# GEOENGINEERING: COMBATING CLIMATE CHANGE WITH WHITE PAINT?

**Global warming as a result of the steady rise in concentration of greenhouse gases in the atmosphere and combating the associated global problems with potentially catastrophic consequences represent one of the major challenges of the 21st century. The international efforts to counteract it by reducing greenhouse gas emissions have had little demonstrable effect to date. According to estimates by the International Energy Agency, $CO_2$ emissions reached another new record level in 2010 – following a slight decline in 2009, the year of the economic and financial crisis. Against this backdrop, there are growing signs that the debate about geoengineering interventions, which has mainly been conducted in academic circles to date, could clearly gain momentum and increasingly also reach the political arena.**

The term *geoengineering* is less about a »new technology« in the sense of a fundamental technical innovation or a new branch of science forming a discrete research field. Rather, it is a collective term for methods and concepts – some of which have been available for a long time – whose aim, as set out in a frequently used but very vague definition of geoengineering, is an »intentional, large-scale manipulation of the environment« (Keith 2009). The actual new element in connection with the development of geoengineering technologies – which are *a priori* not at all restricted just to impacting on the climate – are thus not so much their technological principles, but rather the large scale of application of these technologies which has been announced. However, a precise and universally accepted definition which would enable unambiguous identification of which technologies and concepts with which scale of application merit the label *geoengineering* has yet to become established.

Against the backdrop of anthropogenic global warming, attention in recent times has been increasingly captured precisely by such geoengineering concepts which are intended to have a temperature-reducing impact by means of large-scale interventions in climate-related global cycles in order to check or even reverse the anticipated climate change. This ambitious goal is an indication of the necessary magnitude of these interventions – also termed *climate engineering* (CE) in this context and below: an intentional manipulation of the environment on a *global* scale. There is as yet no example in the history of human culture of a technology whose development and implementation could satisfy both attributes – *intentional* and *global* – whereas an example of a technology which is impacting *unintentionally* and on a global scale can quickly be cited: energy production based on fossil fuels whose unintentional consequence is the warming of the planet which is becoming ever clearer (Keith 2009).

The development of CE technologies differs from other technology creation routes in one further aspect: whereas new scientific findings combined with technical progress are often regarded as key drivers of new technology developments whose application fields and potential uses still have to be identified in some cases (please see in this regard the contributions on nanotechnology by C. Revermann and on synthetic biology by A. Sauter), the development of CE technologies can be interpreted as a search for solutions with a clear objective (reduction in the Earth's temperature). Against this background it should not be a surprise that in some cases long familiar technologies or – from a technical viewpoint – almost trivial concepts, though which are intended to meet their brief by means of a major increase in their scale of application, come under discussion.

At the same time the scaling-up of technologies to a global scale of application means that possible risks and/or unknown or unintended side effects and repercussions could also grow to the same extent. Earth's entire population may potentially have to bear the possible consequences and risks of the technology, with varying effects in terms of extent and time. Consequently, in the event of the development and large-scale implementation of CE technologies it is not just engineers and natural scientists who will face a major challenge, but also researchers in the humanities, social sciences and law as well as policy-makers.

## POSSIBLE CLIMATE ENGINEERING TECHNOLOGIES

What concrete approaches and ideas can be placed under the heading of CE technologies? Differentiation of the technologies into interventions which influence the global radiation balance such that less short-wave solar radiation is absorbed by the Earth's surface or atmosphere and converted to heat (solar radiation management, SRM) and into interventions in the global $CO_2$ cycle with the goal of reducing the atmospheric $CO_2$ concentration (carbon dioxide removal, CDR) in order to eliminate the actual cause of global warming represents a systematic means of classification (in this regard and with reference to the following, Royal Society 2009).

### INFLUENCING THE GLOBAL RADIATION BALANCE

In terms of influencing the global radiation balance, some of the solar radiation could be diverted into space using space-based systems before it even reaches the geosphere or, on the other hand, the reflectiveness of the Earth system (termed albedo) could be increased. The first category includes, for example, the proposal to shade the Earth by means of giant sun-shields to be positioned between the Earth and the sun to reflect or deflect the solar radiation. Assuming the shields can be precisely controlled, direct »weather control« would even become conceivable since the intensity of the solar radiation could be adapted regionally (Keith 2009).

