDR has the potential to slow or even reverse the increase of atmospheric CO_2, its expected climate response would be much slower than that of SRM.

Volcanic eruptions have shown that stratospheric aerosol injection can significantly cool the planet within months (Robock, 2000). Because of the fast response time and the large cooling potential, SRM has been considered as a possibly viable response to climate emergencies (Blackstock et al., 2009). Research on stratospheric aerosol injections has, until now, focused almost entirely on theoretical and modelling studies (e.g., Govindasamy and Caldeira, 2000; Crutzen, 2006; Rasch et al., 2008). Based on such studies it seems possible that SRM could result in a climate that is much more similar to a hypothetical low-CO_2 climate than a high-CO_2 climate in the absence of such engineering (Caldeira and Wood, 2008). Modelling studies have, however, also pointed out considerable adverse impacts on the environment such as a delay in ozone recovery (Tilmes et al., 2008), changes in precipitation (Trenberth and Dai, 2007) and regional seasonal cycles, as well as very high rates of warming once deployment is stopped before atmospheric CO_2 levels have been brought down (Matthews and Caldeira, 2007; Brovkin et al., 2009) - a process that is expected to take thousands of years in the absence of substantial mitigation or CDR efforts (Archer and Brovkin, 2008).

A major question is to what extent modelling studies are reliable and how viable CE strategies could be tested in practice (Blackstock et al., 2009; Robock et al., 2010). A similar difficulty of obtaining reliable evidence applies to other albedo enhancement methods such as cloud whitening, or changing the reflectivity of deserts, vegetation cover, or rooftops. All these schemes will impact surface heat fluxes and thereby affect the hydrological cycle and atmospheric circulation at least on a regional scale (Feichter and Leisner, 2009). A critical control aspect is the problem of identifying CE-induced climate effects that are expected to emerge as weak trends against a substantial internal variability of the climate system (MacMynowski et al., 2011).

CDR approaches suggested so far include options for sequestration on land, including large-scale afforestation (Ornstein et al., 2009) that may be combined with bio-energy and carbon storage (e.g., Kraxner et al., 2003), burial of charcoal created by pyrolysis of biomass ("biochar", e.g., Lehmann, 2007) as well as air capture of CO_2 combined with subsequent underground storage (Keith, 2009).

Marine CDR options include ocean iron fertilisation (Martin and Fitzwater, 1988), fertilisation by artificial upwelling (Lovelock and Rapley, 2007), and an alkalinity enhancement and associated reduction in seawater CO_2 partial pressure by dissolving carbonate or silicate rocks (Rau et al., 2007; Schuiling and Krijgsman, 2006; Köhler et al., 2010). Several *in situ* iron fertilisation experiments have been carried out, though not specifically configured to test the potential for CO_2 sequestration (Buesseler et al., 2008; Bathmann, 2005). A number of likely side effects of ocean fertilisation on both the marine biosphere and on the atmosphere have been discussed (Chisholm et al., 2001; Lawrence, 2002; Strong et al., 2009; Güssow et al., 2010; Oschlies et al., 2010a,b), whereas potential side effects of alkalinity enhancement have, to our knowledge, not yet been investigated at an appreciable level.

All SRM and CDR schemes proposed so far exist only as concept studies and, despite several investigations into the technological feasibility, there remain numerous and substantial engineering aspects to be resolved prior to a measurable test and possible future deployment. For a few methods, however, technical feasibility studies are planned in the form of small-scale field experiments (e.g., cloud whitening in the U.S., aerosol injections in the U.K. and in Russia). Furthermore, a number of start-up companies are investigating direct air capture of CO_2 as well as CDR via afforestation, bio-char, ocean fertilisation or alkalinity enhancement.

Unlike other technologies, CE creates a variety of pressures on existing strategies for coping with climate change: While CDR techniques are sometimes viewed as roughly compatible with existing climate regime, even SRM research is often considered as potent driver of morally hazardous behaviour, in which already the anticipation of a possibly cheap and effective alterative to abatement reduces mitigation and adaptation efforts. On the other hand, it may be argued that early SRM testing may be required in order to (i) eliminate a tempting but impracticable alternative, or (ii) avoid possibly pursuing conflict-prone technology with catastrophic side effects for some stakeholders. In practice, these questions have to be considered thoroughly, working towards a consensus on an international scale.

2.2 Assessment

Assessing the potential impacts and implications of CE approaches will have to consider risks, eventual efficacy, controllability, and legitimacy. The risks will depend on the extent and nature of potentially harmful side effects of CE measures (intended or unintended, anticipated or not) and include societal and political ramifications. Efficacy of CE will depend on the technologies' capacity to cost-efficiently generate the intended mitigation or reversal of climate change processes. Controllability will result from the ways in which both technical aspects of regulating impacts and political aspects of establishing appropriate governance schemes are dealt with. Legitimacy will have to address ethical and political concerns. Any integrated assessment will have to consider the ways in which actors and societies around the globe value the risks, harms and potential benefits. It is important to emphasise that the concept of "side effects" should not prevent researchers from considering the possibility that effects which appear to be minor side effects at a certain point in time may turn out to become the major effects in the future.

Individual theoretical studies on the impacts and possible climatic side effects have been performed on most of the proposed CE options. Lenton and Vaughan (2009) presented a coherent, albeit very approximate, assessment of the efficacy of different CE measures in terms of their respective radiative impact. Our current, although limited, understanding of effects, possible side effects, estimated costs and response timescales of different CE methods has been reviewed by the Royal Society report on “Geoengineering the Climate” (Royal Society, 2009) and the scoping study for the German Federal Ministry of Education and Research (BMBF, Rickels et al., 2011), and an assessment by the German Environmental Agency (UBA, 2011). These studies conclude that the level of understanding of the potential impacts and implications of the various CE schemes is relatively low and, in consequence, any assessment is subject to considerable uncertainty. While incomplete and based on little empirical evidence, the present state of knowledge underscores the fundamental difference between CDR and SRM technologies: SRM techniques are considered more likely to generate a fast, but generally higher risk, response of the climate system, whereas CDR could have a slow but more lasting climatic impact.

