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66

GEOENGINEERING IN RELATION TO THE CONVENTION ON BIOLOGICAL DIVERSITY: TECHNICAL AND REGULATORY MATTERS

Part I. Impacts of Climate-Related Geoengineering on Biological Diversity

Part II. The Regulatory Framework for Climate-Related Geoengineering Relevant to the Convention on Biological Diversity

UNEP

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Biological Diversity

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FOREWORD

Human-driven climate change is becoming an increasingly important cause of biodiversity loss and degradation of ecosystem services. With the relatively limited action to date to reduce greenhouse gas emissions, increasing attention has been recently given to additional options that might lessen the severity of future impacts, through geoengineering. There is a rapidly growing scientific literature on this topic, with recent overview reports published by, for example, the Royal Society, the US Government Accountability Office., and an Expert Meeting of the Intergovernmental Panel on Climate Change. However, those documents did not specifically consider geoengineering from a biodiversity perspective.

The Conference of the Parties (COP) of the Convention on Biological Diversity (CBD) first turned its attention to geoengineering at its ninth meeting in 2008, in the context of ocean fertilization. The COP then requested Parties to ensure that ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities. In response to this request, the Secretariat prepared a synthesis and analysis of the impacts of ocean fertilization on marine biodiversity, which was published as CBD Technical Series 45.

At its tenth meeting in 2010, geoengineering was considered by the COP more generally. Decision X/33, which includes a section on climate-related geoengineering, called for studies on the possible impacts of geoengineering techniques on biodiversity and associated social, economic and cultural considerations, and on gaps in the regulatory mechanisms for climate-related geoengineering relevant to the CBD.

These studies—published here—were conducted by a highly authorative group of experts, thanks to financial support from the Government of the United Kingdom of Great Britain and Northern Ireland, the Government of Norway and the European Commission. The studies were subject to two rounds of peer review, and then discussed at the sixteenth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA-16), where they were well-received.

At SBSTTA-16, the Parties to the CBD recognized that there remain significant gaps in the understanding of the impacts of geoengineering on biodiversity and that there is currently no comprehensive science-based, global, transparent and effective framework for geoengineering, while also noting the relevance of other treaties and organizations for filling such gaps.

I hope that the studies will help inform discussions of those involved in these issues, as well as the very many stakeholders involved in protecting biodiversity.

Braulio Ferreira de Souza Dias
Executive Secretary
Convention on Biological Diversity

PART I

IMPACTS OF CLIMATE-RELATED GEOENGINEERING ON BIOLOGICAL DIVERSITY

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CONTENTS

KEY MESSAGES

1. **Biodiversity, ecosystems and their services are critical to human well-being. Protection of biodiversity and ecosystems requires that drivers of biodiversity loss are reduced.** The current main direct drivers of biodiversity loss are habitat conversion, over-exploitation, introduction of invasive species, pollution and climate change. These in turn are being driven by demographic, economic, technological, socio-political and cultural changes. Human-driven climate change due to greenhouse-gas emissions is becoming increasingly important as a driver of biodiversity loss and the degradation of ecosystem services. A rapid transition to a low-carbon economy is the best strategy to reduce such adverse impacts on biodiversity. However, on the basis of current greenhouse-gas emissions, their long atmospheric residence times and the relatively limited action to date to reduce future emissions, the use of geoengineering techniques has also been suggested as an additional means to limit the magnitude of human-induced climate change and its impacts.

Proposed climate-related geoengineering techniques

2. **In this report, climate-related geoengineering is defined as a deliberate intervention in the planetary environment of a nature and scale intended to counteract anthropogenic climate change and its impacts.** Geoengineering techniques include increasing the reflectivity of the Earth's surface or atmosphere, and removing greenhouse gases from the atmosphere; other approaches have also been proposed. This definition of geoengineering encompasses a wide spectrum of possible actions to counteract (or remedy) global warming and its associated consequences. The commonality of those actions is that they could produce global cooling, if applied at sufficient scale. Geoengineering can therefore be differentiated from actions that mitigate (reduce or prevent) anthropogenic greenhouse-gas emissions. Carbon capture and storage (CCS) linked to fossil fuel combustion is not here considered as geoengineering, although some geoengineering techniques may involve the same or similar processes of managed carbon storage. Afforestation/reforestation and large scale land-management changes are, however, included, notwithstanding that such measures are already deployed for climate-change mitigation and other purposes, and that they involve minimal use of new technologies. (*Sections 2.1-2.2*)[1]

3. **Sunlight reflection methods (SRM), also known as solar radiation management, aim to counteract warming and associated climatic changes by reducing the incidence and subsequent absorption of short-wave solar radiation, reflecting a small proportion of it back into space.** They are expected to rapidly have an effect once deployed at the appropriate scale, and thus have the potential to reduce surface global temperatures within a few months or years if that were considered desirable. SRM would not address the root cause of human-driven climate change arising from increased greenhouse-gas concentrations in the atmosphere: instead they would mask the warming effect of accumulating greenhouse gases. They would introduce a new dynamic between the warming effects of greenhouse gases and the cooling effects of SRM with uncertain climatic implications, especially at the regional scale. SRM would not directly address ocean acidification. SRM proposals include:

    1. *Space-based approaches:* reducing the amount of solar energy reaching the Earth by positioning sun-shields in space with the aim of reflecting or deflecting solar radiation;
    2. *Changes in stratospheric aerosols*: injecting sulphates or other types of particles into the upper atmosphere, with the aim of increasing the scattering of sunlight back to space;
    3. *Increases in cloud reflectivity:* increasing the concentration of cloud-condensation nuclei in the lower atmosphere, particularly over ocean areas, thereby whitening clouds with the aim of increasing the reflection of solar radiation;
    4. *Increases in surface albedo:* modifying land or ocean surfaces with the aim of reflecting more solar radiation out to space.

SRM could be implemented separately or in combination, at a range of scales. (*Section 2.2.1*)

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[1] Information in parentheses indicates where full details, with references, can be found in the main report.

4. **Carbon dioxide removal (CDR) techniques aim to remove CO_2, a major greenhouse gas, from the atmosphere**, allowing outgoing long-wave (thermal infra-red) radiation to escape more easily. In principle, other greenhouse gases, such as nitrous oxide (N_2O), and methane (CH_4), could also be removed from the atmosphere or reduced at source, but such approaches are currently highly speculative. Proposed CDR techniques include:

   1. *Ocean fertilization:* the enrichment of nutrients in marine environments with the intention of stimulating plant production, hence CO_2 uptake from the atmosphere and the deposition of carbon in the deep ocean;
   2. *Enhanced weathering:* artificially increasing the rate by which CO_2 is naturally removed from the atmosphere by the weathering (dissolution) of carbonate and silicate rocks;
   3. *Increasing carbon sequestration through ecosystem management:* through, for example: afforestation, reforestation, or measures that enhance natural carbon storage in soils and wetlands
   4. *Biological carbon capture, using harvested biomass and subsequent carbon storage:* for example, through biochar, the long term storage of crop residues or timber, or bio-energy with carbon capture and storage; and
   5. *Direct, chemical capture of carbon from the atmosphere and its subsequent storage*, for example, with storage as liquid CO_2 in geological formations or in the deep ocean.

CDR approaches involve two steps: (1) CO_2 capture from the atmosphere; and (2) long-term storage (sequestration) of the captured carbon. In the first three techniques, these two steps are very closely linked, although the permanence of the storage may be variable and technique-specific; in the fourth and fifth, capture and storage may be separated in time and space. Ecosystem-based approaches such as afforestation, reforestation or the enhancement of soil carbon are already employed as climate-change mitigation activities, and are not universally regarded as geoengineering technologies. CDR techniques act relatively slowly: to have a significant impact on the climate, such interventions, individually or collectively, would need to involve the removal from the atmosphere of several Gt C/yr (gigatonnes of carbon per year), maintained over decades. This seems unlikely to be achievable for several proposed CDR approaches. (*Section 2.2.2*)

5. **There is no single geoengineering approach that currently meets all three basic criteria for effectiveness, safety and affordability. Different techniques are at different stages of development, mostly theoretical, and many are of doubtful effectiveness.** Few, if any, of the approaches proposed above can be considered well-researched; for most, the practicalities of their implementation have yet to be investigated, and mechanisms for their governance are potentially problematic. Early indications are that several of the techniques, both SRM and CDR, are unlikely to be effective at the global scale. (*Section 2*)

Climate change and ocean acidification, and their impacts on biodiversity

6. **The continued increase in CO_2 and other atmospheric greenhouse gases not only has profound implications for global and regional average temperatures, but also for precipitation, soil moisture, ice-sheet dynamics, sea-level rise, ocean acidification and the frequency and magnitude of extreme events such as floods, droughts and wildfires.** Future climatic perturbations could be abrupt or irreversible, and potentially extend over millennial time scales; they will inevitably have major consequences for natural and human systems, severely affecting biodiversity and incurring very high socio-economic costs. (*Section 3.1*).

7. **Since 2000, the rate of increase in anthropogenic CO_2 emissions has accelerated, averaging ~3.1% per year. Emissions of other greenhouse gases are also increasing. As a result, it will be extremely challenging to limit global warming to the proposed target of 2°C.** In fact, current commitments to limit greenhouse-gas emissions correspond to a 3–5°C warmer world. Avoidance of high risk of dangerous climate change therefore requires an urgent and massive effort to reduce greenhouse-gas emissions, as well as protecting existing natural carbon sinks, including through sustainable land management. If such efforts are not made, geoengineering approaches are likely to be increasingly proposed to offset at least some of the impacts of climate change, despite the risks and uncertainties involved (*Section 3.1.2*).

8. **Even with strong climate mitigation policies, further human-driven climate change is inevitable due to lagged responses in the Earth climate system.** Increases in global mean surface temperature of 0.3–2.2°C are projected to occur over several centuries after atmospheric concentrations of greenhouse gases have been stabilized, with associated increases in sea level due to thermally-driven expansion and ice-melt. The seriousness of these changes provides the reason why geoengineering has attracted attention. (*Section 3.1.2*)

9. **Human-driven climate change poses an increasingly severe range of threats to biodiversity and ecosystem services, greatly increasing the risk of species extinctions and local losses.** Temperature, precipitation and other climate attributes strongly influence the distribution and abundance of species, and their interactions. Because species respond to climate change in different ways, ecosystems (and the services they provide) will be disrupted. Projected climate change is not only more rapid than recent naturally-occurring climate change (e.g., during ice age cycles) but now the scope for such adaptive responses is reduced by other anthropogenic pressures, including over-exploitation, habitat loss, fragmentation and degradation, introduction of non-native species, and pollution. Risk of global extinction and local extirpations is therefore increased, since the abundance and genetic diversity of many species are already reduced, and their adaptive capacity is lessened. (*Section 3.2.1*)

10. **The terrestrial impacts of projected climate change are likely to be greatest for montane and polar habitats, for coastal areas affected by sea-level change, and wherever there are major changes in freshwater availability.** Species with limited adaptive capability will be particularly at risk; while insect pests and disease vectors in temperate regions are expected to benefit. Forest ecosystems, and the goods and services they provide, are likely to be affected as much, or more, by changes in hydrological regimes (affecting fire risk) and pest abundance, than by direct effects of temperature change. *(Section 3.2.2)*

11. **Marine species and ecosystems are increasingly subject to ocean acidification as well as changes in temperature.** Climate driven changes in the reproductive success, abundance and distribution of marine organisms are already occurring, more rapidly than on land. The loss of summer sea-ice in the Arctic will have major biodiversity implications. Biological impacts of ocean acidification (an inevitable chemical consequence of the increase in atmospheric CO_2) are less certain; nevertheless, an atmospheric CO_2 concentration of 450 ppm would decrease surface pH by ~0.2 units, making large-scale and ecologically significant effects likely. Tropical corals seem to be especially at risk, being vulnerable to the combination of ocean acidification, temperature stress (coral bleaching), coastal pollution (eutrophication and increased sediment load), sea-level rise and human exploitation (over-fishing and coral-harvesting). (*Section 3.2.3*)

12. **The biosphere plays a key role in climate processes, especially as part of the carbon and water cycles**. Very large amounts of carbon are naturally circulated and stored by terrestrial and marine ecosystems, through biologically-driven processes. Proportionately small changes in ocean and terrestrial carbon stores, caused by changes in the balance of natural exchange processes, can have climatically-significant implications for atmospheric CO_2 levels. Potential tipping points that may cause the rapid release of long-term carbon stores, e.g., as methane, are poorly understood. (*Section 3.3*)

Potential impacts on biodiversity of SRM geoengineering

13. **SRM, if effective in abating the magnitude of warming, would reduce several of the climate-change related impacts on biodiversity. Such techniques are also likely to have other, unintended impacts on biodiversity.** Assessment of the totality of those impacts is not straightforward: not only are the effects of specific SRM measures uncertain, but the outcome of the risk assessment will depend on the alternative, non-SRM strategy used as the 'control' for comparisons. Because climate change is projected to occur, climate-change scenarios provide relevant controls for assessing the risks and benefits of geoengineering, including the implications for biodiversity (*Chapter 4; Introduction*)