In view of the enormous logistical demands involved in transporting the sun-shields to their destination, these concepts are pure science fiction at present. By contrast, the CE concepts for increasing the Earth's albedo, whose basically very simple principle is to make the Earth brighter overall, is easier to implement – even though it would entail appropriate efforts. The ideas, which are surprisingly simple from a technical viewpoint in some cases, include (Rösch et al. 2010; Leisner/Müller-Klieser 2010):

- Increasing the brightness of the Earth's surface – e.g. by painting roofs and roads white, planting fields and grasslands with more reflective plant types and varieties or covering deserts with reflective films;
- Enhancing the reflectivity of the lowest atmospheric layer (troposphere) – e.g. by artificially whitening low-lying marine clouds with the aid of sea salt aerosols which are sprayed into the clouds by unmanned boats;
- Enhancing the reflectivity of the atmospheric layer above the troposphere (stratosphere) – e.g. by delivering sulphate aerosols or aluminium nanoparticles, which help to scatter or reflect sunlight, into the stratosphere by means of aircraft.

The delivery of sulphate aerosols into the stratosphere is the subject of intense debate since it is already known from volcanic eruptions that sulphate aerosols in the atmosphere can generate a cooling effect (Crutzen 2006).

### INFLUENCING THE GLOBAL $CO_2$ CYCLE

While the concepts for influencing the global radiation balance aim at compensating for the global warming caused by the greenhouse effect by reducing the net incoming solar radiation received, the objective of interventions for influencing the global $CO_2$ cycle is to stabilise or lower the atmospheric $CO_2$ concentration, and such interventions therefore address the root of the problem. One of the best known examples for CE in this category is the fertilisation of large areas of open ocean with nutrients (e.g. iron). The intention is to stimulate the growth of algae artificially, thereby fixing more $CO_2$ from the atmosphere in the algal biomass which would then – according to the theory – sink into the deep ocean with the dead algal biomass. The high level of awareness of ocean fertilisation methods compared with other CE proposals is a result of the fact that this is the only CE idea for which field trials have taken place on a significant scale to date – accompanied by public controversy over the legality and meaningfulness of these trials, such as the German-Indian »LOHAFEX« experiment clearly demonstrated in the spring of 2009.

A similarly simple proposal from a technical perspective provides for large quantities of biomass to be converted into stable carbon compounds (biochar) by heating in the absence of air in order to remove them from the natural cycle of biological decomposition. Regional concepts from the fields of agriculture and forestry, based on natural processes for sequestering $CO_2$ from the atmosphere, are also under discussion (Rösch et al. 2010): these methods, also collated under the term »climate farming«, entail, for example, afforestation, reforestation and avoidance of deforestation, conserving and expanding bogs or avoiding turning grassland into arable land in order to maintain or replenish the terrestrial carbon store.

Carbon dioxide capture and storage (CCS) from industrial flue gases and the direct removal of $CO_2$ from ambient air (»air capture«) with the aid of »artificial trees« are technically more challenging. Both processes presuppose that long-term, secure storage of large quantities of $CO_2$ in geological formations is feasible.

The CE proposals outlined – which do not claim to be exhaustive – can be classified according to their effort/effect ratio (Leisner/Müller-Klieser 2010):

- CE interventions with a small effort/effect ratio (which are also termed measures with a »large lever«) unleash a large and generally immediate effect with comparatively little effort and cost. CE concepts for increasing the reflectivity of the atmosphere and fertilising large areas of ocean fall into this category.
- CE interventions with a large effort/effect ratio aim to use a large input of labour and technical equipment in order to compensate for greenhouse gas emissions on a tonne-for-tonne basis or influence the radiation balance by changing the colour of the Earth's surface. This category includes the production of biochar, the creation of whole forests of artificial trees, the plan to paint all roofs and roads white and the proposed climate farming solutions. These interventions do not represent a quick fix for climate stabilisation since their implementation will

probably only proceed slowly and will require major effort.

It is generally believed that CE technologies with a large effort/effect ratio can be better controlled and monitored than interventions with a »large lever« (in particularly their use can be geographically delimited and halted faster in the event of unacceptable consequences) and entails fewer risks and side effects (Ott 2010; Rösch et al. 2010). In view of this, many scientists are of the opinion that only technologies with a »large lever« merit the term CE.