Some SRM approaches appear to pose small to medium technological challenges, with low marginal costs when calculated relative to the costs inflicted by unhindered global warming. The cooling potential, particularly of stratospheric aerosol injections, seems very high and in principle larger and more evenly distributed geographically than the potential of enhancing the albedo of land and sea surfaces as well as of clouds. Deployment costs have, in some assessments, been considered to be “incredibly low” (Barrett, 2008). However, the costs to societies associated with the considerable risks of so far unknown and unintended consequences in addition to already known side effects of SRM have not been assessed. SRM can be viewed as a “palliative” treatment that is likely to have many unintended side effects. Although it may easily be stopped, ending SRM measures could result in severe adverse effects due to rapid warming (Blackstock et al., 2009; Horton, 2011). Therefore a reliable “exit strategy” may be a mandatory requirement.

CDR methods that are ecosystem-based, such as afforestation, peatland restoration and ocean fertilisation, appear economically viable, with some sensitivity to the scale of the operation and the accounting method chosen (Rickels et al., 2010). However, consequences of such large-scale interventions in ecosystems are difficult to confine in space and time, and attribution of ecological changes to CE activities would be particularly challenging (Cullen and Boyd, 2008). Abiotic CDR methods are thought to be more expensive and technologically challenging then biotic ones (Lampitt et al., 2008; Keith, 2009). However, even current cost estimates at the higher end may become competitive relative to other mitigation efforts due to learning effects and as increases in scale push traditional mitigation activities move upwards on the marginal cost curve (e.g., Pielke, 2009).

With respect to societal response to, and rejection or acceptance of, CE measures we have hardly any knowledge (GAO, 2011). There is general agreement that in terms of final outcomes, CE measures will create winners and losers at the individual, national, and international level. What is unknown are the specific societal and geographical patterns of distribution. Perception of possible losses, e.g. through unintended side effects, is a well-known driver of public acceptance as we know from risk perception research on "electrosmog" and "biotechnology" in Europe (e.g., Cousin and Siegrist, 2010; Gaskell et al., 2000; Slovic, 1987). Thus it is likely that any proposal to implement CE will be met with significant public resistance, which will vary from country to country. A lack in public acceptance and intense controversies should, however, not be equated with a well-balanced ethical judgment based on in-depth deliberation. Therefore, complementary sociological and ethical reflections about the dynamics and the substance of debates should both be pursued.

While the public discourse on CE is now beginning to intensify, only a few researchers have yet addressed its linguistic, communicative, ethical and political aspects. Previous work in the field of global change research with a (media-)linguistic, sociological, psychological, political-science or philosophical background has focussed on “risk governance“, ”risk management“ and “risk communication” (e.g., Felt et al., 2007), on the relations and the communication between sciences and mass media (Weingart et al., 2002; Oreskes and Conway, 2010) and on linguistic strategies of knowledge constitution, knowledge transfer, knowledge popularisation and knowledge contestation (e.g., Liebert, 2002; Felder and Müller, 2009). The role of uncertainty and ignorance in scientific communication and its consequences for the public and political discourse has also received significant attention (Böschen and Wehling, 2004; Proctor and Schiebinger, 2008; Barben, 2010; Newell and Pitman, 2010; Janich et al., 2010), but has not yet been discussed in the context of CE.

Human actions with expectedly long-term consequences, such as climate intervention, pose peculiar ethical problems. Accordingly, such actions have been the subject of considerable controversy in philosophy, economics, and political science (e.g., Schröder et al., 2002; Gardiner, 2004; Stern, 2007; Hillerbrand, 2006). Special attention has been paid to the responsibility vis-à-vis future generations (Birnbacher, 1988), to the permissibility of discounting future damages and benefits (Portney and Weyant, 1999; Birnbacher, 2001; Ott, 2003; Broome, 2006), to the appropriate normative evaluation of climate impacts (Broome, 1992; Lumer, 2002; Broome, 2004), to the appropriate handling of risk and uncertainty (Thompson, 1986; Gottschalk-Mazouz and Mazouz, 2003), and to the fair allocation of emission permits and reduction obligations (Ott and Döring, 2008; Shue, 2008). So far, these studies have primarily served for articulating and justifying mitigation and adaptation efforts. More recently, scholars have begun to develop more comprehensive normative frameworks that integrate mitigation, adaptation and CE (Moreno-Cruz and Smulders, 2010; Ott, 2011).

The emergence of CE as a potential option in the climate change debate is just starting to be reflected among scholars from the humanities and social sciences. Yet the very proposal to engineer the climate on a planetary scale raises new challenges for these disciplines. For example, questions pertaining to the validity of arguments in favour of or against CE research and deployment, or to the prioritisation of mitigation, adaptation and climate engineering policies (Morrow et al., 2009) have not been thoroughly addressed. For notable exceptions see, for example, Jamieson (1996), Gardiner (2010), Elliott (2010), Betz (2011) and the special issues of Jahrbuch Ökologie (2011), Technikfolgenabschätzung – Theorie und Praxis, 19(2) (2010). A moral discourse on CE is thus emerging and discourse analysis will be a central element of the social sciences research conducted in the Priority Programme.

2.3 Governance

At present, there is no established global governance framework dedicated to regulating and overseeing possible field trials or eventual deployment of CE measures. The current state of knowledge regarding CE technologies indicates, however, that the predominant incentive structures may favor a high-risk strategy based on SRM techniques, to the extent that these are considered solutions, allowing for quick and effective responses by national decision-makers to a “climate emergency situation” (Lawrence, 2006) while obfuscating the follow-on costs and probable unintended consequences of their application. The possibly hazardous environmental effects of SRM are intensified by their potential impact on international relations: SRM deployment raises a set of governance issues (problem of coordination) that differ fundamentally from that of mitigation (problem of participation), but are just as important (Barrett, 2008). For example, it requires very careful calibration because of its potentially strong distributional effects (e.g., on precipitation). This high “leverage effect” (unilateral applicability/strong distributional effects) sets the stage for conflicts between the implementing and the aggrieved parties including the hostile application of SRM (Robock et al., 2009; Horton, 2011). The introduction of CE technologies has thus considerable potential to create a new set of "winners and losers" (Victor, 2008). Countries also differ in their ability to assess, voice, and defend their position vis-à-vis CE measures taken by others. This can give rise to various political conflicts in bilateral or multilateral relations, which may require specifically-tailored governance approaches in addition to the ones dealing with the environmental risks discussed above (Virgoe, 2009).