14. **Model-based analyses and evidence from volcanic eruptions indicate that uniform dimming of sunlight by 1–2% through an unspecified atmospheric SRM measure could, for most areas of the planet, reduce future temperature changes projected under unmitigated greenhouse gas emissions.** Overall, this would reduce several

of the adverse impacts of projected climate change on biodiversity. These benefits would vary regionally, and might be negligible or absent for some areas. However, only limited research has been done; uniform dimming is a theoretical concept and may not be achievable; and many uncertainties remain concerning the effects of different atmospheric SRM measures and their geo-spatial consequences, for the hydrological cycle as well as for heat distribution. It is therefore not yet possible to predict effects with any confidence. (*Section 4.1.1*)

15. **SRM would introduce a new dynamic between the heating effects of greenhouse gases and the cooling due to sunlight reduction**. There are no known palaeo-precedents for the radiative impacts of high greenhouse-gas concentrations to be balanced by reduced light quantity; thus the stability of that combination is uncertain, and it is not clear what specific environmental challenges an "SRM world" might present to individual species and ecosystems, either on a short-term or a long-term basis. (*Section 4.1.3*)

16. **The amount of anthropogenic CO_2 in the atmosphere is unaffected by SRM. Thus SRM would have little effect on ocean acidification and its associated impacts on marine biodiversity, nor the impacts (positive or negative) of elevated atmospheric CO_2 on terrestrial ecosystems.** Some indirect effects of SRM on atmospheric CO_2 are possible; e.g., if such techniques prevent the temperature-driven release of additional CO_2 from natural systems. Nevertheless, SRM cannot be considered as an alternative to emission mitigation or CDR in terms of avoiding detrimental effects on the (marine) biosphere. (*Section 4.1.4*)

17. **Rapid termination of SRM, that had been deployed for some time and masking a high degree of warming due to continued greenhouse-gas emissions, would almost certainly have large negative impacts on biodiversity and ecosystem services.** Those adverse consequences would be more severe than those resulting from gradual climate change, since the opportunity for adaptation, including through population migration, would be much reduced. (*Section 4.1.5*)

18. **Stratospheric aerosol injection, using sulphate particles, would affect the overall quantity and quality of light reaching the biosphere; have relatively minor effects on atmospheric acidity; and could also contribute to stratospheric ozone depletion.** All these unintended impacts have implications for biodiversity and ecosystem services. Stratospheric aerosols would decrease the amount of photosynthetically active radiation (PAR) reaching the Earth by 1–2%, but would increase the proportion of diffuse (as opposed to direct) radiation. This would be expected to affect community composition and structure. It may lead to an increase of gross primary productivity (GPP) in forest ecosystems whilst decreasing ocean productivity. However, the magnitude and nature of effects on biodiversity are likely to be mixed, and are currently not well understood. Increased ozone depletion, primarily in the polar regions, would cause an increase in the amount of ultra violet (UV) radiation reaching the Earth, although potentially offset by the UV scattering of the aerosol particles themselves. (*Section 4.2.1*)

19. **Cloud brightening is a more localised SRM proposal, with its application likely to be limited to specific ocean areas. The predictability of its climatic impacts is currently uncertain;** nevertheless regional cooling with associated atmospheric and oceanic perturbations are likely, with potentially significant effects on terrestrial and marine biodiversity and ecosystems. Unintended impacts could be positive as well as negative. (*Section 4.2.2*)

20. **Surface albedo changes would need to be deployed over very large land areas (sub-continental scale) or over much of the global ocean to have substantive effects on the global climate, with consequent impacts on ecosystems. Strong localized cooling could have a disruptive effect on regional weather patterns.** For instance, covering deserts with reflective material on a scale large enough to be effective in addressing the impacts of climate change would greatly reduce habitat availability for desert fauna and flora, as well as affecting its customary use. (*Section 4.2.3*)

Potential impacts on biodiversity of CDR geoengineering techniques

21. **Carbon dioxide removal techniques, if effective and feasible, would be expected to reduce the negative impacts on biodiversity of climate change and, in most cases, of ocean acidification.** By removing CO_2 from the atmosphere, CDR techniques reduce the concentration of the main causal agent of anthropogenic climate change,

Acidification of the surface ocean would also be reduced, but the effect of CDR on the ocean as a whole will depend on the location of long-term carbon storage. CDR methods are generally slow in affecting the atmospheric CO_2 concentration, with further substantial time-lags in the climatic benefits. Several of the techniques are of doubtful effectiveness, because of limited scalability. (*Section 5.1*)

22. **Individual CDR techniques may have significant unintended impacts on terrestrial, and/or ocean ecosystems, depending on the nature, scale and location of carbon capture and storage.** In some biologically-driven processes (ocean fertilization; afforestation, reforestation and soil carbon enhancement), carbon removal from the atmosphere and its subsequent storage are very closely linked. In these cases, impacts on biodiversity are likely to be limited to marine and terrestrial systems respectively. In other cases, the steps are discrete, and various combinations of capture and storage options are possible. Thus the carbon that is fixed within land biomass, for example, could be either: dumped in the ocean as crop residues; incorporated into the soil as charcoal; or used as fuel with the resultant CO_2 chemically removed at source and stored either in sub-surface reservoirs or the deep ocean. In these cases, each step will have different and additive potential impacts on biodiversity, and potentially separate impacts on marine and terrestrial environments. (*Section 5.1*)

23. **Ocean fertilization involves increased biological primary production with associated changes in phytoplankton community structure and species diversity, and implications for the wider food web.** Ocean fertilization may be achieved through the external addition of nutrients (Fe, N or P) or, possibly, by modifying ocean upwelling. If carried out on a climatically significant scale, changes may include an increased risk of harmful algal blooms, and increased benthic biomass. Potential effects on fisheries are uncertain. If Fe is used to stimulate primary production, increases in one region may be offset, to some degree, by decreases elsewhere. Ocean fertilization is expected to increase the midwater production of methane and nitrous oxide; if released to the atmosphere, these greenhouse gases would significantly reduce the effectiveness of the technique. Large-scale ocean fertilization would slow near-surface ocean acidification but increase acidification (and potential anoxia) in mid- and deep-water. The small-scale experiments conducted to date indicate that this is a technique of doubtful effectiveness for geoengineering purposes. (*Sections 5.2–5.3*)

24. **Enhanced weathering would involve large-scale mining and transport of carbonate and silicate rocks, and the spreading of solid or liquid materials on land or sea. The scale of impacts (that may be positive as well as negative) on terrestrial and coastal ecosystems will depend on the method and scale of implementation.** CO_2 is naturally removed from the atmosphere by the weathering (dissolution) of carbonate and silicate rocks. This process could be artificially accelerated by techniques that include releasing calcium carbonate or other dissolution products of alkaline minerals into the ocean or spreading abundant silicate minerals such as olivine over agricultural soils. In the ocean, this technique could, in theory, be used to counter ocean acidification; the practicalities have yet to be tested. (*Section 5.4*)

25. **The impacts on biodiversity of ecosystem carbon storage through afforestation, reforestation, or the enhancement of soil and wetland carbon depend on the method and scale of implementation.** If managed well, such approaches have the potential to increase or maintain biodiversity. Afforestation, reforestation and land-use change are already being promoted as climate change mitigation options, and are not considered by many to be geoengineering. Much guidance has already been developed, by the Convention on Biological Diversity and others, to maximize the biodiversity benefits of these approaches and minimize the disadvantages (e.g., planting assemblages of native species rather than exotic monocultures). (*Section 5.5*)

26. **Production of biomass for carbon sequestration on a scale large enough to be climatically significant is likely to either compete for land with food and other crops or involve large-scale land-use change, with impacts on biodiversity as well as greenhouse-gas emissions that may partially offset (or even exceed) the carbon sequestered as biomass.** The coupling of biomass production with its use as bioenergy in power stations equipped with effective carbon capture at source has the potential to be carbon negative. The net effects on biodiversity and greenhouse-gas emissions would depend on the approaches used. The storage or disposal of biomass may have impacts on biodiversity separate from those involved in its production. Removal of organic matter from agricultural

ecosystems is likely to have negative impacts on agricultural productivity and biodiversity, and may increase the need for fertilizer application to maintain soil fertility. (*Section 5.6.1*)

27. **The impacts of long-term storage of biochar (charcoal) in different soil types and under different environmental conditions are not well understood.** Important issues that need to be resolved include the stability of carbon in the biochar, and effects on soil water retention, N_2O release, crop yields, mycorrhizal fungi, soil microbial communities and detritivores. (*Section 5.6.2*)

28. **Ocean storage of terrestrial biomass (e.g., crop residues) is expected to have a negative impact on biodiversity.** The deposition of ballasted bales would likely have significant local physical impacts on the seabed due to the sheer mass of the material. Wider, long-term indirect effects of oxygen depletion and deep-water acidification could be regionally significant if there were cumulative deposition, and subsequent decomposition, of many gigatonnes of organic carbon. (*Section 5.6.3*)

29. **Chemical capture of CO_2 from ambient air would require a large amount of energy. Some proposed processes may also have high demand for freshwater, and potential risk of chemical pollution from sorbent manufacture; otherwise they would have relatively small direct impacts on biodiversity.** Removal of CO_2 from the ambient air (where its concentration is 0.04%) is much more difficult and energy intensive than its capture from flue gases of power stations (where levels are about 300 times higher, at ~12%); it is therefore unlikely to be viable without additional carbon-free energy sources. CO_2 extracted from the atmosphere would need to be stored either in the ocean or in sub-surface geological reservoirs with additional potential impacts; alternatively, it could be converted to carbonates and bicarbonates. (*Section 5.7.1*)

30. **Ocean CO_2 storage will necessarily alter the local chemical environment, with a high likelihood of biological effects.** Effects on mid-water and seafloor ecosystems are likely through the exposure of marine invertebrates, fish and microbes to pH reductions of 0.1–0.3 units. Near-total destruction of deep seafloor organisms can be expected if lakes of liquid CO_2 are created. Chronic effects on ecosystems of direct CO_2 injection into the ocean over large ocean areas and long time scales have not yet been studied, and the capacity of ecosystems to compensate or adjust to such CO_2 induced shifts is unknown. (*Section 5.7.2*)

31. **Leakage from CO_2 stored in sub-seafloor geological reservoirs, though considered unlikely if sites are well selected, would have biodiversity implications for benthic fauna on a local scale.** CO_2 storage in sub-seafloor geological reservoirs is already being implemented at pilot-scale levels. Its effects on lithospheric microbial communities seem likely to be severe, but have not been studied (*Section 5.7.2*)

Social, economic, cultural and ethical considerations of climate-related geoengineering

32. **The consideration of geoengineering as a potential option raises many socio-economic, cultural and ethical issues, regardless of the specific geoengineering approach.** Such issues include global justice, the unequal spatial distribution of impacts and benefits, and intergenerational equity. Confidence in technological solutions, or alternatively risk-aversion, may be both highly differentiated across social groups and highly dynamic. (*Section 6.3*)

33. **Humanity is now the major force altering the planetary environment**. This has important repercussions, not only because it forces society to consider multiple and interacting global environmental changes, but also because it requires difficult discussions on whether it is desirable to move from (1) unintentional modifications of the Earth system, with implications that until a few decades ago we were unaware of; to (2) attempts to reach international agreement to reduce the actions causing the damage; and finally to (3) consideration of actions to deliberately modify global cycles and systems, to try to avoid the worst outcomes of climate change. (*Section 6.3.1*)

34. **The 'moral hazard' of geoengineering is that it is perceived as a technological fallback, possibly reducing effort on mitigation.** However, the opposite may also occur: when there is wider knowledge on geoengineering, and its limitations and uncertainties, increased policy effort might be directed at emission reductions. Other ethical considerations include the question of whether it is acceptable to remediate one pollutant by introducing another. (*Section 6.3.1*)

35. **In addition to limiting the undesirable impacts of climate change, the large-scale application of geoengineering techniques is near-certain to involve unintended side effects and increase socio-political tensions.** While technological innovation has helped to transform societies and improve the quality of life in many ways, it has not always done so in a sustainable manner. Failures to respond to early warnings of unintended consequences of particular technologies have been documented, and it has been questioned whether technological approaches are the best option to address problems created by the application of earlier technologies. (*Section 6.3.2*)

36. **An additional issue is the possibility of technological, political and social "lock in"**, whereby the development of geoengineering technologies might also result in the emergence of vested interests and increasing social momentum. It has been argued that this path of dependency could make deployment more likely, and/or limit the reversibility of geoengineering techniques. To minimize such risks, research to assess the safety, feasibility and cost-effectiveness of geoengineering must be open-minded and objective, without prejudice to the desirability or otherwise of geoengineering implementation. (*Section 6.3.2*)

37. **Geoengineering raises a number of questions regarding the distribution of resources and impacts within and among societies and across time.** Access to natural resources is needed for some geoengineering techniques. Competition for limited resources can be expected to increase if land-based CDR techniques emerge as a competing activity for land, water and energy use. The distribution of impacts (both positive and negative) of SRM geoengineering is unlikely to be uniform—neither are the impacts of climate change itself. (*Section 6.3.4*)

38. **In cases in which geoengineering experimentation or interventions might have transboundary effects or impacts on areas beyond national jurisdiction, geopolitical tensions could arise** regardless of causation of actual negative impacts, especially in the absence of international agreement. As with climate change, geoengineering could also entail intergenerational issues: future generations might be faced with the need to maintain geoengineering measures in order to avoid termination effects that might be mostly caused by emissions from several decades earlier. (*Section 6.3.5*)

Synthesis

39. **The deployment of geoengineering techniques, if feasible and effective, could reduce the magnitude of climate change and its impacts on biodiversity. At the same time, most geoengineering techniques are likely to have unintended impacts on biodiversity, particularly when deployed at a climatically-significant scale, together with significant risks and uncertainties.** The nature of the unintended effects, and their spatial distribution, will vary among techniques; overall outcomes are difficult to predict. For several techniques, there would increases in land use change, and there could also be an increase in other drivers of biodiversity loss. (*Section 7.1*)

40. **There are many areas where knowledge is still very limited**. These include: (1) the overall effectiveness of some of the techniques, based on realistic estimates of their scalability; (2) how the proposed geoengineering techniques can be expected to affect weather and climate regionally and globally; (3) how biodiversity, ecosystems and their services are likely to respond to geoengineered changes in climate; (4) the unintended effects of different proposed geoengineering techniques on biodiversity; and (5) the social and economic implications, particularly with regard to geo-political acceptability, governance and the potential need for international compensation in the event of there being 'winners and losers'. Targeted research could help fill these gaps (*Section 7.3*)

41. **There is very limited understanding among stakeholders of geoengineering concepts, techniques and their potential positive and negative impacts on biodiversity.** Not only is much less information available on geoengineering than for climate change, but there has been little consideration of the issues by indigenous peoples, local communities and marginalized groups, especially in developing countries. Since these communities play a major role in actively managing ecosystems that deliver key climatic services, the lack of knowledge of their perspective is a major gap that requires further attention (*Section 7.3*)

CHAPTER 1

MANDATE, CONTEXT AND SCOPE OF WORK

1.1 MANDATE

At the tenth meeting of the Conference of the Parties (COP-10) to the Convention on Biological Diversity (CBD), Parties adopted a decision on climate-related geoengineering[2] and its impacts on the achievement of the objectives of the CBD as part of its decision on biodiversity and climate change.