## HOPE: PLAN B FOR EMERGENCIES

Mankind's long-standing desire to shape the environment or the climate in accordance with his own ideas and wishes by means of technical solutions is also addressed in the novels of Jules Verne (e.g. Sardemann 2010). In his novel »The Purchase of the North Pole«, published in 1889, for instance, the Baltimore Gun Club plans to shift the Earth's axis as a result of the recoil from a gigantic cannonball such that the polar ice of the Arctic could be melted, freeing the Earth's population at the same time from the annoying fluctuations of the seasons. The prospect of a more constant climate which would allow every citizen of Earth to live in a pleasant, stable climate zone initially results in worldwide agreement with and enthusiasm for the project. The Gun Club's action is, of course, primarily motivated by the goal of accessing the coal reserves thought to be under the ice and less by the prospect of helping mankind.

The technical optimism documented in Jules Verne's novels and fed by the rapid pace of technical development of those years may have awoken hopes of ultimately also being able to exercise control over the weather and climate thanks to scientific and technical advances. At that time no one suspected that the manipulation of the global climate had already started as an unintended consequence of precisely such technical advances – which we are experiencing ever more markedly today. The wish to shape our climate to suit our needs with the aid of large-scale technology-based interventions is thus now motivated less by mankind's desire to dominate nature, and more by the hope of having an emergency plan to safeguard our survival in the event that efforts to reduce greenhouse gas emissions fail.

The results of the international climate policy, which have generally been disappointing to date, really do make it doubtful whether the goal of limiting the rise in global warming to 2 °C above the pre-industrial level can actually be achieved by reducing greenhouse gas emissions. It is from this fear that many scientists derive their view that research into the opportunities and risks of CE interventions should not be a taboo subject but rather should be supported, even if it is usually emphasised at the same time that top priority must be given to the »classic« strategies for dealing with climate change – reducing greenhouse gas emissions (mitigation strategies) and adapting to climate change (adaptation strategies) – (e.g. Crutzen 2006; Royal Society 2009, p. ix). A weighty argument put forward by many proponents – known as the arming-the-future argument – states that is it almost a moral imperative to identify suitable CE technologies with minimal risks at the earliest possible stage in order to be able to offer future generations an optimum knowledge base for all possible actions and, if appropriate, also a last-resort, a »plan B«, against global warming (please see the box for a selection of pro and contra arguments).

The scientific interest in CE technologies could grow stronger still if is confirmed that »tipping elements« could represent an additional danger. These are critical subsystems within the climate system which could be switched into a qualitatively different state with potentially serious impacts if a system-dependent temperature level (the tipping point) were to be exceeded. It cannot be ruled out, for example, that a critical temperature level, which could trigger the continuing melting of the Arctic and Greenland ice, could be reached with global warming of less than 2 °C above the current level, i.e. possibly within this century. Additional solar radiation would be absorbed by the darker ocean and land masses, causing the rate of temperature rise to accelerate still further (ice-albedo feedback) – a development which could result in the complete disappearance of these ice caps in the summer within just a few centuries and a rise in sea levels by up to 7 m (Lenton et al. 2008).

The announcement by the Intergovernmental Panel on Climate Change (IPCC) that its fifth assessment report scheduled for 2013/2014 will for the first time assess possible impacts of CE proposals on human and natural systems and on mitigation cost, as well as evaluate options for appropriate governance mechanisms of CE options is an indication that scientists really are increasingly placing their hopes in potential CE technologies – because hopes are dwindling at the same time that the required reduction in greenhouse gas emissions can be achieved within the target timescale (www.ipcc-wg3.de/meetings/expert-meetings-and-workshops/em-geoengineering; 11.8.2011). It is to be expected that the issue of CE will therefore increasingly move into the focus of public discourse and gain momentum. NGOs and environmental organisations are already criticising the IPCC because the mere fact of describing possible CE technologies could push the actual target of emissions reduction further and further into the background (see also the moral-hazard argument in the box). This could ultimately further hamper the already difficult climate negotiations and increasingly exert pressure on the political decision-making process with reference to, for instance, funding programmes for CE research or to the licensing of large-scale field trials.