It is likely that prior to the decision whether large-scale deployment is a viable option or not, national or private interests, or perhaps scientific researchers themselves, will aim for field trials large enough to assess the potential impacts on the climate. Evidently, such experiments may affect a very large number of people. The intricate complexity of the Earth system, the inertia and pervasiveness of unintended consequences of CE technologies as well as the well-documented tendency of experts to overestimate their expertise (Jasanoff, 1987; Jamieson, 1992) suggest that, at this stage, the level of reliability of predictions is low and the risk of harmful and irreversible decision-making is high. It is highly questionable whether large field tests can be substantiated with respect to the principle of freedom of scientific research, since such freedom is constrained by the informed-consent-principle in any research that affects humans. Appropriate governance structures therefore have to be in place well before any possible CE field trials or deployment, requiring approaches to anticipatory governance (Banerjee, 2011; Barben et al., 2008). Those international mechanisms currently applicable to regulate applications of CE methods (such as the London Convention and Protocol on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter) have not been developed for this purpose, but some may be adapted to it. While ocean iron fertilisation has received considerable attention in the context of the London Convention (Rayfuse et al., 2008; Güssow et al., 2010), no comprehensive regulatory mechanism is in place for other CE methods. This explains why there exists only very little literature on the field (but see Bodansky, 1996; Victor, 2008; Virgoe, 2009) and evidences the need for further research from the perspectives of political science and international law.

There is an incipient CE governance debate in the U.S. House of Representatives, the U.K. House of Commons and the German Bundestag. The House of Commons has discussed a set of principles, the so-called Oxford Principles on Regulation of Geoengineering, which is one of the first attempts to present practical guidelines for governing research and implementation of CE techniques. A comprehensive and coherent socio-economic and scientific research effort as proposed here is considered essential for an informed engagement in international climate policy discussions and in potential efforts for developing a framework for regulating CE research and technological development.

3. Research programme

The overall goal of this Priority Programme is to reduce the significant uncertainties in our current understanding of the environmental, societal and political risks, the challenges and the possible opportunities of climate engineering. Our approach of problem-oriented fundamental research will evaluate potential CE effects on natural and social systems and international relations, examine CE research and governance strategies, and investigate possible impacts of CE on climate policy in the context of mitigation and adaptation. Issues to be addressed range from the potential environmental impacts of individual CE measures to various social implications, including the effects resulting from the mere existence of a CE debate on global climate policy. Research will be organised according to two research pillars:

1. Assessing the potential effects, uncertainties and challenges of CE
2. Evaluating the legal, moral and public acceptability issues of potential CE measures

For a selected set of key proposed CE measures, which broadly cover typical characteristics of the CE spectrum debated so far, we will investigate a wide range of issues across scientific, technological, economic, environmental, political, legal and ethical dimensions. The integrated assessment of CE requires substantial cross-disciplinary exchange. To facilitate collaboration across disciplines, each individual research project of the Priority Programme will be expected to either feature a genuine interdisciplinary component, be closely linked to a complementary partner project, or contain, at a meta-level, an explicit focus on the process and challenges of interdisciplinary CE research.

Interdisciplinary work will benefit from the fact that disciplinary CE research has not yet segregated into distinct isolated branches. The interdisciplinary information exchange will have to occur in an iterative fashion. The details of this concept are part of the embedded meta-level research and will undergo further development as the interdisciplinary research evolves. The Priority Programme will provide the necessary framework to coordinate these complex interactions. Annual workshops will bring together the individual research projects and disciplines. These workshops will also be open to researchers from outside the Priority Programme to ensure transparency and allow for the full consideration of new aspects and ideas in this rapidly evolving field. Results will be communicated via an internet portal based at www.climate-engineering.eu in order to allow for a rapid flow of information within the scientific community and to the interested public. Via a moderated internet forum, we will encourage participation of the wider public in the ongoing discourse on CE.

3.1 Assessing the potential effects, uncertainties and challenges of CE

Research pillar one will assess the potential consequences of CE, including the risks and potential opportunities, and the various uncertainties in our understanding such an assessment has to face. Research will involve primarily the natural and social sciences, including economics, political sciences and sociology. Work will be organised along three sub-tasks: (i) to investigate the environmental and social risks, (ii) to evaluate the epistemic uncertainties and institutional characteristics, and (iii) to explore potential political and governance challenges. While many of the issues to be investigated are generic to a wide range of potential CE measures, more specific case studies will be performed with regard to three measures that broadly cover typical characteristics of the CE spectrum debated so far: Aerosol injection into the troposphere and stratosphere, dissolving carbonate and silicate rocks to enhance marine CO_2 uptake, and forest engineering. As described in more detail in section 3.3 below, these three measures differ not only in approach and deployment, but also in response timescale, climate-change potential, and likely extent of possible side effects. They also cover a large part of the spectrum of ethical, legal, political and other societal issues.

(i) Environmental and social risks and uncertainties

A careful analysis of the potential risks and opportunities of CE is required that studies the reliability of our knowledge about the relevant natural and social systems, addresses their complexity and fathoms their uncertainties. Research will examine technical deployment issues as well as climate-impact assessments and accounting aspects using mostly numerical models ranging from small-scale process models to planetary-scale Earth System models. Thereby, an improved understanding of the space-time distribution of physical, chemical and biological effects and side effects of CE will be developed, providing scenarios for a societal and economic assessment. Uncertainties have to be related to uncertain model assumptions, estimated model deficiencies and uncertainties in attribution of effects to CE measures against the background of large internal variability of the climate system.

Another kind of uncertainty to be evaluated in the context of CE is introduced by the irreversibility and non-linearity of social feedback processes. When risks materialise, they turn into a danger or a threat (Daase, 2002). Research is required to clarify the tipping points of such a change in the nature of risk, the societal conditions that give rise to a shift from uncertain risk to certain threat (e.g. irreversible threshold effects), the identification of leading technical indicators of such a change, and appropriate response mechanisms. This analysis needs to show awareness of the different constellations of risk when comparing mitigation and CE strategies, and of the different risk attitudes within and across societies.

Climate policy to date, the scenario simulations carried out by the natural sciences, and the analysis of social feedback processes form the background for an economic assessment of risks and opportunities of CE measures. Cost-benefit analyses of different CE options will be carried out on their own and compared both against each other and against mitigation or adaptation options. Various actors will be considered, both nationally and internationally, and possible interactions with mitigation efforts will be especially accounted for. The analysis of asymmetric allocations of risk-bearing, costs, and benefits of CE will be sensitive to spatial and temporal dimensions (e.g. intergenerational relationships). New developments in decision theory (e.g. ambiguity aversion) will be considered in the analysis. Different risk management procedures and instruments will be compared on the basis of global efficiency and contribution to conflict resolution, among them an international torts process for CE measures. The potential for such procedures and instruments to manage the risks and uncertainties of deleterious effects of CE measures is a key focus of the research. Other uncertainties to be considered relate to uncertainties in the socio-economic scenarios and models.