Specifically, in paragraph 8 of decision X/33, the Conference of the Parties:

> Invite[d] Parties and other Governments, according to national circumstances and priorities, as well as relevant organizations and processes, to consider the guidance below on ways to conserve, sustainably use and restore biodiversity and ecosystem services while contributing to climate change mitigation and adaptation to (….)
>
> (w) Ensure, in line and consistent with decision IX/16 C, on ocean fertilization and biodiversity and climate change, in the absence of science based, global, transparent and effective control and regulatory mechanisms for geo-engineering, and in accordance with the precautionary approach and Article 14 of the Convention, that no climate-related geo-engineering activities[3] that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting in accordance with Article 3 of the Convention, and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment;
>
> (x) Make sure that ocean fertilization activities are addressed in accordance with decision IX/16 C, acknowledging the work of the London Convention/London Protocol."

Further, in paragraph 9 of the same decision, the Conference of the Parties:

> Request[ed] the Executive Secretary to:
>
> (l) Compile and synthesize available scientific information, and views and experiences of indigenous and local communities and other stakeholders, on the possible impacts of geo-engineering techniques on biodiversity and associated social, economic and cultural considerations, and options on definitions and understandings of climate-related geo-engineering relevant to the Convention on Biological Diversity and make it available for consideration at a meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) prior to the eleventh meeting of the Conference of the Parties; and
>
> (m) Taking into account the possible need for science based global, transparent and effective control and regulatory mechanisms, subject to the availability of financial resources, undertake a study on gaps in such existing mechanisms for climate-related geo-engineering relevant to the Convention on Biological Diversity, bearing in mind that such mechanisms may not be best placed under the Convention on Biological Diversity, for consideration by SBSTTA prior to a future meeting of the Conference of the Parties and to communicate the results to relevant organizations.

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[2] To match wider usage, "geoengineering" is unhyphenated in this report (except where quoting previous CBD documents).

[3] "Without prejudice to future deliberations on the definition of geo-engineering activities, understanding that any technologies that deliberately reduce solar insolation or increase carbon sequestration from the atmosphere on a large scale that may affect biodiversity (excluding carbon capture and storage from fossil fuels when it captures carbon dioxide before it is released into the atmosphere) should be considered as forms of geo-engineering which are relevant to the Convention on Biological Diversity until a more precise definition can be developed. It is noted that solar insolation is defined as a measure of solar radiation energy received on a given surface area in a given hour and that carbon sequestration is defined as the process of increasing the carbon content of a reservoir/pool other than the atmosphere."

Accordingly, this report has been prepared by a group of experts[4] and the CBD Secretariat following discussions of a liaison group convened thanks to financial support from the Government of the United Kingdom of Great Britain and Northern Ireland, and the Government of Norway. The report compiles and synthesizes available scientific information on the possible impacts of geoengineering techniques on biodiversity, including preliminary information on associated social, economic and cultural considerations. Related legal and regulatory matters are treated in a separate study (see Part II of this volume). In addition, a complementary consultation process was carried out by the CBD to seek the views of indigenous and local communities on the possible impacts of geoengineering techniques on biodiversity and associated social, economic and cultural considerations.

The study on the impacts of climate-related geoengineering on biodiversity and on the regulatory framework for geoengineering were presented to the sixteenth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (in documents UNEP/CBD/SBSTTA/16/INF/28 and UNEP/CBD/SBSTTA/16/INF/29, respectively). The present volume comprises the edited versions of these studies. After being presented to SBSTTA, a limited number of additional references have been reviewed; these are identified in the footnotes. In addition, supplementary information on definitions of climate-related geoengineering is provided in Annex II of Part I of this volume, as well as in Information Note UNEP/CBD/COP/11/INF/26, prepared for the eleventh meeting of the Conference of the Parties.

1.2 CONTEXT FOR THE CONSIDERATION OF POTENTIAL IMPACTS OF GEOENGINEERING ON BIODIVERSITY

Biodiversity, ecosystems and their services (provisioning, regulating, cultural and supporting) are critical to human well-being. They are being directly and adversely affected by habitat conversion, over-exploitation, invasive species, pollution and climate change. These in turn are driven by demographic, economic, technological, socio-political and cultural changes (Figure 1.1). Protection of biodiversity and ecosystems means that we urgently need to address the direct drivers of change, as well as giving further consideration to indirect drivers.

Climate change is becoming increasingly important as a driver of biodiversity loss and the degradation of ecosystems and their services. It is best addressed by a rapid and major reduction in global greenhouse-gas emissions, requiring a transition to a low-carbon economy through changes in how energy is produced and used, and in the way the environment is managed. However, international commitment is currently lacking to reduce future greenhouse-gas emissions at the scale required, with two main consequences. First, serious and possibly irreversible climate disruption is now much more likely within the next 50–100 years;[5,6] second, to potentially avoid that outcome, increasing attention has been recently given to a range of climate geoengineering techniques, as a different, and as yet unproven, strategy. The early motivation for exploring such concepts was, at least partly, that they might offer an alternative to strong emission reductions; however, geoengineering is now primarily considered by its proponents as an additional action, complementing other efforts to limit the magnitude of human-induced climate change.

Assessment of the impact of geoengineering techniques on biodiversity—the mandate for this report—requires an evaluation of their potential for both positive and negative effects, in the context of climate changes that are already occurring and their projected trajectories. Future climate conditions will be largely determined by future anthropogenic greenhouse-gas emissions, in turn largely determined by future mitigation policies agreed at the global level. Since global greenhouse-gas emissions are currently continuing to increase at a rapid rate, the main comparisons made here are in relation to a 2–3 fold increase in atmospheric greenhouse gas concentrations compared to pre-industrial levels, with associated projected increases in average global surface temperature of

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[4] Annex III provides information on expert group members and others who contributed to this report.

[5] Anderson & Bows (2011).

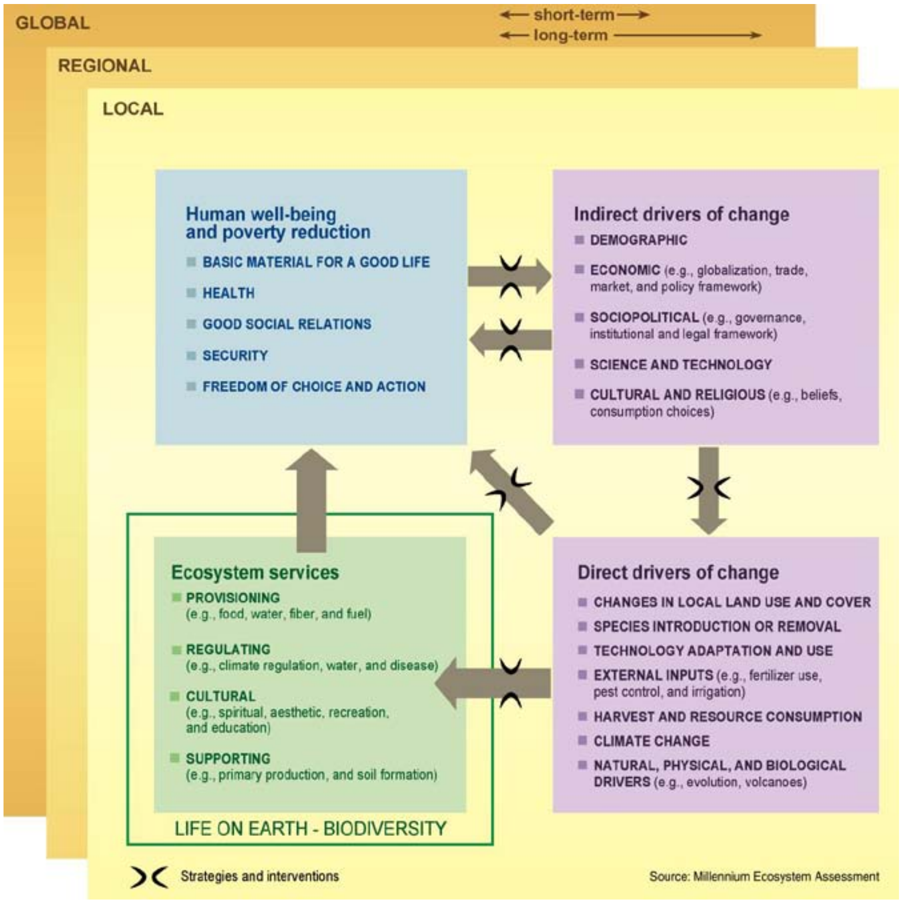
[6] Myhrvold & Caldeira (2012).

around 3°C–5°C by 2100. The consequences for biodiversity of such climate change scenarios are summarised in Chapter 3 of this report. Other climate projections, based on other emission pathways, are also possible.

The scale and nature of potential geoengineering impacts on biodiversity will necessarily depend on the 'baseline' comparison made. Such impacts will also closely depend on the effectiveness, feasibility and implementation scenario for the specific techniques under consideration. The timing of deployment may also be important. Thus the impacts for a potentially rapid-acting geoengineering technique might vary according to whether it is deployed in the near future, i.e. under 'present day' climatic conditions, or in (say) 50 or 100 years time, and whether deployment is made slowly or rapidly.

The CBD generic guidance on impact assessment, discussed below, provided a wider framework for this study.

Figure 1.1. Linkage between biodiversity, ecosystem services, human well-being and direct and indirect drivers of change.[7]



Source: Millennium Ecosystem Assessment

Climate change is one of several drivers of changes to biodiversity and ecosystem services, operating over local, regional and global spatial scales, and short-term and long-term timescales. Any proposed geoengineering actions are superimposed on this framework.

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[7] Millennium Ecosystem Assessment (2005a).

1.3 RELEVANT GUIDANCE UNDER THE CONVENTION ON BIOLOGICAL DIVERSITY

Decision X/33 adopted by the Conference of the Parties at its tenth meeting, in paragraph 8(w), refers to the precautionary approach and to Article 14 of the Convention.

The precautionary approach contained in Principle 15 of the Rio Declaration on Environment and Development is an approach to uncertainty, and provides for action to avoid serious or irreversible environmental harm in advance of scientific certainty of such harm. In the context of the Convention, it is referred to in numerous decisions and pieces of guidance, including the Strategic Plan for Biodiversity 2011–2020; the ecosystem approach; the voluntary guidelines on biodiversity-inclusive impact assessment; the Addis Ababa principles and guidelines for the sustainable use of biodiversity; the guiding principles for the prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species; the programme of work on marine and coastal biological diversity; the proposals for the design and implementation of incentive measures; the Cartagena Protocol on Biosafety; agricultural biodiversity in the context of Genetic Use Restriction Technologies; and forest biodiversity with regard to genetically modified trees.

In decision X/33, the Conference of the Parties calls for precaution in the absence of an adequate scientific basis on which to justify geoengineering activities and appropriate consideration of the associated risks for the environment and biodiversity, and associated social, economic and cultural impacts. Further consideration of the precautionary approach is provided in the study on the regulatory framework of climate-related geoengineering relevant to the Convention on Biological Diversity[8] available in Part II of this volume.