## HYPE: CLIMATE PROBLEM SOLVED!

A possible and probable scenario for the ongoing CE debate could therefore be a rise in the number of those within the scientific community declaring themselves in favour of considered, internationally coordinated research into CE technologies in order to be forearmed and in a position to act in the event of an emergency.

However, a different scenario can also be pictured: CE technologies could be not only an emergency strategy but also perhaps a possible *alternative* to the classic climate protection strategies of avoidance and adaptation. It could, for example, be conceivable that research into and the development and deployment of CE technologies could be advocated not primarily by scientists but by the general public in view of the laborious and expensive efforts involved in avoidance and adaptation actions. The following framework conditions would underpin such a scenario, which is still purely hypothetical from today's perspective:

- Research results could show that certain CE technologies would offer a simple, effective and – compared with the classic strategies – very inexpensive and resource-friendly technical solution to the climate problem (efficiency argument);
- CE interventions would – compared with the classic strategies – be perceived as having far less impact on people's existing lifestyles and ownership structures, particularly in societies which are geared towards prosperity (easiness argument);
- As a consequence of global warming, climate-related environmental disasters causing major damage could occur regularly in future. This could increase the acceptance of CE technologies in light of the unknown risks (lesser-evil argument);
- Most CE concepts can be illustrated in very simple images and thus be easily communicated to the general public. The CE technologies with a »large lever« in particular really can be compared with the idea of the Gun Club from Jules Verne's novel in terms of their technical approach: pouring large quantities of iron into the oceans, delivering sulphur aerosols into the stratosphere by means of tanker aircraft, weather balloons or cannons (!) or painting all building roofs and roads white;
- In societies with a pronounced technical optimism far less attention would be paid to the possible risks and side effects, while the hoped-for benefit of the technology, on the other hand, would be greatly overestimated;
- Under certain circumstances »large-lever« CE technologies could be implemented unilaterally by individual states or special-interest groups with the corresponding resources. International consent would therefore not be a necessary prerequisite for the use of CE – those states which reject this action would be faced with a *fait accompli*.

The significant increase in media reporting of the CE issue in the last ten years compared with the 1990s indeed indicates that – in addition to interest among scientists – the public interest in CE technologies is continuing to grow (e.g. ETC 2010, p. 12). This could be interpreted as the first indication of a »hype cycle« (Konrad 2011, p. 157 f.): the positive expectations of what technology can deliver are gaining ever broader acceptance and are being rated ever more optimistically, accompanied by a strong increase in interest from the media. As a rule, such a »hype phase« culminates in exaggerated expectations which regularly prove infeasible in practice, at which point the expectant attitude disappears and the (public) interest settles back down. Only after this »disappointment phase« are the potentials of a technology assessed more realistically.

It seems plausible that none of the CE technologies has already peaked in terms of a comprehensive »hype phase«. If, however, it were to come to a marked level of public hype, which could easily take on global dimensions in light of the scale of use, the public pressure on political decision-makers would probably rise further still. The following quotation from US politician Newt Gingrich illustrates that this view is not entirely without foundation: »Geoengineering holds forth the promise of addressing global warming concerns for just a few billion dollars a year. Instead of penalizing ordinary Americans, we would have an option to address global warming by rewarding scientific innovation …« (after ETC 2010, p. 14).

Interestingly, some of the proposed CE concepts have already undergone such a »hype cycle« *within* the science community. For example, the results of a series of small-scale trials of iron fertilisation of the oceans show that the initial optimistic expectations relating to the induced algal bloom and the sinking rate of the biomass were not achieved and consequently the effectiveness of the method has been

**SELECTION OF PRO AND CONTRA ARGUMENTS ON CLIMATE ENGINEERING**

*Pro arguments*

- *Arming-the-future argument*: We are morally obliged to examine every option in order to offer future generations the optimum basis on which to make decisions. Linked to this is the *last-resort argument*: we should prepare ourselves for emergencies so that unpopular options are also available.
- *Easiness argument*: CE is less difficult to implement in political and cultural terms than motivating people and industry to avoid emissions. Unpopular interventions in lifestyles, habits and economic ownership structures could be avoided.
- *Efficiency argument*: Direct and indirect costs of CE interventions are lower than the costs of avoidance and adaptation. It would be a waste of resources to prioritise avoidance and adaptation.
- *Lesser-evil argument*: The consequences of CE interventions, when compared with those of unrestrained climate change, could constitute the lesser evil overall.