Extending the scope of cost-benefit analysis, we will also look at other approaches pursued in technology assessment. We will aim at elaborating a sophisticated analytical framework for mapping and analyzing different kinds of uncertainty, risk and ignorance (Stirling, 2008; Groß, 2010). Hereby, it will also be important to distinguish between different kinds of ignorance, e.g. specific and unspecific ignorance (which relate to what we know that we do not know and, respectively, what we do not know that we do not know).

(ii) Epistemic uncertainties and institutional characteristics

As CE is an emerging conceptual approach dedicated to deliberate interventions in the climate system, a fundamental set of questions relates to the epistemic quality of this field of science and technology, along with its institutional framing. For example, what is the notion of engineering implied in CE by different communities concerned with exploring and/or exploiting CE? What is the relationship between scientific inquiry and technology development in CE? In its relatively brief history, has CE – or, respectively, SRM and CDR – already achieved a degree of maturation that it can be characterised by distinctive knowledge practices and cultures? Further, which institutional contexts have played a major role in shaping CE as a field of science and technology to date? How do diverging notions and institutional framings of CE influence the ways in which its risks, opportunities and uncertainties are conceived?

Coping with uncertainties of CE, which are also inherent in predictions of numerical models of complex systems, will benefit from a deepened methodological analysis by integrating philosophy and sociology of science. Within the past two decades, it has become clear that the grip of comprehensive theoretical principles on the details of climate phenomena is less strong than anticipated and that a lot of auxiliary assumptions and process parameterisations, whose nature and interactions are not always well understood, significantly affect the outcome of the models (Morrison, 1999; Winsberg, 2003; Carrier, 2004). As a consequence, the evaluation of a model's appropriateness can be based only to a limited degree on the truth of the theoretical principles underlying the models (Humphreys, 2004; Humphreys, 2008; Lenhard and Winsberg, 2010). Within the proposed Priority Programme, such evaluation procedures and the associated model building process will benefit from direct interaction with an "embedded philosopher of science".

(iii) Political and governance challenges

Research, development and eventual implementation of CE technologies will pose an array of challenges to domestic and international institutions. For example, climate intervention to control the global-mean temperature will affect various climate components on various time and space scales**.** Research will examine the potential conflicts resulting from the development and eventual deployment of CE technologies in terms of social and political conflicts (collective versus unilateral action, moral hazard, and the termination problem) and security concerns. Specific governance schemes, ranging from a global moratorium on any experimental CE research over an uncoordinated use of CE technologies to a fully-fledged regulated global implementation of CE research, field trials and deployment give rise to a variety of political and security challenges

Key research questions in this field to be addressed by the Priority Programme are: Which security interests will be affected by potential field experiments or eventual CE deployment? What are the strategic responses by other countries to experiments or deployment by another state? Which types of conflict prevention and resolution measures may be suited best for addressing security concerns? What are the trade-offs in security risks between impending "climate emergencies" and implementation of CE?

A second class of questions addresses the role of knowledge management and the responsibilities of scientists in the CE debate: What could be a regime for sharing public and proprietary information and knowledge on both technological solutions and impacts? How do actors (individuals, consortia, states) deal with innovation and research opportunities? In which way and to what extent should scientists participate in the political discourse and how do they influence the policy-making process? Who is undertaking research at this time, on what, since when, and for what reason? Under what system of monetary and non-monetary rewards is R&D and possible deployment of CE organised?

As regards the development of a governance system for CE research and potential CE deployment, research has to start out from the currently relevant institutions, norms, principles and legal conventions (Lin, 2009; Zedalis, 2010; Lattanzio and Barbour, 2010). Thus the experiences with adapting the current climate regime to the challenges posed by CE technologies, as starting to emerge from the adaptation of the London Convention, the Convention on Biological Diversity (CBD) and the working group process in the IPCC for AR5 need to be studied in depth. First, policies may have to be adapted to the different phases relating to research, development, testing, establishment and large-scale use of CE measures, taking into consideration the perceptions and responses of various stakeholders potentially affected along the pathway. Second, the Priority Programme will identify several distinct risk assessment patterns that capture the variations between different discourse levels as well as between different political communities, nations or states. This should allow deducing a set of norm-setting behaviours that follow from the respective risk assessment and demonstrate that (a) CE risk assessments relate to the current behavioural patterns in the climate regime (i.e., vis-à-vis mitigation and adaptation) and (b) CE risk-taking behaviour relates to the degree of climate injustice the actor claims under the given climate regime.

The research will also have to show awareness of the specific economic and political incentives that different governance approaches will present to the key decision-makers on CE, be it governments, companies, or citizens. Instruments for a proper internalisation of the specific externalities of CE measures need to be developed. Strategic behaviour and time inconsistencies in society's responses to such behaviour need to be anticipated through institutional safeguards. The quests for an optimum could be approached both normatively and positively, and should take into account the experiences and developments of the climate policy regimes already established.

Should an international scientific consensus emerge that CE provides sufficiently viable and reliable options for intervening into the climate system, CE and mitigation may be applied together. Research is required to identify the main determinants of a beneficial combination of CE and mitigation measures, to understand how an international governance system could reflect this and balance the different approaches (Wigley, 2006). At the same time, there is a need to better understand the interaction between the development or testing of CE options and the (inter)national willingness to devote resources to ambitious mitigation.

3.2 Appraising legal, moral and public acceptability

The second research pillar will focus on normative questions of acceptability, comprising legal, ethical and cultural perspectives. Work will be organised along the following aspects: (i) compatibility with the requirements of international law, (ii) moral admissibility, (iii) credibility and transparency in communication and public participation in the discourse on CE.