Article 14 of the Convention includes provisions on environmental impact assessment of proposed projects as well as strategic environmental assessment of programmes and policies that are likely to have significant adverse impacts on biodiversity. To assist Parties in this area, a set of voluntary guidelines were developed:

- Voluntary guidelines for biodiversity-inclusive impact assessment, adopted through decision VIII/28;
- Additional guidance on biodiversity-inclusive Strategic Environmental Assessment, endorsed through decision VIII/28;
- Akwé: Kon voluntary guidelines for the conduct of cultural, environmental and social impact assessment regarding developments proposed to take place on, or which are likely to impact on, sacred sites and on lands and waters traditionally occupied or used by indigenous and local communities, adopted through decision VII/16;
- Tkarihwaié:ri code of ethical conduct to ensure respect for the cultural and intellectual heritage of indigenous and local communities; and
- Draft voluntary guidelines for the consideration of biodiversity in environmental impact assessments (EIAs) and strategic environmental assessments (SEAs) in marine and coastal areas, including those beyond national jurisdiction.

Article 14 includes further provisions for activities which are likely to have significant adverse effects on the biodiversity of other States or areas beyond the limits of national jurisdiction. Given the large scale of geoengineering interventions, the need for notification, exchange of information and consultation as well as readiness for emergency responses called for in this provision would likely apply to the originator of such geoengineering activities. To date, the Convention has not developed further guidance in this area. Issues of liability and redress, including restoration and compensation for damage to biodiversity caused by activities under the jurisdiction of other States, are still under debate.

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[8] Bodle et al. (2012).

The guidelines developed under Article 14 provide useful elements that can inform analysis of the impacts of geoengineering on biodiversity, both at the level of specific activities and at the level of broader assessments. The assessment frameworks of other bodies may also be relevant; e.g., as developed by the London Convention/London Protocol, and the more general requirement of Article 206 of the UN Convention on Law of the Sea (UNCLOS) requiring States to assess the potential effects of activities taking place at sea. Given the broad scope of the present study, the CBD guidelines for strategic environmental assessment would seem particularly useful. Those guidelines recommend consideration of the following:

i) How the proposed techniques are expected to impact on the various components and levels of biodiversity and across ecosystem types, and the implications for ecosystem services, and for the people who depend on such services;

ii) How the proposed techniques are expected to affect the key direct and indirect drivers of biodiversity change.

Where such information is available, Chapters 3, 4 and 5 provide an assessment of how specific geoengineering techniques might affect the various components of biodiversity for a range of ecosystems, and the implications of those impacts for ecosystem services. However, in many cases, detailed information is lacking, particularly with regard to potential impacts on biodiversity at the genetic level.

At a global scale, the largest driver of terrestrial biodiversity loss has been, and continues to be, land use change. In the ocean, over-exploitation has also been a major cause of biodiversity loss and food-web perturbations. Such changes, on land and in the ocean, can have climatic implications, through effects on greenhouse gases fluxes, and climate change itself is rapidly increasing in importance as a driver of biodiversity loss. However, the importance of different drivers of loss varies among ecosystems and from region to region.[9,10] An overview of the potential impacts of geoengineering and of alternative actions on the drivers of biodiversity loss is provided in Chapter 7.

The CBD guidelines on impacts assessment also highlight, as key principles, stakeholder involvement, transparency and good quality information.

Since good quality information on many aspects of geoengineering is still very limited (and may not be readily available to all stakeholders),[11] this study should be regarded as a first step in assessing its potential impacts on biodiversity. Key knowledge gaps include: i) the overall effectiveness of many of the geoengineering techniques, based on realistic estimates of their scalability; ii) how the proposed techniques affect weather and climate regionally and globally; iii) how biodiversity, ecosystems and their services might respond to geo-engineered changes in climate; iv) the unintended effects of geoengineering on biodiversity; and v) the social and economic implications of deliberate climate manipulations, in the context of changes to biodiversity and ecosystem services.

With a view to encouraging involvement of stakeholders, a number of consultations have been held[12] and drafts of this report were made available for two rounds of peer review. It is nevertheless recognized that the opportunities for full and effective participation of stakeholders have been limited. To some extent, this is an inevitable consequence of the relative novelty of the issues under discussion. Some indigenous and local communities and stakeholder

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[9] Millennium Ecosystem Assessment (2005a).

[10] Secretariat of the Convention on Biological Diversity (2010).

[11] The number of scientific publications relating to geoeengineering is currently increasing at a rapid rate, with associated increases in information accessibility. Nevertheless, it is recognised that much of the relevant literature may not be readily available to everyone with interests.

[12] Consultations have involved: 1) Mini-workshop on biodiversity and climate-related geoengineering, 10 June 2011, Bonn, Germany; 2) Liaison Group Meeting on Climate-Related Geoengineering as it relates to the Convention on Biological Diversity, 29 June–1 July, 2011, London, UK; 3) Informal Dialogue with Indigenous Peoples and Local Communities on Biodiversity Aspects of Geo-engineering the Climate; side event during the Seventh Meeting of the Ad Hoc Open-ended Working Group on Article 8(j) and Related Provisions, 2 November 2011, Montreal, Canada; and 4) Consultation on Climate-related Geo-engineering relevant to the Convention on Biological Diversity; side event during the fifteenth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA 15), 9 November 2011, Montreal, Canada.

groups do not consider themselves sufficiently prepared to contribute to such an effort in a full and effective manner. It is hoped that this report, together with related efforts,[13] will help to expand information and understanding on geoengineering issues.

1.4 SCOPE OF TECHNIQUES EXAMINED IN THIS STUDY

There is a range of views as to what should be considered as climate-related geoengineering relevant to the CBD. Approaches may involve both hardware- or technology-based engineering as well as 'natural' processes[14] that might have a climatically-significant impact at the global scale, depending on the spatial and temporal scale of interventions. Several approaches that may be considered as geoengineering can also be considered as climate change mitigation and/or adaptation; for example, some ecosystem restoration activities.

This study defines geoengineering in a relatively inclusive way, without prejudice to any definition of the term that may subsequently be agreed under the Convention or elsewhere, and recognizing that there is not yet scientific consensus on the scope of the term. Nevertheless, the definition used in this study is considered consistent with COP 10 decision X/33, paragraph 8(w). In particular, it excludes carbon capture from fossil fuels (i.e, preventing the release of CO_2 into the atmosphere), whilst recognizing that the carbon storage components of that process are also shared by other climate remediation techniques that are considered as geoengineering and are therefore included.

For some proposed techniques, there is insufficient information to make an evidence-based assessment of potential impacts. The scope of the study is therefore limited, and should not be taken as a comprehensive analysis of all matters related to geoengineering.

1.5 STRUCTURE OF THE STUDY

Chapter 2 considers definitions of geoengineering for the purposes of this study, based on a compilation and summary of existing definitions (given in Annex I). Chapter 2 also provides an overview of the range of techniques here considered as geoengineering.

Chapter 3 provides a summary of projected climate change and the related phenomenon of ocean acidification under commonly-used emission scenarios, together with the expected impacts of those changes on biodiversity. Such information provides the necessary context for the assessment of the impacts of geoengineering, as discussed in Section 1.2 above.

The potential intended and unintended impacts on biodiversity and ecosystem services (where known) of different geoengineering techniques are reviewed in Chapters 4 and 5, focussing on the potential impacts of sunlight reflection methods (SRM) and carbon dioxide removal (CDR) techniques respectively. Such impacts, that may be positive or negative, are considered for deployment scales intended to reduce solar radiation sufficiently to have a substantive effect on global warming, or to achieve the long-term removal of a climatically significant amount of CO_2 from the atmosphere. For smaller-scale deployments, including local trials that might be made for research purposes, the magnitude of effects will necessarily be less, and impacts might either be undetectable or insignificant for biodiversity.

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[13] Online discussion on indigenous peoples and local communities and geoengineering, Climate Frontlines—Global forum for indigenous peoples, small islands and vulnerable communities; www.climatefrontlines.org.

[14] The distinction between technological and natural is not clear-cut in the geoengineering context, Thus most proposed geoengineeering techniques involve enhancement or simulation of naturally-occurring processes that already play a major role in climate dynamics, and that are naturally variable on decadal to geological timescales. Furthermore, many natural processes relevant to geoengineering are already subject to significant human manipulation and perturbation, involving technology (= applied science) to some degree.

Chapter 6 gives a preliminary review of possible social, economic and cultural impacts associated with the impacts of geoengineering on biodiversity, whilst Chapter 7 presents some general conclusions.

1.6 KEY SOURCES OF INFORMATION

The study builds on past work on geoengineering, climate change and biodiversity, including information available from the Intergovernmental Panel on Climate Change;[15] the Royal Society;[16] the 2011 workshop 'Ecosystem impacts of geoengineering' held by the International Geosphere-Biosphere Programme and associated publication;[17] the Technology Assessment of Climate Engineering by the US Government Accountability Office;[18] relevant CBD Technical Series reports;[19,20] and a range of topic-specific scientific publications, as individually cited. Nevertheless, it should be noted that the peer-reviewed literature on geoengineering is mostly on its intended, climatic effects. Information on unintended impacts (of greatest relevance here) is limited, and mostly of a theoretical nature; many uncertainties remain.

While this study is primarily based on recent literature, the concept of large-scale, deliberate climate modification is not new.[21,22] The main focus of ideas developed in the 1950s and 1960s was, however, to increase, not decrease, temperatures (particularly in the Arctic), or increase rainfall on a regional basis. The first proposals to counteract human-induced changes in the climate (then given the name geoengineering) date from the 1970s. Historical examples of climate control proposals are given in Table 1 below, with a more extensive listing available in the report of the U.S. Government Accountability Office.[23]

Table 1: Historical examples of proposals for regional and global-scale climate modifications and control.

Date	Author	Proposal
1877	N. Shaler	Re-routing the Pacific's warm Kuroshio Current through the Bering Strait to raise Arctic temperatures by around 15°C
1958	M. Gorodsky and V. Cherenkov	Placing metallic potassium particles into the Arctic stratosphere with the aim of thawing permafrost in Russia, Canada and Alaska, and melting polar ice
1960s	M. Budyko and others	Melting of Arctic sea-ice by adding soot to its surface
1977	C. Marchetti	Disposal of liquid CO_2 to the deep ocean, via the Mediterranean outflow
1990	J. Martin	Adding iron to the ocean to enhance ocean CO_2 uptake
1992	US National Academy of Science Committee on Science, Engineering, and Public Policy	Adding aerosols to the stratosphere to increase the reflection of sunlight

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[15] IPCC (2007a); IPCC (2005a); and IPCC (2000b). The IPCC Fifth Assessment Report (AR5) is currently in preparation.

[16] The Royal Society (2009).

[17] Russell et al. (2012).

[18] U.S. Government Accountability Office (2011).

[19] Secretariat of the Convention on Biological Diversity (2009c).

[20] Secretariat of the Convention on Biological Diversity (2009a).

[21] Lamb (1977).

[22] Fleming (2010).

[23] U.S. Government Accountability Office (2011).

More recently, several professional societies[24] have argued that geoengineering might need to be taken seriously, and have called for further research in this area. At the same time, there has also been considerable public discussion and enunciation of social, economic, cultural and ethical considerations. Concerns have been raised[25] by civil society organizations, indigenous communities and others, and have featured in popular books and in the media. Some reference to this debate is included in Chapter 6 of this report, in the context of CBD-relevant issues. An assessment of the regulation of geoengineering is covered in a separate study[26] (see Part II of this volume), as has already been noted; the governance of research on SRM has recently been reviewed;[27] and an Expert Meeting[28] of the Intergovernmental Panel on Climate Change has considered the main issues that will be given more detailed consideration in the IPCC's Fifth Assessment Report.

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[24] For example, the American Meteorological Society, the American Geophysical Union and the UK-based Institute of Physics.

[25] For example: ETC Group (2010).

[26] Bodle et al. (2012).

[27] Solar Radiation Management Governance Initiative (SRMGI) (2011).

[28] IPCC (2012).

CHAPTER 2

DEFINITION AND FEATURES OF GEOENGINEERING APPROACHES AND TECHNIQUES

2.1 DEFINITION OF CLIMATE-RELATED GEOENGINEERING

The term geoengineering has been defined and used in different ways by different authors and bodies (Annex I). Many of the existing definitions contain common elements but within different formulations. A starting point is the interim definition developed by the tenth Conference of the Parties to the CBD:[29]

> "Without prejudice to future deliberations on the definition of geo-engineering activities, understanding that any technologies that deliberately reduce solar insolation or increase carbon sequestration from the atmosphere on a large scale that may affect biodiversity (excluding carbon capture and storage from fossil fuels when it captures carbon dioxide before it is released into the atmosphere) should be considered as forms of geo-engineering which are relevant to the Convention on Biological Diversity until a more precise definition can be developed. It is noted that solar insolation is defined as a measure of solar radiation energy received on a given surface area in a given hour and that carbon sequestration is defined as the process of increasing the carbon content of a reservoir/pool other than the atmosphere."

Based on the above, and consistent with most of the definitions listed in Annex I, this study defines climate-related geoengineering as:

> A deliberate intervention in the planetary environment of a nature and scale intended to counteract anthropogenic climate change and its impacts.

This definition is broad in scope, yet includes important criteria to clarify its intended meaning in an objective and consistent way. Key features of this definition are that the interventions are deliberate, that their purpose is to address human-driven climate change,[30] and that the implementation of the proposed technique is on a scale large enough to have a significant counter-acting effect; i.e. reducing or potentially reversing human-induced temperature increases and associated changes. The definition includes, but is not necessarily limited to, sunlight reflection methods, (SRM, also known as solar radiation management), and carbon dioxide removal (CDR) techniques, also known as negative emission methods or negative emission techniques.[31]

Unlike some definitions of geoengineering, the above definition includes the potential removal of greenhouse gases other than CO_2, such as methane;[32] it also includes the possibility that cooling might be achieved by enhancing the loss of long-wave radiation from the Earth, through cirrus-cloud manipulations.[33] However both those approaches are currently speculative, with little or no peer-reviewed discussion of their methods and potential impacts: they are therefore not further examined in this report, nor are others of a similar, very preliminary, status.