*Contra arguments*

- *Moral-hazard argument*: The mere prospect of CE as the answer to our problems will cause many players to continue to emit large volumes of $CO_2$.
- *Termination-problem argument*: The use of CE technologies could give rise to a dilemma in future: if highly problematical side effects were to have occurred and, at the same time, the concentration of greenhouse gases were to have increased, future generations would be faced with the dilemma of either living with these side effects or bringing about rapid climate change by abruptly stopping the CE intervention.
- *Risk-transfer argument*: The risks caused by an economic model associated with high emissions will be passed down unfairly to future generations.
- *Informed-consent argument*: Actions with global and long-term impacts would only be legitimate if there were to be broad informed consent by those affected. Strictly speaking, that would be all people living now and in the future and would mean a legitimacy condition which can scarcely be met.

Source: according to Ott 2010

greatly overestimated. At the same time, it is becoming more and more clear that very little is known so far about the very complex interactions of maritime life and that the possible risks and consequential impacts of such an intervention are largely unknown (e.g. Strong et al. 2009).

## FEAR: IT COULD ALSO GO WRONG

After the initial euphoria for the Gun Club's plan in Jules Verne's novel, the mood is quickly reversed once the news, review and feature pages of all the world's newspapers start to look into the side effects of the intervention: the flooding or creation of entire continents, climatic turbulences and the destruction of huge tracts of land as a result of the enormous recoil of the cannon, among other things, are expected. But by the time the governments of the world would like to halt the undertaking, the Gun Club has already started construction of the giant cannon in an unknown location which the rest of the world is unable to trace. The drama proceeds.

With reference to the »large-lever« CE technologies in particular, a comparable scenario of possibly frivolous unilateral action by private foundations, the world's richest individuals (Keith 2009) or governments acting in isolation does not seem to be plucked entirely out of thin air. Companies could also be tempted to such a careless use of these technologies in order to pocket a large profit in return for a small level of expenditure, e.g. by selling $CO_2$ emission certifications to which – if »negative« emissions of CE interventions in the $CO_2$ cycle were to be recognised in future within the framework of the market-based instruments of international climate policy – these companies would be entitled (Wiertz/Reichwein 2010). A glance at the large number of patent applications in the field, for instance, of technological solutions for biochar production, the manufacture of artificial trees or the optimum supply of nutrients for marine algae appears to lend support to the assumption that speculation on such a recognition of CE technologies is in progress (e.g. ETC 2010, p. 30 ff.).

The »large-lever« CE technologies in particular can entail significant risks and side effects which are not regionally limited because they intervene in sensitive cycles and could therefore have unintended impacts with, under certain circumstances, far-reaching consequences for environmental and socio-economic systems on a global level. A further cause for concern is the fact that the necessary field trials which would have to be conducted on a sufficiently large scale to eliminate any final uncertainties could themselves have unwanted and harmful repercussions which – given the complex interactions that pertain – could remain undetected for a long period or may not have their cause identified.

Sulphate aerosols, for example, once generated, can remain in the atmosphere for several years and display their effect. Possible risks and repercussions of the method – based on model calculations and observations following major volcanic eruptions – are addressed in the Royal Society's report (2009, p. 29 f.) (see also Crutzen 2006; Leisner/Müller-Klieser 2010):

- Global impacts on vegetation, forests, agricultural yields and the carbon cycle as a result of possible changes in the distribution of rainfall and wind and in incident solar energy;
- Modifications to the Asian and African summer monsoon, reducing precipitation and thus potentially impacting the food supply to billions of people;
- Reduction in stratospheric ozone;
- Some whitening on the sky;
- So far unexplored feedback mechanisms could have additional significant effects on atmospheric processes.

In addition to these specific risks, this method also shares the problems of all interventions in the global solar radiation balance: Since these do not eliminate the actual cause of global warming – the high man-made concentration of greenhouse gases in the atmosphere – the (negative) impacts associated with the high greenhouse gas content (e.g. acidification of the oceans) are not corrected; on the contrary, they are further amplified. In addition, the cooling of the climate by means of these methods would have to be continued over decades or centuries since halting the action would result in a sudden, rapid rise in temperature which would scarcely allow mankind to implement the then necessary adaptation strategies in good time (termination-problem argument).