(i) Legal issues

In a governance scheme based on the principle of the rule of law, international law sets the ultimate limits for policy options in the field of CE. As no comprehensive legal instrument governing all issues of CE technologies has been adopted or implemented so far, the existing legal tools that are potentially relevant (e.g. the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, the UN Framework Convention on Climate Change and the Kyoto Protocol thereto, the Outer Space Treaty, and the Convention on Long-Range Transboundary Air Pollution) must be analysed in light of their applicability vis-à-vis particular technologies. As regards the relevance and future development of general international law, the distinction between rules and principles recognised in legal theory could be of particular importance. Unlike rules, principles cannot tell the relevant actors how exactly they should behave and what measures ought to be taken (Alexy, 2002). Principles can be realised 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 commonly results in a fair balance of values. The precautionary principle is a legal principle in terms of the aforementioned definition, and it may be described as the common denominator of virtually all relevant international legal instruments (including the United Nations Framework Convention on Climate Change, the Convention on Biological Diversity, and the United Nations Convention of the Law of the Sea). One option regarding the regulation of CE might be to develop a reading of this principle under which it could be used as a legal mechanism to balance the risks arising from certain CE activities against the potential advantages in view of the objective to combat global warming (Proelss, 2010). Naturally, such a weighting of conflicting values will have to be conducted on the basis of scientific, economic, political, social and ethical parameters, which are the subject of the other research questions (Davies, 2009; Lin, 2009; Zedalis, 2010). A more traditional reading of the precautionary principle would insist on its strict application vis-à-vis all parts of the environment and would thus militate against the option of balancing environmental risks (Ginzky, 2011). This situation requires some clarification, as do potential CE-related human-rights, responsibility and liability issues.

(ii) Ethical and moral issues

In the debate about CE research and deployment, moral arguments coexist alongside economic, political or technical ones. To understand the risks, challenges, and opportunities of CE, research therefore needs to take moral arguments serious as such. Ethics is seen as a discipline that critically reflects on moral arguments. Clearly, any ethical analysis should take into account the plurality of ethical and religious systems from which individual arguments stem. Several arguments for and against CE, especially SRM, have been presented in recent years (Moreno-Cruz and Smulders, 2010; Ott, 2010; Gardiner, 2011). Such arguments constitute a complex, highly interwoven and dense interdisciplinary discursive landscape that can be mapped and analysed. Discourse ethics provides an appropriate framework for an in-depth analysis of such landscapes (Ott, 1998; Gottschalk-Mazouz, 2000). In order to keep track of the individual lines of thought, identifying the different reasons put forward, as well as their mutual dependencies, the debate about CE can be analysed and visualised as an argument map (Betz and Cacean, 2011). Employing the relatively new and innovative method of argument mapping (Betz, 2010) promises not only to facilitate the interdisciplinary communication between the Priority Programme's projects, but may also turn out to help communicate results to stakeholders and the broader public. It can be stated as working hypothesis that these moral arguments are implicitly, if not explicitly, present in the political and public debate on CE. Currently, there still is a "window of opportunity" to make the CE-controversy a paradigmatic case of a global moral discourse based on arguments.

The moral evaluation is inevitably based on empirical predictions, which are always uncertain and subject to change as new information becomes available. Hence, besides respecting the plurality of existing normative values within a society, one has to account for predictive uncertainties when assessing the moral acceptability of CE research and possible deployment or their governance. New techniques for integrating the presence of uncertainties in scientific forecasts into the choice of an appropriate normative framework will be investigated.

It is an important task of moral philosophy to enhance governance by shaping participatory processes by bringing in an ethical perspective. Ethical considerations have to do with rights, maxims or demands that can be universalised (Kant, 1785; Habermas, 1983; Habermas, 1999). They abstract from the specific individual points of view and recognise claims of other persons as having equal rights as one's own. Such claims are often in conflict with individual aspirations. Yet public participation tends to emphasise arguments that are related to self-interests. Uninformed participation often highlights short-term assets and liabilities and brings to bear local points of view (Collins and Evans, 2002). By contrast, a deliberative conception of public participation places the promotion of the common good at the focus. Politics is viewed as a process of exchanging arguments with the aim of reaching a consensus.

The research endeavour to be pursued in this area is directed to developing means for stimulating a deliberative debate about CE. The persuasiveness of ethical arguments can be examined by doing "experimental philosophy" or "experimental sociology" within participatory settings (as citizens' juries, Renn, 1999; Smith and Wales, 2000; Skorupinski and Ott, 2000). Such approaches have been applied to exploring public intuitions regarding various philosophical issues. This method would be used for identifying convincing argumentative strategies within deliberative settings. Thereby, CE is placed at the interface between moral argumentation and their public take-up. In such a situation, the traditional task of clarifying how viable or cogent an argument is, needs to be supplemented with an examination of how convincing an argument is. Accordingly, this research field brings together philosophy, sociology and communication science. By doing so, the public attention for CE can be raised.

(iii) Science communication, public participation and deliberation

Climate change risks are of interpretative and normative ambiguity (Liverman, 2009). People think differently about the values and thresholds underlying what could be regarded as tolerable or acceptable. Therefore, the linguistic and communicative research will focus on the information exchange and discourse structures between different scientific disciplines and also between science, mass media, the public, and policy makers. The former will include a meta-analysis of the interdisciplinary communication among the participants of the Priority Programme. The main questions include: Who says what with which interests and which aims in which style and with which rhetorical and visual strategies - and who has enough power to have any impact in the CE discourse? What images of science and scientists will be generated by the public discourse (e.g., between expert and "mad scientist") and what media instruments and communication strategies are employed? How relevant is scientific and technological knowledge in the public discourse and what is the role played by political optimism and public faith in technology? How is it possible to inform and to affect the public and to communicate in a credible, transparent, responsible and respectful way? What political and other strategies can be observed that aim at shaping the acceptance and acceptability of CE in positive or negative ways? New ways of facilitating participation, deliberation and, eventually, representation will have to be explored not only for finding consent but also for dealing with dissent with respect to CE as a possible approach to tackle global warming in the context of the broader range of climate change policy options.

3.3 Exemplary CE measures

While many of the above issues are generic to a wide range of potential CE measures, more detailed case studies will be performed with regard to three measures that broadly cover typical characteristics of the CE spectrum debated so far: Aerosol injection into the troposphere and stratosphere, dissolving carbonate and silicate rocks to enhance marine CO_2 uptake, and forest engineering. These three measures differ not only in approach and deployment, but also in response timescale, climate-change potential, and likely extent of possible side effects. They also cover a large part of the spectrum of ethical, legal, political and other societal issues. Other CE options may be considered as well, but should be put into perspective to the three “exemplary” cases.

(i) Aerosol injection into the troposphere or stratosphere

Because of the short response timescale, aerosol injection seems attractive as an emergency response method. In order to decide on whether or not this could be a viable option, more research is required on the particle dynamics and chemistry close to the injection site, on the fate of the injected aerosol particles, and on impacts on atmospheric dynamics and chemistry, on the ocean, the hydrological cycle and the terrestrial vegetation. Tools to be employed range from high-resolution Large-Eddy Simulation models to global Earth System models, possibly complemented by lab studies and designs for small-scale field experiments. Research undertaken should also take advantage of already-present, related aerosol and aerosol precursor injections, e.g., ship tracks, contrails and large volcanic eruptions.