The above definition excludes "conventional" carbon capture and storage (CCS) from fossil fuels, since that involves the capture of CO_2 before it is released into the atmosphere. Thus that form of CCS reduces the problem of greenhouse-gas emissions, rather than counter-acting either their presence in the atmosphere or their climatic

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[29] Footnote to CBD decision X/33, paragraph 8(w).

[30] Geoengineering could also be defined with non-climatic objectives; for example, to counteract ozone depletion or specifically to address ocean acidification.

[31] McLaren (2011).

[32] Boucher & Folberth (2010).

[33] Mitchell et al. (2011).

effects. Nevertheless, all CDR techniques necessarily involve carbon capture, by either biological or chemical means, and some may involve the same or similar processes of managed carbon storage as used for at-source CCS.[34]

As noted in Chapter 1, there is currently a range of views concerning whether geoengineering should include or exclude a number of activities involving bio-energy, afforestation and reforestation, and changing land management practices. If such techniques are deployed at sufficient scale to significantly counteract climate change, and are implemented with that intention, then their inclusion within the definition of geoengineering seems logically justified, notwithstanding that such measures are already being used for climate change mitigation and other purposes, and that they may involve minimal use of new technologies.[35]

There is also a range of views concerning the inclusion or exclusion of weather modification technologies, such as cloud seeding, within the definition of geoengineering. Proponents of inclusion argue that the history, intention, institutions, technologies themselves, and impacts are closely related to geoengineering. Nevertheless, unless they can be scaled-up sufficiently to achieve (beneficial) climatic effects at the global level, they are considered out of scope for the current study.[36]

The above definition is broad in scope, suitable for broad-based analysis such as this study. More specific definitions that are narrower in scope and allow for more precise legal interpretations may be required for some purposes, such as providing policy advice and regulation. Such definitions might be confined to specific techniques, classes of techniques, or environments, and the distinction between regional and global-scale effects may be less important. For example, definitions relating to SRM techniques or CDR techniques that have the potential for significant negative transboundary implications, or the potential to directly affect all or part of the global commons in a negative way, may warrant separate treatment.

Supplementary information on definitions of climate-related geoengineering is provided in Annex II of Part I of this volume, as well as in Information Note UNEP/CBD/COP/11/INF/26, prepared for the eleventh meeting of the Conference of the Parties.

2.2 FEATURES OF PROPOSED GEOENGINEERING TECHNIQUES

Based on the definition of geoengineering given above, this study considers a range of techniques and their potential impacts. They are grouped into sunlight reflection methods (SRM) and carbon dioxide removal (CDR) methods, whilst recognising that other approaches might also be possible.

When considering the potential effectiveness and impacts of such approaches, the report examines the spatial and temporal scales at which the approaches would have to operate in order to offset the projected changes arising from future anthropogenic emissions of greenhouse gases. These projected changes are based on scenarios for anthropogenic emissions of greenhouse gases developed by the Intergovernmental Panel on Climate Change (IPCC) as Special Report Emissions Scenarios (SRES) (see Chapter 3, section 3.1). More recently, alternative scenarios (Representative Concentration Pathways, RCPs) have been developed by IPCC,[37] but these have not yet been widely used in the literature.

A conceptual overview showing how SRM and CDR techniques exert their intended and unintended effects is given in Figure 2.1.

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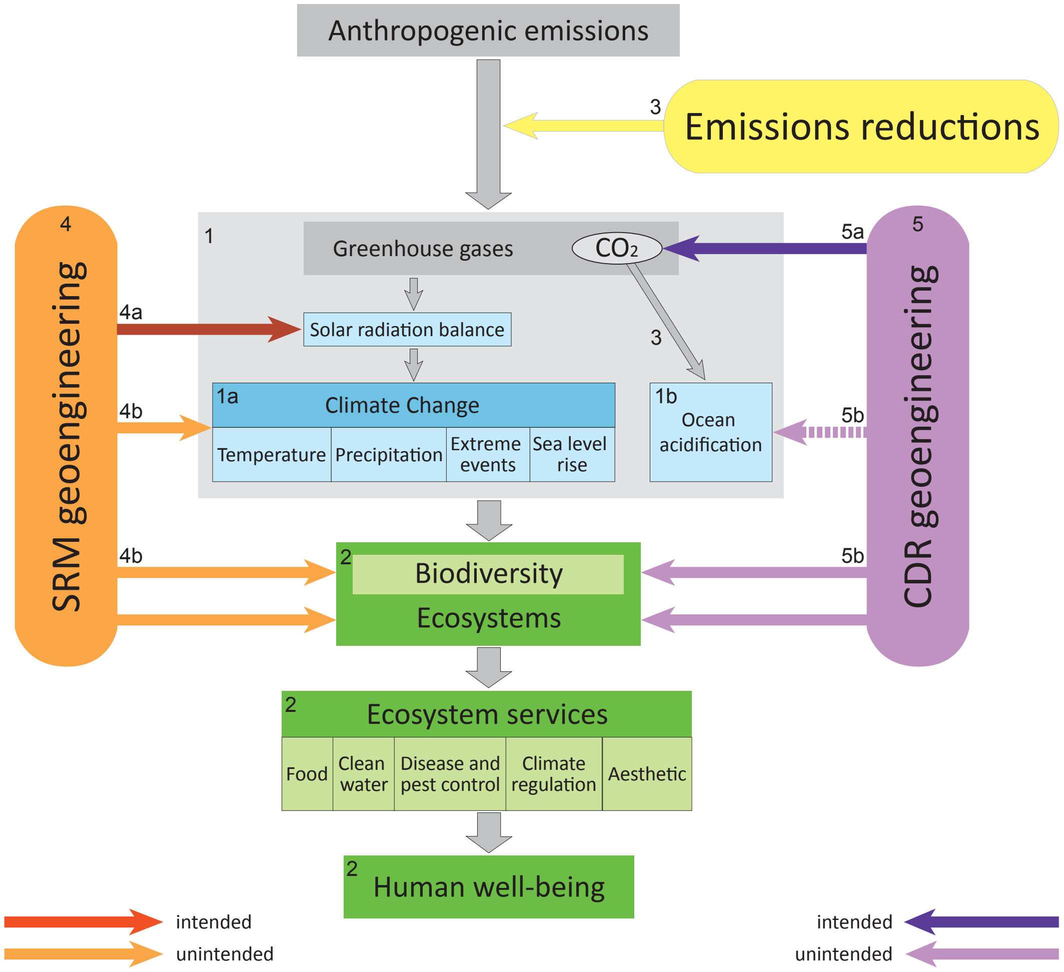
[34] Most CCS techniques involve the storage of CO_2 in depleted hydrocarbon reservoirs and saline aquifers. However, it has also been proposed that liquid CO_2 could be injected into basaltic rocks, to form calcium and magnesium carbonates—as discussed in Chapter 5.

[35] The expert group considered defining geoengineering on the basis that (novel) technologies were necessarily involved. However, that did not provide a workable definition, since most human activities (including agriculture and forestry) are, to some degree, technological, and ‘novel’ did not unambiguously define what was in scope.

[36] A similar conclusion (to exclude weather modification) was made by the UK House of Commons Science and Technology Committee (2010).

[37] Moss et al. (2010).

Figure 2.1. Conceptual overview of how greenhouse-gas emission reductions and the two main groups of geoengineering techniques may affect the climate system, ocean acidification, biodiversity, ecosystem services and human well-being.



Anthropogenic emissions of greenhouse gases are influencing the balance of solar radiation entering and leaving the atmosphere resulting in global warming and associated climate change phenomena such as changes in temperature, precipitation, sea level rise and increased incidence of extreme events (1a). In addition, increased atmospheric CO_2 *concentrations leads directly to increased ocean acidification (1b). Climate change and ocean acidification affect biodiversity and ecosystem functioning, with a range of mostly negative impacts on human well-being (2). The impacts of climate change on biodiversity are examined in Chapter 3 of this study. Climate change and ocean acidification are best mitigated by reductions in greenhouse-gas emissions (3). Given the insufficient action to date to reduce such emissions, the use of geoengineering techniques has been suggested to limit the magnitude of human-induced climate change and or its impacts. There are two major broad groups of approaches, as described in Chapter 2 of this study:*

Sunlight reflection methods (SRM) aim to counteract warming by reducing the incidence and subsequent absorption of incoming solar radiation (4a).

Carbon dioxide removal (CDR) techniques are aimed at removing CO_2 *from the atmosphere (5a).*

However, both groups of techniques are likely to have unintended effects (4b and 5b) with potentially negative impacts on biodiversity. These impacts are examined in Chapters 4 and 5 of this study. Note that this diagram has been simplified for clarity; for example, the feedback linkages between biodiversity, ecosystems and climate are not shown.

2.2.1 Sunlight reflection methods (SRM)

Description

Sunlight reflection methods (SRM, also known as solar radiation management) would counteract warming by reducing the incidence and subsequent absorption of incoming solar (short-wave) radiation, often referred to as insolation. This would be achieved by making the Earth more reflective, i.e. increasing the planetary albedo, or using space-based devices to divert incoming solar energy.[38] The resultant cooling effect would counteract the warming influence of increasing greenhouse gases. It may be possible to apply some of these techniques so that their effects are greatest within particular regions or latitude bands, with lesser effects elsewhere.

SRM is expected to rapidly have an effect on climate if deployed at the appropriate scale. However, SRM does not treat the root cause of anthropogenic climate change, arising from increasing greenhouse gas concentrations in the atmosphere, nor would it directly address ocean acidification or the CO_2 fertilization effect.[39,40] Moreover, it would introduce a new dynamic between the warming effects of greenhouse gases and the cooling effects of SRM with uncertain climatic implications, especially at the regional scale.

Proposed SRM techniques considered in this document comprise four main categories:

i) *Space-based approaches:* reducing the amount of solar energy reaching Earth by positioning sun-shields in space with the aim of reflecting or deflecting solar radiation;

ii) *Changes in stratospheric aerosols*: injecting sulphates or other types of particles into the upper atmosphere, with the aim of increasing the scattering of sunlight back to space;[41]

iii) *Increases in cloud reflectivity:* increasing the concentration of cloud-condensation nuclei in the lower atmosphere, particularly over ocean areas, thereby whitening clouds with the aim of increasing the reflection of solar radiation;

iv) *Increases in surface albedo:* modifying land or ocean surfaces, with the aim of reflecting more solar radiation out to space. This could include growing crops with more reflective foliage, painting surfaces in the built environment white, or covering areas (e.g., of desert) with reflective material.

Scope in terms of the scale of the responses

The aim of SRM is to counteract the positive radiative forcing of greenhouse gases with a negative forcing. To be effective in reducing a rise in global temperature, the reduction in absorbed solar radiation would need to be a significant proportion of the increases in radiative forcing at the top of the atmosphere caused by anthropogenic greenhouse gases. For example, to fully counteract the warming effect of a doubling of the CO_2 concentration would require a reduction in total incoming solar radiation by about 2% (at the top of the atmosphere) and a reduction in absorbed heat energy by about 4 $W\ m^{-2}$ (watts per square meter) as a global average (for both the atmosphere and the Earth's surface).

The impact on radiative forcing of a given SRM method is dependent on altitude (whether the method is applied at the surface, in the atmosphere, or in space), as well as the geographical location of its main deployment site(s). Other factors that need to be taken into account include the negative radiative forcing of other anthropogenic

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[38] The Royal Society (2009).

[39] CO_2 fertilization effect: higher CO_2 concentrations in the atmosphere increase productivity in some plant groups under certain conditions.

[40] SRM would not alter anthropogenic CO_2 in the atmospheric. However, if it prevented warming, it could reduce additional CO_2 releases from the terrestrial biosphere. Such effects are discussed in greater detail in Chapter 4.

[41] Sulphur dioxide emissions into the troposphere (e.g., as currently happening from coal-fired power stations) result in an increase in sulphate aerosol concentration that also reflects solar radiation and therefore has a similar counteracting effect to that of stratospheric aerosols. However, different physico-chemical reactions occur at different levels of the atmosphere, affecting aerosol processes and removal rates.

emissions such as sulphate and nitrate aerosols that together may provide a forcing of up to –2.1 W m^{-2} by 2100.[42] Such uncertainties and interactions make it difficult to assess the scale of geoengineering that would be required, although quantitative estimates of the effectiveness of different techniques have been made.[43]

2.2.2 Carbon dioxide removal (CDR)

Description

Carbon dioxide removal (CDR) involves the extraction of CO_2, a major greenhouse gas, from the atmosphere, allowing more outgoing long-wave (thermal infra-red) radiation to escape.[44] In principle, other greenhouse gases, such as nitrous oxide (N_2O) and methane (CH_4),[45] could also be removed from the atmosphere; however, such approaches have yet to be developed.