In view of the possible global risks and repercussions of a technology which may have to be applied over several generations, a decision about deploying or not deploying it cannot be taken solely on the basis of technological and scientific criteria (feasibility, climatic effectiveness, environmental risks etc.) or cost considerations; rather, it also requires an evaluation based on ethical, socio-economic, legal (including international law), political and, possibly, other criteria. In fact, up till now, a technological/scientific perspective dominates, whereas research in the social sciences, humanities and law has only been addressing CE technologies in depth for just a few years.

The issues to be addressed by social scientists and legal academics are very ambitious. One issue to be discussed, for example, is the question of which body has the legitimacy and capability, in light of the potentially high risks and possibly based on an uncertain knowledge base, to take an accountable decision about the use or non-use of CE technologies in accordance with ethical standards. Such a decision would have to morally justify the fact that benefits and risks may well be distributed unevenly and that certain population groups could be affected more seriously by the adverse impacts for the benefit of others or that the problems caused today would be passed on to future generations (risk-transfer argument). But how could the risks (and opportunities) be communicated openly and transparently so that all those affected by the action can develop their own informed view and contribute actively to the decision-making process (informed-consent argument)?

Furthermore, there is no international mechanism which deals explicitly with CE or which could be applied in a comprehensive and legally binding manner to the various CE technologies. On the one hand, this is because CE represents a very heterogeneous group of technologies and there is as yet no definition on which a consensus might be reached. On the other hand, most CE concepts so far only exist as an idea or in computer models, and to date no one has seriously considered using the technology. However, the controversy surrounding the German-Indian »LOHAFEX« experiment of fertilising the ocean with iron, for instance, shows that there is a definite need for debate and action with reference to regulating CE.

Against the backdrop of transnational or global, possibly regionally differentiated, side effects and repercussions, the conventions based on international law, such as those negotiated in relation to earlier international climate and environmental polices, could act as a role model for such a global governance of CE technologies. At the same time, however, the climate negotiations of the past illustrate how difficult international agreement can be.

Furthermore, the fact that CE interventions could, under certain circumstances, be carried out by individual states or by small numbers of states in isolation would jeopardise the principle of consensus – a cornerstone of international climate policy (the targeted reduction in greenhouse gas emissions is only achievable in a joint show of strength). In connection with conventions on CE technologies, this principle would no longer have a key role to play: in particular, nations could claim national security interests as a reason for defying existing international norms and agreements, especially as these frequently tend to be more of a recommendation and less of a legally binding character (Wiertz/Reichwein 2010).

## OUTLOOK

On the one hand, CE research, which has been dominated by scientists and engineers up till now, has already curbed the high expectations associated with certain technologies (e.g. iron fertilisation of the oceans); on the other hand, it has shown that – even if the technologies are simple in concept – potential side effects and repercussions can entail major systematic complexity and are largely not understood. The academic and public discourse, which has been technologically and scientifically based up till now, will increasingly benefit from research from the fields of social sciences, humanities and law since it is recognised that an evaluation of CE technologies requires contributions from every discipline. Various indicators allow us to conclude that the debate about CE technologies will gain momentum in the next few years and that the political pressure to make decisions and act could grow correspondingly.

With that in mind, TAB has been commissioned by the Committee for Education, Research and Technology Assessment of the German Bundestag to undertake a TA project in the field of geoengineering which will start in the summer of 2011 and is scheduled to be concluded in the autumn of 2012. The aim of the TAB project is, on the one hand, to provide a comprehensive overview of the current status of knowledge relating to scientific and technological aspects of the various CE technologies proposed with particular reference to possible risks and repercussions and, on the other hand, to develop and discuss the legal (including international law), ethical, socio-economic and political facets of the issue.

By the way, in Jules Verne's novel the effect expected from the cannon shot fails to materialise because of a trivial calculation error – the cannonball is sized far too small. The rejoicing citizens of the world keep their seasons, and disaster is not visited upon them. Let us hope, should it ever actually become necessary to use »large-lever« CE technologies, that no calculation errors are made!

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