(ii) Ocean alkalinity enhancement

By adding alkalinity to the ocean, enhanced weathering of limestone and silicate rocks reduces the partial pressure of surface-water CO_2 and thereby allows for net carbon sequestration (Keshgi, 1995). An advantage of this approach is that by adding a basic compound to the ocean it directly counteracts ocean acidification. Open research questions include uncertainties about an efficient dispersal of the added base and associated side effects – also from natural impurities of the utilised minerals – on the marine biota and chemistry as well as on optical properties and associated heating profiles of the surface ocean. Experimental work will focus on lab and mesocosm studies that will help to provide appropriate parameterisations for regional to global modelling studies of the potential impacts of enhancing weathering by dissolving limestone or silicate rocks.

(iii) Afforestation

Afforestation has been incorporated into the Kyoto protocol and is widely accepted as a viable carbon sequestration method. However, physical effects (albedo, surface roughness, evaporation) and biogeochemical effects (CO_2 and other greenhouse gases) tend to oppose each other so that the net effect is not always clear (Pongratz et al., 2010). Some studies reveal that afforestation of boreal areas could enhance global warming (Betts, 2000; Claussen et al., 2001; Bathiany et al., 2010), while others suggest that abandonment of agriculture areas in mid and high latitudes could help to cool the climate (Pongratz et al., 2009). More research is needed to assess the net benefits and side effects in more quantitative terms. This will exploit information derived from remotesensing data of historical changes in vegetation cover, which will be combined with numerical modelling studies of the physical and biogeochemical impacts of a large-scale “forest engineering”. More research is needed also on the potential effects of engineering the terrestrial biosphere on biogeochemical and hydrological cycles. Aspects to be considered related to afforestation include peatland restoration, bio-char, food production, bioenergy, and the possible coupling of bioenergy with carbon capture and sequestration.

Research will in all cases concentrate on assessment and will not be directed to preparing eventual deployment. In particular, no large-scale field experiments will be performed. Instead, most research in the natural sciences will be based on numerical modelling, combined with re-analysis of historical natural and unintended anthropogenic “experiments”, possibly supplemented by laboratory, mesocosm and small-scale field studies.

4. Why undertake this Priority Programme?

(i) The questions addressed are highly relevant.

Despite some positive developments in the international efforts of the past and present to reduce CO_2 emissions, we are nevertheless faced with a rapidly increasing global CO_2 burden as well as a rising awareness of climate impacts amongst the public and policy makers. It is still an open question whether political goals to limit global warming to two degrees will succeed or fail within the next few decades. Although costs of mitigation may be lower than previously expected, there is no guarantee for the techno-economic success of large-scale implementation of standard mitigation schemes even if a stringent mitigation policy were implemented. Accordingly, parts of society may find it useful to have additional options at its disposal to combat “dangerous” climatic change that may possibly lead to unacceptable situations for a large part of the planet’s population.

Apart from mitigation and adaptation, climate engineering has only recently entered the political stage as a possible third option for addressing climate change (see recent review papers such as BMBF scoping study (Rickels et al., 2011), the report of the German Environmental Agency (UBA, 2011), and the forthcoming study of the Office of Technology Assessment at the German Bundestag (TAB). Without CE technologies being rigorously investigated, their specific risks and side-effects might be ignored, leading to premature approval and dangerous reliance on actually ineffective options. At the same time, uncertainty about CE options might forestall early investments in technologies that may eventually turn out to be reliable and highly beneficial. To better inform policy makers and society about the potential opportunities and risks of different climate engineering technologies and to enable an informed public debate, a transparent and thorough scientific evaluation of research, assessment methods, and governance options is needed.

(ii) The research effort is timely.

Given the potential benefits some CE methods seem to offer at relatively low costs compared to standard mitigation efforts, there are strong incentives to push for field trials and possible deployment of CE. Publicly and privately funded CE research efforts have already been initiated in other countries, including concrete preparations for field experiments of some CE methods. It is therefore urgent to investigate the risks this involves and to study potential global governance frameworks.

(iii) Collaboration has already started, further successful progress can be expected

CE is a relatively new topic that has gained some traction in the last few years. This proposal has nevertheless brought together a multi-disciplinary group of experts from all disciplines relevant to address this topic. Until now largely without dedicated funding, these highly motivated experts have already devoted research time to questions arising in the context of climate engineering proposals. A number of publications resulting from these pilot efforts have already had significant impact within the international community; some of these have shown the benefit of trans-disciplinary collaboration. Many scientists of this community perceive independence from industrial or private funding as an asset that is particularly strong in Germany compared to the U.S. and the U.K.

(iv) It improves Germany's position in climate policy negotiations.

A CE governance debate has begun in both the U.S. House of Representatives and the U.K. House of Commons, but until now there is a lack of an independent and comprehensive research effort to clarify the situation and develop such a framework in a transparent way. We are not aware of any other national consortium with a similar multi-disciplinary expertise on CE. The unique funding instrument of a highly interdisciplinary Priority Programme will allow us to play a leading role in the global research on CE risks, challenges and potential opportunities. This independent scientific research can help to support efficient policy decisions and may strengthen Germany's position in international climate policy negotiations.

5. Interdisciplinarity, coordination and networking

In four round-table discussions during the preparation of this proposal, the first two and the fourth one funded by the DFG, about 40 scientists from a wide range of scientific disciplines and from different universities and research institutions across Germany have shown their strong interest in the challenges CE poses for research, assessment, and governance. This common motivation and interest is also reflected in the relatively large number of proponents that have all jointly and actively contributed to the development and writing of this proposal. In order to efficiently run the Priority Programme, an interdisciplinary executive board, consisting of the coordinator and 4 further representatives (G. Betz, S. Harnisch, G. Klepper, A. Proelss) will be in charge of directive decisions and actions. It will continue to draw on the expertise of the whole group of proponents.

During the lifetime of the Priority Programme, national and international networking will be supported by the following activities:

- Annual workshops addressing the research tasks of all individual projects, fostering exchange and possible adjustment of research efforts in this rapidly evolving field.
- Two meetings per year of all PhD students and PostDocs employed within the Priority Programme to facilitate interdisciplinary and inter-institutional communication and research.
- Regular summer schools and interdisciplinary colloquia for PhD students and young PostDocs, building on the 2010 summer school "Governing Climate Engineering" in Heidelberg, and the 2010 Interdisciplinary PhD Colloquium on "Marine CO_2 Sequestration" in Kiel.