CDR approaches involve two steps: 1) CO_2 capture from the atmosphere; and 2) long-term storage (sequestration) of the captured carbon. In some biologically- and chemically-driven processes, these steps are very closely linked, although the permanence of the storage may be variable and technique-specific. This is the case for ocean fertilization, afforestation, reforestation and soil carbon enhancement. In such cases, the whole process, and their unintended impacts on biodiversity, are effectively confined to marine and terrestrial systems respectively.

In other cases, the steps are discrete and various combinations of removal and storage options are possible, separated in time and space. Carbon captured in terrestrial ecosystems as biomass, for example, could be disposed either in the ocean as plant residues or incorporated into the soil as charcoal. It could also be used as fuel with the resultant CO_2 (re-)captured at source and stored either in sub-surface reservoirs or the deep ocean. In these cases, each step will have its advantages and disadvantages, and all need to be examined.

Proposed CDR techniques considered in this document (based on the definition of geoengineering used here) include:

i) *Ocean fertilization:* the enrichment of nutrients in the marine environment with the principal intention of stimulating primary productivity in the ocean, and hence CO_2 uptake from the atmosphere, and the deposition of carbon in the deep ocean. Two techniques have been proposed with the aim of achieving these effects:

  (a) *Direct ocean fertilization:* the artificial addition of limiting nutrients from external (non-marine) sources. This proposed approach includes addition of the micro-nutrient iron, or the macro-nutrients nitrogen or phosphorus.

  (b) *Upwelling modification:* for the specific purpose of enhancing nutrient supply, and hence biologically-driven carbon transfer to the deep sea. Increased upwelling in one part of the ocean necessarily causes increased downwelling elsewhere, and downwelling modification has itself been proposed as a geoengineering approach (although not involving a fertilization effect).

  For both the above, local-scale activities that are carried out for other purposes (but might cause ocean fertilization as a side effect) are not considered to be geoengineering; for example, nutrient additions as part of conventional aquaculture, or pumping cold, deep water to the surface for cooling or energy-generating purposes.

ii) *Enhanced weathering:* artificially increasing the rate by which CO_2 is naturally removed from the atmosphere by the weathering (dissolution) of carbonate and silicate rocks, including:

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[42] IPCC (2007a).

[43] Lenton & Vaughan (2009).

[44] The Royal Society (2009).

[45] Boucher & Folberth (2010).

(a) *Enhanced ocean alkalinity*: adding alkaline minerals or their dissolution products (e.g., calcium carbonate, bicarbonate or hydroxide) in order to chemically enhance ocean storage of CO_2. This process buffers the ocean to decreasing pH, and thereby, in theory, could help to counter ocean acidification.

(b) *Enhanced weathering of rocks:* the slow natural reaction of silicate rocks with CO_2 (to form solid carbonate and silicate minerals) can be accelerated by spreading finely-ground silicate minerals such as olivine over agricultural soils.

iii) *Increasing carbon sequestration through ecosystem management:*[46]

(a) *Afforestation*: direct human-induced conversion of land that has not been forested (for a period of at least 50 years) to forested land through planting, seeding and/or the human-induced promotion of natural seed sources.

(b) *Reforestation*: direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was previously forested but converted to non-forested land.

(c) *Enhancing soil and wetland carbon*: through improved land management activities including retaining captured CO_2 so that it does not reach the atmosphere and enhancing soil carbon via livestock management.

iv) *Biological carbon capture, using harvested biomass and subsequent carbon storage.* This consists of two relatively discrete steps, with various options for the storage step:

(a) *Production of biomass*: This can be done through the use of conventional crops, trees and algae, and possibly also through plants bioengineered to grow faster and take up more carbon in more long-lived forms (wood or roots).

(b) *Bio-energy carbon capture and storage (BECCS):* Bioenergy with CO_2 sequestration combining existing technology for bioenergy / biofuels and for carbon capture and storage (geological storage).

(c) *Biochar:* the production of black carbon, most commonly through pyrolysis (heating, in a low- or zero-oxygen environment) and its deliberate application to soils.

(d) *Ocean biomass storage:* depositing crop waste or other terrestrial biomass onto the deep ocean seabed, possibly in high sedimentation areas.

v) *Direct, chemical capture of carbon from the atmosphere and its subsequent storage.* This also consists of two discrete steps with various options for the storage step:

(a) *Direct carbon capture from ambient air* ("artificial trees"): the capture of CO_2 from the air by either its adsorption onto solids, or its absorption into highly alkaline or moderately alkaline solutions (that may involve using a catalyst).

(b) *Sub-surface storage in geological formations*: the subsequent storage of the captured carbon (usually but not necessarily as liquid CO_2) in oil or gas fields, un-minable coal beds, deep saline formations or basaltic/peridotite rocks where stable carbonate minerals might be formed.

(c) *Ocean CO_2 storage:* ocean storage of liquid CO_2 (e.g., as obtained from air capture) into the water column through either a fixed pipeline or a moving ship, or by injecting liquid CO_2 into deep sea sediments below 3,000 m depth, or by depositing liquid CO_2 via a pipeline onto the sea floor. At depths $> 3{,}000$ m, liquid CO_2 is denser than water and is expected to form a "lake" that would delay its dispersion into the surrounding environment;

As previously mentioned, there is a range of views as to whether activities such as large-scale afforestation or reforestation should be classified as geoengineering. These approaches are already widely deployed for climate

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[46] IPCC definitions are used here for afforestation and reforestation, providing consistency with other CBD Reports. Note that for the first commitment period of the Kyoto Protocol, reforestation activities are limited to those occurring on land that did not contain forest on 31 December 1989.

change mitigation as well as other purposes, and involve minimal use of novel technologies. For similar reasons, there is debate over whether biomass-based carbon should be included. However, for the sake of completeness, all of these approaches are discussed in this report without prejudice to any subsequent discussions within the CBD on definitions or policy on geoengineering.

Scope in terms of the scale of the response

The natural balance of plant growth and decomposition in the terrestrial biosphere currently results in a net uptake of about 2.6 Gt C/yr (gigatonnes of carbon) from the atmosphere, although this is partially offset by emissions of about 0.9 Gt C/yr from tropical deforestation and other land use changes. In comparison, the current CO_2 release rate from fossil fuel burning alone is about 9.1 Gt C/yr;[47] so to have a significant positive impact, one or more CDR interventions would need to remove from the atmosphere several Gt C/yr, maintained over decades and more probably centuries. It is very unlikely that such approaches could be deployed on a large enough scale to alter the climate quickly; thus they would be of little help if there was a need for "emergency action" to cool the planet.

2.2.3 Comparison between SRM and CDR techniques

Although described above separately, it is possible that, if geoengineering were to be undertaken, a combination of SRM and CDR techniques could be used, alongside mitigation through emission reductions, with the objective of off-setting at least some of the impacts of changes to the climate system from past or ongoing emissions. While SRM and CDR interventions would both have global effects, since climate operates on a global scale, some of the proposed SRM interventions (such as changing cloud or land surface albedo) could result in strong hemispheric or regional disparities, likely to change the frequency of extreme events and the behaviour of major weather systems, e.g. the South East Asia monsoon. Under conditions of rapid climate change, the unequivocal separation of impact causality between those arising from the SRM intervention and those that would have happened anyway would probably not be possible. Likewise, CDR techniques will ultimately reduce global CO_2 concentrations but might also involve regional effects, e.g. if removal is strongly hemispherically biased. Furthermore, climatic conditions for a particular atmospheric CO_2 level are likely to be different according to whether global CO_2 is increasing or decreasing.[48]

In general, SRM can have a relatively rapid impact on the radiation budget once deployed, whereas the effects of many of the CDR processes are relatively slow. Furthermore, while approaches using SRM have the potential to offset the radiative effects of all greenhouse gases, they do not directly alleviate other consequences of changes in atmospheric chemistry, such as ocean acidification. In contrast, CDR techniques do address changes in atmospheric CO_2 concentrations, but they do not address the radiative effects of increased atmospheric concentrations of other greenhouse gases (e.g., methane, nitrous oxide, tropospheric ozone, and halocarbons) and black carbon. Whilst CDR techniques would reduce or slow surface ocean acidification to some degree (in relation to their overall effectiveness), that benefit could be compromised if the carbon or CO_2 removed from the atmosphere is subsequently added elsewhere to the ocean.

The 2009 Royal Society report[49] provided a generally well-regarded overview of the effectiveness, affordability safety and timeliness of the main SRM and CDR techniques that have been proposed. Several other reviews have since been published,[50,51,52,53] including those giving quantitative comparisons of maximum potential effectiveness, in

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[47] Global Carbon Project (2011).

[48] Chadwick et al. (2012).

[49] The Royal Society (2009).

[50] McLaren (2011).

[51] Ginzky et al. (2011).

[52] Rickels et al. (2011).

[53] Gordon (2010).

terms of radiative forcing.[54,55] The IPCC Fifth Assessment Report (AR5), in preparation at the time of publishing this report, is understood to include assessments of the climatic effectiveness of both SRM and CDR techniques, partly based on an expert group meeting.[56] With regard to readiness, the U.S. Government Accountability Office report[57] ranked all geoengineering technologies as immature, with a technology readiness level of 2 or 3 on a scale of 1 to 9.

Clearly, interventions that are deemed to be "safe" (i.e., low relative risk) are preferable. However, a consistent finding of the reviews that included a safety assessment was that techniques considered low risk did not score highly for effectiveness at scale. Fast reversibility is also an important consideration, even for techniques assessed as "safe", since if the safety evaluation should prove incorrect, any unintended—and unexpected—adverse consequences could be reversed relatively quickly.

Unless there are also strong emission reductions, the commitment to geoengineering as a means of avoiding dangerous climate change needs to be continued for decadal to century timescales (and potentially for millennia). This "treadmill" problem is particularly acute for SRM interventions, whose intensity would need to be progressively increased unless other actions are taken to stabilize greenhouse gas concentrations. The cessation of SRM interventions could be a highly risky process, particularly if it were carried out rapidly after being deployed for some time and greenhouse gas levels in the atmosphere were high: the likely result would be a rapid increase in the solar radiation reaching the Earth's surface, causing very rapid increase in surface temperature.[58] Under such circumstances, high reversibility is not necessarily advantageous.

2.2.4 Additional speculative techniques

In addition to the SRM and CDR techniques described above, a number of more speculative approaches have been mooted. These have not been evaluated and are not discussed further in this report. They include some approaches based on increasing the rate of loss of long-wave heat radiation, for example, by reducing the amount of cirrus clouds by injection of an appropriate substance to form ice particles as a sink for upper tropospheric water vapour.[59] Another enhanced heat-loss approach is to use icebreakers to open up passages in Arctic ice in autumn and winter, to reduce the insulating effect of the ice (so more heat is transferred from the ocean to the atmosphere), thus thickening adjacent ice and increasing the amount of reflected solar radiation the next spring.

Other proposed (speculative) approaches have included carrying out major geomorphological changes, such as draining seawater into the Qattara Depression (central Sahara) to increase regional moisture levels[60] and slow sea level rise, or fully or partly blocking the Bering Strait to reduce Arctic Ocean circulation and promote the formation of sea ice.

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[54] Lenton & Vaughan (2009).

[55] Vaughan & Lenton (2011).

[56] Blackstock et al. (2012).

[57] U.S. Government Accountability Office (2011).

[58] In one model simulation, the rate was up to 20 times greater than present-day rates [Matthews & Caldeira (2007)].

[59] Mitchell et al. (2011).

[60] Cathcart & Badescu (2004).

CHAPTER 3

OVERVIEW OF CLIMATE CHANGE AND OCEAN ACIDIFICATION AND OF THEIR IMPACTS ON BIODIVERSITY

Geoengineering techniques are being proposed to counteract some of the negative impacts of climate change, which include impacts on biodiversity. This chapter therefore provides an overview of projected climate change (Section 3.1) and its impacts on biodiversity and ecosystems (Section 3.2), in order to provide context, and a possible baseline which can be taken into account when the impacts of geoengineering techniques are reviewed in subsequent chapters.

3.1 OVERVIEW OF PROJECTED CLIMATE CHANGE AND OCEAN ACIDIFICATION

Human activities have already increased the concentration of greenhouse gases, such as CO_2, in the atmosphere. These changes affect the Earth's energy budget, and are considered to be the main cause of the ~0.8°C average increase in global surface temperature that has been recorded over the last century.[61] The continued increase in atmospheric greenhouse gases has profound implications not only for global and regional average temperatures, but also for precipitation, ice-sheet dynamics, sea-level rise, ocean acidification and the frequency and magnitude of extreme events. Future climatic perturbations could be abrupt or irreversible, and are likely to extend over millennial time scales; they will inevitably have major consequences for natural and human systems, severely affecting biodiversity and incurring very high socio-economic costs.

3.1.1 Scenarios and models

Our main comparisons here are based on future scenarios for anthropogenic emissions of greenhouse gases developed and used by the Intergovernmental Panel on Climate Change (IPCC), particularly those given in its Special Report on Emissions Scenarios (SRES).[62] A new generation of emission scenarios has since been developed[63] for use in the IPCC fifth assessment report (AR5). We make no attempt to pre-empt the AR5 findings; nevertheless, more recent results are discussed below as appropriate, in the context of current emission trajectories.