- An internet portal managed by the central office of the Priority Programme and containing a continuous update on scientific developments and the scientific and public debate. This will be built on the already established information site www.climate-engineering.eu in order to support rapid exchange of information both among participants of the Priority Programme as well as with international collaborators and interested people both in academia and the public.
- A public synthesis workshop in the final year of the proposed project that will include the international collaborators listed under point 8 below.

6. Relation to other programmes

The proposed Priority Programme integrates into the context of the following funded projects:

- Future Ocean cluster of excellence, University of Kiel: A number of interdisciplinary research efforts on research needs and economic and scientific aspects of ocean fertilisation have emerged from collaborations initiated within the Future Ocean network (M. Visbeck (speaker), A. Oschlies, A. Proelss, G. Klepper et al.).
- “The Global Governance of Climate Engineering” at the Marsilius Kolleg, University of Heidelberg. The project studies various CE proposals from an interdisciplinary viewpoint and with regard to different global governance schemes (T. Goeschl, T. Leisner, U. Platt, S. Harnisch et al.).
- EU IMPLICC (Implications and risks of engineering solar radiation to limit climate change, funded until mid-2012) is examining CE by aerosol injections into the stratosphere and into marine clouds (H. Schmidt (coordinator), M. Lawrence, C. Timmreck et al.).
- Network „BiCoDa Alliance for the History and Philosophy of the Technological Sciences“ (Universities of Bielefeld, Darmstadt und Columbia/South Carolina; M. Carrier, N. Janich et al.).
- Project House HumTec at RWTH Aachen, fostering high-level interdisciplinary research between the humanities/social sciences and the engineering/natural sciences. (R. Hillerbrand).
- SFB 574 “Volatiles and Fluids in Subduction Zones Climate Feedback and Trigger Mechanisms for Natural Disasters” University of Kiel: Modeling climate impacts and feedbacks of major volcanic eruptions (K. Krüger, M. Latif et al.).
- Super Volcano project at MPI-M, Hamburg (C. Timmreck et al.).
- SPP 1409 Wissenschaft und Öffentlichkeit, subproject “Vom Umgang der Wissenschaftler und Wissenschaftsjournalisten mit Nichtwissen und unsicherem Wissen in laienadressierten Texten” (N. Janich).
- Project "Geo-Engineering" of the Office of Technology Assessment at the German Bundestag (TAB) is to give a comprehensive overview of the current state of knowledge (G. Klepper, D. Barben, T. Goeschl, A. Grunwald, N. Janich, S. Harnisch, A. Oschlies, A. Proelss, J. Scheffran, et al.).

7. Education and public outreach

PhD education is an integral part of the proposed Priority Programme, aiming at a total of 25 PhD students. Being part of a highly interdisciplinary network, the students will receive a very intense and broad education. While each PhD student will submit her/his thesis to one faculty of one university, the structure of the SPP will allow and encourage the students to acquire expertise also outside their specific discipline and to strengthen their capabilities to communicate and interact with all disciplines involved. Students are encouraged specifically

- to participate in the two meetings per year of all PhD students and PostDocs employed within the Priority Programme, which will take place at the different participating universities and research institutions. The meetings at the end of the 2^{nd} and 5^{th} year, respectively, will be used to provide training in presentation and communication skills and to address issues such as career planning, becoming relevant for the then 2^{nd}-year PhD students;
- to spend part of their PhD at different research groups of the consortium or abroad at working groups of international collaborators, with financial support for this included in the coordination budget;
- to participate in local graduate programmes offering soft-skill courses, mentoring or coaching, for example at the Integrated School of Ocean Sciences in Kiel (http://www.ozean-der-zukunft.de/ausbildung-isos/startseite/), the Graduate School "Humanities and Social Sciences" at the TU Darmstadt, Bremen International Graduate School for Marine Sciences "Global Change in the Marine Realm" (GLOMAR, http://www.glomar.uni-bremen.de/), Earth System Science Research School (ESSReS, http://earth-system-science.org/);
- to present results at international scientific meetings.

One of the strategic goals of the SPP is to further equal opportunities at early career stages. Those efforts aim at both female and male PhD students but with a focus on gender issues and gender specific communication structures. This will be conducted through local mentoring and coaching efforts, organised by the PIs at their respective institutions and reporting to the central project office. Additionally, if a pregnant scientist needs extra support by a student assistant during pregnancy or the time she will be away from work, this will be supported as a measure for equality.

A public relations office associated with the project coordinator will coordinate all public outreach activities. These include the continuously updated internet portal as well as providing a point of contact for the press as well as the general public. This office will also support all scientists involved in the programme by offering to coordinate the responses to individual requests for information, answering emails and internet blogs, which may otherwise require a substantial amount of a researcher's time and possibly lead to difficult situations for scientists not trained in dealing with the media. Proposals are encouraged that plan to involve the public, e.g., schools in public outreach activities.

8. Prospective participants

Name	Institution	Interest/expertise
Bathmann, Ulrich	IO-Warnemünde, U. Rostock	Biological oceanography
Barben, Daniel	Political Science, RWTH Aachen	Sci. & technol. in society, governance
Betz, Gregor	Philosophy, KIT, U. Karlsruhe	Ethics and methodology
Carrier, Martin	Philosophy, U. Bielefeld	Methodology
Claussen, Martin	U.Hamburg, MPI Meteorologie	Land-surface – climate interaction
Goeschl, Timo	Economics, U. Heidelberg	Environmental economics
Grunwald, Armin	ITAS, KIT Karlsruhe	Technology assessment
Harnisch, Sebastian	Political Science, U. Heidelberg	Global governance; CE policy
Held, Hermann	KlimaCampus, U. Hamburg	Economics of climate protection
Hillerbrand, Rafaela	HumTec, RWTH Aachen	Ethics for energy technology
Janich, Nina	Sprach- u. Lit.wiss., TU Darmstadt	Scient.communic., knowledge transfer
Kaiser, Florian G.	Psychology, OvGU Magdeburg	Social & environmental psychology
Klepper, Gernot	Kiel Inst. for the World Economy	Environment and natural resources
Kriegler, Elmar	Potsdam Inst. Climate Impact Res.	Integr. assessment of climate change
Krüger, Kirsten	GEOMAR, U. Kiel	Stratospheric dynamics and chem.
Latif, Mojib	GEOMAR, U. Kiel	Meteorology and climate dynamics
Lawrence, Mark	IASS Potsdam, U. Mainz	Atm. chemistry-climate modelling
Leisner, Thomas	Env. Physics, U. Heidelberg, KIT	Aerosols in climate syst. hydrol. cycle
Levermann, Anders	PIK, U. Potsdam	Dynamics of the climate system
Lucht, Wolfgang	PIK, Humbold Universität Berlin	Land-use – climate interaction
Menzel, Annette	Ecoclimatology, TU München	Atmosphere-biosphere interactions
Oschlies, Andreas	GEOMAR, U. Kiel	Modelling marine C sequestration
Ott, Konrad	Philosophy, U. Greifswald	Environmental ethics
Platt, Ulrich	Env. Physics, U. Heidelberg	Environmental physics
Proelss, Alexander	Public Law, U. Trier	International law and governance
Scheffran, Jürgen	Geography, U. Hamburg	Security risks, conflicts and governance
Schmidt, Hauke	MPI for Meteorology, Hamburg	SRM modelling
Timmreck, Claudia	MPI for Meteorology, Hamburg	Supervolcanoes, modelling
Visbeck, Martin	GEOMAR, U. Kiel	Physical oceanography
Wolf-Gladrow, Dieter	AWI Bremerhaven	Theoretical marine ecology
Zürn, Michael	Social Sci. Res. Center Berlin	Transnat. confl. & internat. institutions

International Collaboration with:

- GeoEngineering Assessment & Research (GEAR), University of East Anglia, UK (www.gear.uea.ac.uk)
- Oxford Geoengineering Programme, UK (www.geoengineering.ox.ac.uk)
- Energy and Environm. Systems Group, U. Calgary, Canada (www.iseee.ca/eesg/)
- Center for Law and the Environment, University College London, UK (www.ucl.ac.uk/laws/environment)
- The Geoengineering Model Intercomparison Project (GeoMIP, http://climate.envsci.rutgers.edu/GeoMIP/publications.html)
- Earth System Governance Project (IHDP, www.earthsystemgovernance.org)

- Canadian Centre for International Governance (CIGI, www.cigionline.org)
- Integrated Assessment of Geoengineering Proposals (IAGP, Univ. Cardiff et al., http://www.iagp.ac.uk/)
- Center of Ethics, University of Montana, USA (www.umt.edu/ethics/EthicsGeoengineering/default.aspx)

9. Envisaged funding periods and estimate of funding required

The envisaged funding period is 2 x 3 years, beginning in October 2012. We plan to have about 30 individual projects within this Priority Programme, with some projects involving several PIs from different disciplines, overall requiring about 25 PhD students, 10 PostDocs, and 15 student assistants. The requested annual budget is:

	EUR per year
Staff:	
PhD students (25)	920.000,00
PostDocs (10)	588.000,00
Student assistants (15)	180.000,00
Consumables:	
7,500 per project (30)	225.000,00
Publication costs:	
750 per project (30)	22.500,00
Project-specific travel (conferences):	
5,000 per project (30)	150.000,00
Coordination budget:	
Project coordination (Ulrike Bernitt)	58.800,00
Press Office & Web portal	30.000,00
Workshops & meetings	80.000,00
PhD student visits to research groups of national & international collaborators	60.000,00
Guest scientists	50.000,00
Measures to promote equality	15.000,00
Total:	**2.379.300,00**

Declarations

In submitting this proposal for a DFG Priority Programme grant, we agree to adhere to the rules of good scientific practice. Our proposal is in compliance with the rules for lists of publications and bibliographies.

On behalf of all co-proponents

Kiel, 15.11.2011,

Prof. Dr. Andreas Oschlies

Appendix I: Literature

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Appendix II: 18 Peer-reviewed CE-related publications of the proponents

1. **Barben, D.** (2010), Analyzing Acceptance Politics: Towards an Epistemological Shift in the Public Understanding of Science and Technology, *Public Understanding of Science,* 19(3), 274-292.
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4. Brovkin, V., V. Petoukhov, **M. Claussen**, E. Bauer, D. Archer, and C. Jaeger (2009), Geoengineering climate by stratospheric sulfur injections: Earth system vulnerability to technological failure, *Climatic Change* 92, 243-259.
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6. **Goeschl, T.** and G. Perino (2009), On Backstops and Boomerangs: Environmental R&D under Technological Uncertainty*, Energy Economics*, 31(5), 800-809.
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8. **Kaiser, F. G**., Midden, C. & Cervinka, R. (2008). Evidence for a data-based environmental policy: Induction of a behavior-based decision support system. *Applied Psychology: An International Review*, 57, 151-172.
9. Köhler, P., J. Hartmann, and **D.A. Wolf-Gladrow** (2010), The geoengineering potential of artificially enhanced silicate weathering of olivine, *Proceedings of the National Academy of Sciences,* 107(47), 20228-20233.
10. **Lawrence, M. G.** (2002), Side effects of oceanic iron fertilization, *Science*, 297, 1993.
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12. **Oschlies, A**., M. Pahlow, A. Yool, and R. J. Matear (2010), Climate engineering by artificial ocean upwelling - channelling the sorcerer's apprentice, *Geophys. Res. Lett.*, 37, L04701, doi:10.1029/2009GL041961.
13. **Oschlies, A.,** W. Koeve, W. Rickels, and K. Rehdanz (2010), Side effects and accounting aspects of hypothetical large-scale Southern Ocean iron fertilization, *Biogeosciences,* 7, 4017-4035.
14. **Ott, K.** (2010): Kartierung der Argumente zum Geoengineering. Jahrbuch Ökologie 2011, 20-32.
15. **Ott, K.** (2011): Domains of Climate Ethics. Jahrbuch für Wissenschaft und Ethik (forthcoming)
16. Pongratz, J., C. H. Reick, T. Raddarz, and **M. Claussen** (2010), Biogeophysical versus biogeochemical climate response to historical anthropogenic land cover change, *Geophys. Res. Lett.*, 37, L08702, doi:10.1029/2010GL043010.
17. Rayfuse R., **M. G. Lawrence**, and K. M. Gjerde (2008), Ocean fertilisation and climate change: the need to regulate emerging high sea uses, *International Journal of Marine and Coastal Law*, 23, 297-326.
18. Rickels, W., K. Rehdanz, and **A. Oschlies** (2010), Methods for greenhouse gas offsets accounting: A case study of ocean iron fertilization, *Ecological Economics*, 69, 2495-2509.

Appendix III: CV of applicants