The SRES scenarios were grouped into four families (A1, A2, B1 and B2) according to assumptions regarding the rates of global economic growth, population growth, and technological development. The A1 family includes three illustrative scenarios relating to dependence on fossil fuels (A1FI, fossil fuel intensive; A1B, balanced; and A1T, non-fossil energy sources); the other families each have only one illustrative member. The B1 scenario assumes the rapid introduction of resource-efficient technologies, together with global population peaking at 8.7 billion in 2050.

The six SRES illustrative scenarios were used in the IPCC's fourth assessment report (AR4) in a suite of climate change models to estimate a range of future global warming of 1.1 to 6.4°C by 2100, with a "best estimate" range of 1.8 to 4.0°C (Figures 3.1 and 3.2).[64] A seventh scenario assumed that atmospheric concentrations of greenhouse gases remain constant at year 2000 values. Note in Figure 3.2 the very large regional differences in temperature increase, and between land and ocean areas, with increases of up to 7°C for the Arctic. The projected precipitation changes also have high spatial variability, with both increases and decreases of ~20% in most continents.

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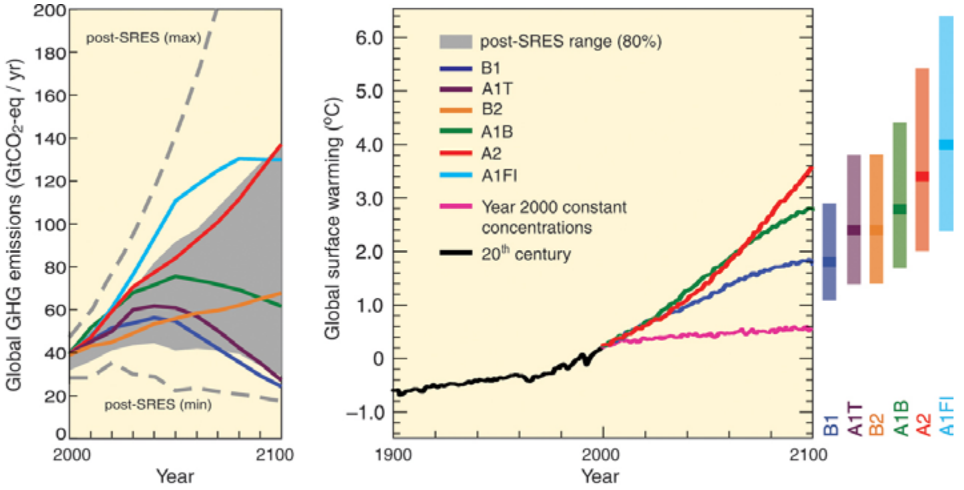
[61] IPCC (2007a).

[62] IPCC (2000a).

[63] Moss et al. (2010).

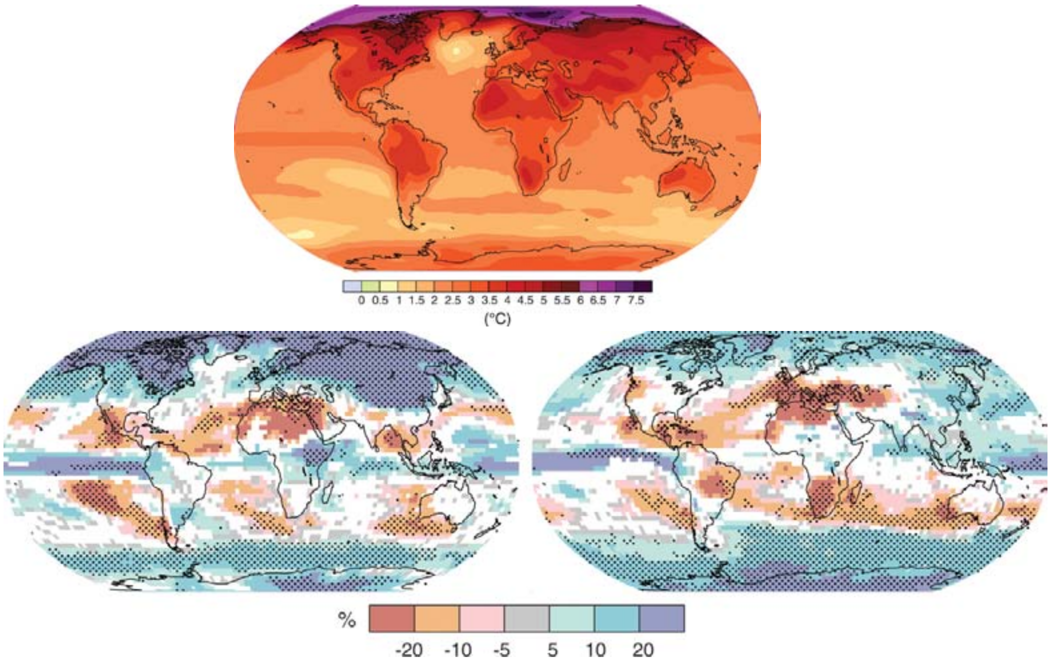
[64] IPCC (2007a).

Figure 3.1: IPCC AR4 scenarios for greenhouse gas annual emissions to 2100



Left: Six illustrative scenarios for greenhouse gas annual emissions from 2000 to 2100, as gigatonnes of CO_2 equivalent. Greenhouse gases include CO_2, CH_4, N_2O and F-gases. The grey shaded area shows the 80th percentile range of other scenarios published since the IPCC Special Report on Emission Scenarios; the dashed lines [labelled post-SRES (max) and post-SRES (min)] show the full range of post-SRES scenarios. Right: Vertical bars show range of temperature increases and best estimates for IPCC's six illustrative emission scenarios, based on multi-model comparisons between 1980–1999 and 2090–2099. Temporal changes in global surface warming also shown for scenarios A2, A1B and B1 (red, green and dark blue lines respectively), with pink line showing temperature change if atmospheric concentrations of greenhouse gases could be held constant at year 2000 values.

Figure 3.2: IPCC AR4 projections of changes in temperature and precipitation to 2100



Projected increase in annual mean temperature (upper map) and percentage precipitation change (lower maps; left, December to February; right, June to August) for the SRES A1B scenario, based on multi-model comparisons between 1980–1999 and 2090–2099. Coloured areas on precipitation maps are where >66% of the models agree in the sign of the change; for stippled areas, >90% of the models agree in the sign of the change.

IPCC AR4 estimated global sea level rise (relative to 1990) to be 0.2 to 0.6 m by 2100; however, those projections excluded ice sheet changes. Taking such effects into account, more recent empirical estimates[65] give projected sea level increases of 0.4–2.1 m, with similar values obtained from measurements of ice-sheet mass balance,[66] although with large uncertainties relating to current loss rates (particularly for Antarctica).[67] Future sea level change will not be globally uniform:[68] regional variability may be up to 10–20 cm for a projected global end-of-century rise of around 1 m.

The broad pattern of climate change observed since ~1850 has been consistent with model simulations, with high latitudes warming more than the tropics, land areas warming more than oceans, and the warming trend accelerating over the past 50 years. Over the next 100 years, interactions between changes in temperature and precipitation (Figure 3.2) will become more critical; for example, affecting soil moisture and water availability in both natural and managed ecosystems. These effects are likely to vary across regions and seasons, although with marked differences between model projections. By 2050, water availability may increase by up to 40% in high latitudes and some wet tropical areas, while decreasing by as much as 30% in already dry regions in the mid-latitudes and tropics.[69] Additional analyses[70] of 40 global climate model projections using the SRES A2 scenario indicate that Northern Africa, Southern Europe and parts of Central Asia could warm by 6–8°C by 2100, whilst precipitation decreases by ≥10%.

The IPCC SRES scenarios can be considered inherently optimistic, in that they assume continued improvements in the amounts of energy and carbon needed for future economic growth. Such assumptions have not recently been met;[71] if future improvements in energy efficiency are not achieved, emission reductions would need to be substantively greater than estimated in AR4.

As noted above, new emission scenarios[72] will be used in the IPCC fifth assessment report (AR5). These will include both baseline and mitigation scenarios, with emphasis on Representative Concentration Pathways (RCPs) and cumulative emissions to achieve stabilization of greenhouse gas concentrations at various target levels, linked to their climatic impacts. For example, stabilization at 450, 550 and 650 ppm CO_2eq (carbon dioxide equivalent; taking account of anthropogenic greenhouse gases and aerosols in addition to CO_2), is expected to provide around a 50% chance of limiting future global surface temperature increase to 2°C, 3°C and 4°C respectively. Note that anthropogenic sulphate aerosols have a negative CO_2eq value; thus if their emissions are reduced, the rate of warming would increase.

3.1.2 Current trajectories for climate change

One of the goals of the United Nations Framework Convention on Climate Change (UNFCCC) is to prevent dangerous anthropogenic interference in the climate system. This aim is stated in the UNFCCC Objective (Article 2 of the Convention):

> "*The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*"

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[65] Rahmstorf (2010).

[66] Rignot et al. (2011).

[67] Zwally & Giovinetto (2011).

[68] Milne et al. (2009).

[69] IPCC (2007a).

[70] Sanderson et al. (2011).

[71] Pielke et al. (2008).

[72] Moss et al. (2010).

However, there are both political and technical difficulties in deciding what "dangerous" means in terms of equivalent temperature increase and other climate changes (and hence CO_2eq stabilization value). The Copenhagen Accord[73] recognized "the scientific view that the increase in global temperature should be below 2°C", which equates to a target of around 400–450 ppm CO_2eq. Lower stabilization targets have also been proposed[74,75,76] on the basis that a 2°C temperature increase represents an unacceptable level of climate change.[77]

Currently, the ensemble of greenhouse gases and aerosols are equivalent to around 495 ppm CO_2eq, but cooling by anthropogenic sulphate aerosols offsets around 100 ppm CO_2eq. Progress towards achieving emission reduction targets for greenhouse gases has been recently reviewed.[78,79]

Since IPCC AR4, much additional evidence has been published showing that the world is warming.[80] Furthermore, the rate of increase in anthropogenic CO_2 emissions has accelerated since 2000,[81,82] averaging 3.1% per year and reaching 5.9% in 2010 (Figure 3.3). Such emissions match or exceed the rates of the highest IPCC SRES scenarios for that period (A1B, A1FI and A2) despite the Kyoto Protocol and the recent global economic downturn. Emissions (and atmospheric levels) of other greenhouse gases, e.g. methane,[83] have also shown recent increases. As a result, it is now very likely that the 450 ppm CO_2eq target will be exceeded. For example, for ~50% success in reaching that target, it has been estimated that global greenhouse-gas emissions would need to peak in the period 2015–2020, with an annual reduction of emissions of >5% thereafter.[84] Other recent studies have reached similar conclusions;[85] nevertheless, the inclusion of additional mitigation measures (for methane and carbon black) could substantially reduce the risks of crossing the 2°C threshold.[86] Whilst such changes in greenhouse-gas emissions are not unrealistic for some developed countries, a rapid transition to a low-carbon economy has yet to be agreed at the global level and its implementation is likely to be extremely difficult[87]—primarily because the necessary planning for radical changes in energy infrastructure and associated economic development[88,89,90] is not yet in place. If large-scale and rapid mitigation measures are not effected, IPCC AR4 models project a global warming of at least 3–5°C by 2100. In that context, geoengineering approaches have received increasing attention, to counteract at least some of the impacts of such climate change, despite the risks and uncertainties involved.

Climate-carbon-cycle feedbacks were not included in all the climate models used for IPCC AR4, but will be included in AR5. Ensemble-based analyses[91] of the A1FI scenario with such feedbacks matched the upper end of the AR4 projections, indicating that an increase of 4°C relative to pre-industrial levels could be reached as soon as the early 2060s. The omission of non-linearities, irreversible changes[92] and tipping points[93] from global climate

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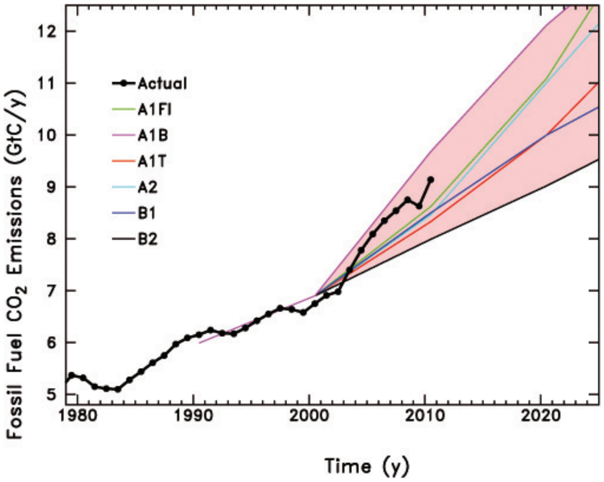
[73] UNFCCC (2010).
[74] Rockström et al. (2009b).
[75] Hansen et al. (2008).
[76] Veron et al. (2009).
[77] Anderson & Bows (2011).
[78] UNEP (2011).
[79] IAEA (2011).
[80] Summary given in: Pope et al. (2011).
[81] Peters et al. (2012).
[82] Global Carbon Project (2011).
[83] Rigby et al. (2008).
[84] Anderson & Bows (2008).
[85] Ranger et al. (2012).
[86] Shindell et al. (2012).
[87] Myhrvold & Caldeira (2012).
[88] Brown (2011).
[89] UNEP (2011).
[90] IAEA (2011).
[91] Betts et al. (2011).
[92] Solomon et al. (2009).
[93] Lenton et al. (2008).

models makes them more stable than the real world. As a result of that greater stability, models can be poor at simulating previous abrupt climate change due to natural causes.[94] However, the recent improvements in Earth system models (and computing capacity) give increasing confidence in their representations of future climate-ecosystem interactions.

Figure 3.3: Global emissions of CO_2 for 1980–2010 in comparison to IPCC SRES emission scenarios for 2000–2025[95]



The average rate of increase of CO_2 emissions since 2000 has been around 3% per year (increasing atmospheric concentrations by ~2 ppm per year), tracking the highest IPCC emission scenarios used for AR4 climate projections. The increase in emissions in 2010 was 5.9%, the highest total annual growth recorded.

Even with strong climate mitigation policies, further climate change is inevitable due to lagged responses in the Earth climate system (so-called unrealized warming). Increases in global mean surface temperature of 0.3–2.2°C are projected to occur over several centuries after atmospheric concentrations of greenhouse gases have been stabilized,[96] with associated increases in sea level due to thermally-driven expansion and ice-melt. Due to the long residence time of CO_2 in the atmosphere, it is an extremely slow and difficult process to return to a CO_2 stabilization target once this has been exceeded. For other short-lived greenhouse gases, climate system behaviour also prolongs their warming effects.[97]

Such lag effects have particular importance for ocean acidification. Thus, changes in surface ocean pH (due to the solubility of CO_2, and the formation of carbonic acid) closely follow the changes in atmospheric CO_2. The penetration of such pH changes to the ocean interior is, however, very much slower, depending on the century-to-millennium timescale of ocean mixing.[98,99]

Differences between the behaviour and impacts of different greenhouse gases and aerosols are not discussed in detail here, but are also very important. For example: tropospheric ozone, methane and black carbon all have relative short atmospheric lifetimes, and therefore may be amenable to emission control with relatively rapid benefits, not only to climate but also human health (black carbon)[100] and agricultural productivity (tropospheric ozone).[101] Black carbon particles have significant heating effect on the lower troposphere and potential effect on the hydrological cycle through changes in cloud microphysics, and snow and ice surface albedo.[102]

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[94] Valdes (2011).

[95] Le Quéré (2011).

[96] Plattner et al. (2008).

[97] Solomon et al. (2010).

[98] The Royal Society (2005).

[99] Joos et al. (2011).

[100] Shindell et al. (2012).

[101] UNEP-WMO (2011).

[102] Ramanathan & Carmichael (2008).

3.2 OBSERVED AND PROJECTED IMPACTS OF CLIMATE CHANGE, INCLUDING OCEAN ACIDIFICATION, ON BIODIVERSITY

3.2.1 Overview of climate change impacts on biodiversity

Temperature, rainfall and other components of climate strongly influence the distribution and abundance of species; they also affect the functioning of ecosystems, through species interactions. Whilst vegetation shifts, population movements and genetic adaptation have lessened the impacts of previous, naturally-occurring climate change (e.g., during geologically-recent ice age cycles),[103] the scope for such responses is now reduced by other anthropogenic pressures on biodiversity, including over-exploitation; habitat loss, fragmentation and degradation;[104] the introduction of non-native species; and pollution, and the rapid pace of projected climate change. Thus, anthropogenic climate change carries a higher extinction risk,[105] since the abundance (and genetic diversity) of many species is already depleted. Human security may also be compromised by climate change,[106,107] with indirect (but potentially serious) biodiversity consequences in many regions.

Whilst some species may benefit from climate change, many more will not. Observed impacts and adaptation responses arising from anthropogenic climate changes that have occurred to date include the following:[108]

- Shift in geographical distributions towards higher latitudes and (for terrestrial species) to higher elevations.[109] This response is compromised by habitat loss and anthropogenic barriers to range change;
- Phenological changes relating to seasonal timing of life-cycle events;
- Disruption of biotic interactions, due to differential changes in seasonal timing; e.g., mismatch between peak of resource demand by reproducing animals and the peak of resource availability;
- Changes in photosynthetic rates and primary production in response to CO_2 fertilization and increased nutrient availability (nitrogen deposition and coastal eutrophication). Overall, gross primary production is expected to increase, although fast growing species are likely to be favoured over slower growing ones, and different climate forcing agents (e.g., CO_2, tropospheric ozone, aerosols and methane) may have very different effects.[110]

As noted above, the IPCC AR4 report estimated future global warming to be between 1.1°C to 6.4°C by 2100, with the upper part of that range becoming increasingly likely if current trajectories continue. Five reasons for concern for a similar temperature range had been previously identified in the IPCC's Third Assessment Report,[111] relating to risks to unique and threatened (eco)systems; risks of extreme weather events; disparities of (human) impacts and vulnerabilities; aggregate damages to net global markets; and risks of large-scale discontinuities. These reasons for concern were re-assessed eight years later using the same methodology,[112] with the conclusion that smaller future increases in global mean temperature—of around 1°C—lead to high risks to many unique and threatened systems, such as "coral reefs, tropical glaciers, endangered species, unique ecosystems, biodiversity hotspots, small island states and indigenous communities" (Figure 3.4).

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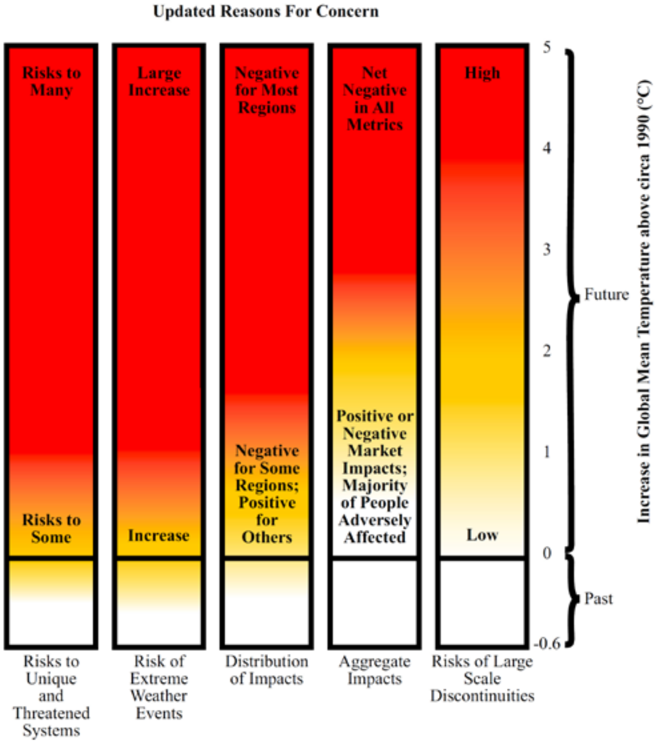
[103] Jackson & Overpeck (2000).
[104] Ellis (2011).
[105] Maclean & Wilson (2011).
[106] Barnett & Adger (2007).
[107] Hsiang et al. (2011).
[108] Secretariat of the Convention on Biological Diversity (2009a).
[109] Cheng et al. (2011).
[110] Huntingford et al. (2011).
[111] Smith et al. (2001).
[112] Smith et al. (2009).

Figure 3.4: Projected impacts of global warming, as "Reasons for Concern"[113]



Updated "reasons for concern" plotted against increase in global mean temperature. Note that: i) this figure relates risk and vulnerability to temperature increase without reference to a future date; ii) the figure authors state that the colour scheme is not intended to equate to "dangerous climatic interference" (since that is a value judgement); and iii) there was a marked worsening of the authors' prognosis in comparison to an assessment published 8 years earlier,[114] using the same methodologies.

The relatively specific and quantifiable risk of rate of extinction was assessed by the CBD's Second Ad hoc Technical Expert Group on Biodiversity and Climate Change, with the estimate that ~10% of species will be at risk of extinction for every 1°C rise in global mean temperature.[115] A recent meta-analysis[116] provides a similar, although lower, estimate, indicating that extinction is likely for 10–14% of all species by 2100. Even if such losses only occur locally or regionally rather than globally (i.e. extirpations, with species possibly "saved from extinction" in zoos, seed-banks or culture collections), biodiversity reductions at those scales must inevitably lead to severe disruptions of many ecosystems and their services,[117] with serious social, cultural and economic consequences. Due to the complex nature of the climate-biodiversity link, there will inevitably be uncertainty about the extent and speed at which climate change will impact biodiversity, species interactions,[118] ecosystem services, the thresholds of climate change above which ecosystems no longer function in their current form,[119] and the effectiveness of potential conservation measures.[120,121]

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[113] Smith et al. (2009).

[114] Smith et al. (2001).

[115] Secretariat of the Convention on Biological Diversity (2009a).

[116] Maclean & Wilson (2011).

[117] Isbell et al. (2011).

[118] Brooker et al. (2007).

[119] Pereira et al. (2010).

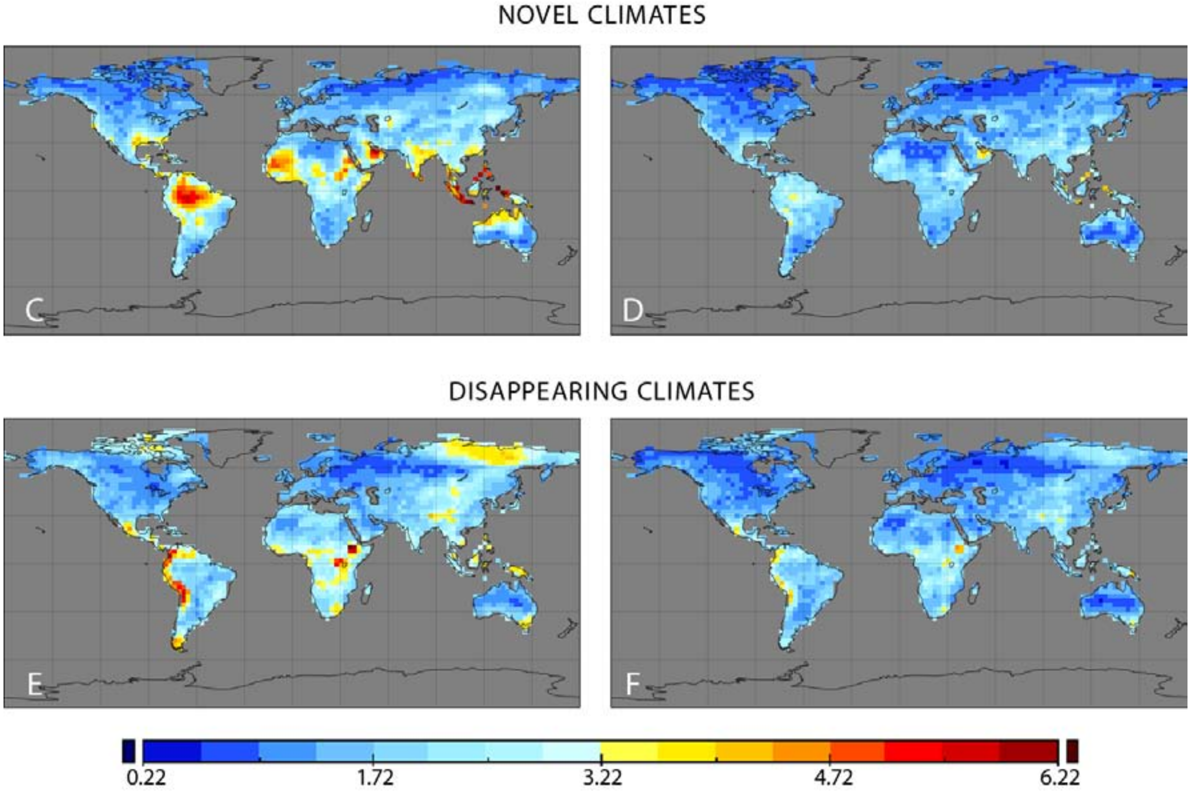
[120] Hoegh-Guldberg et al. (2008).

[121] Dawson et al. (2011).

3.2.2 Projected impacts of climate change on terrestrial ecosystems

The geographical locations where greatest terrestrial biodiversity change might be expected has been assessed using multi-model ensembles and IPCC SRES A2 and B1 emission scenarios to predict the appearance or disappearance of new and existing climatic conditions (Figure 3.5).[122] The A2 scenario indicates that, by 2100, 12–39% of the Earth's land surface will experience "novel" climatic conditions (where the 21st century climate does not overlap with 20th century climate); in addition, 10–48% will experience disappearing climatic conditions (where the 20th century climate does not overlap with the 21st century climate).

Figure 3.5: Novel and disappearing terrestrial climatic conditions by 2100



Model projections of novel (upper) and disappearing (lower) terrestrial climatic conditions by 2100. Left-hand maps: based on A2 emission scenario; right-hand maps: based on B1 emission scenario. Novel climatic conditions are projected to develop primarily in the tropics and subtropics. Disappearing climatic conditions are concentrated in tropical montane regions and the poleward parts of continents. Scale shows relative change, with greatest impact at the yellow/red end of the spectrum.

Montane habitats (e.g., cloud forests, alpine ecosystems) and endemic species (e.g. on actual islands or "stranded" species) have also been identified[123] as being particularly vulnerable because of their narrow geographic and climatic ranges, and hence limited—or non-existent—dispersal opportunities. Other terrestrial and coastal habitats considered to be at high risk include tundra ecosystems, tropical forests and mangroves. For coastal habitats, rising sea level will be an additional environmental stress.

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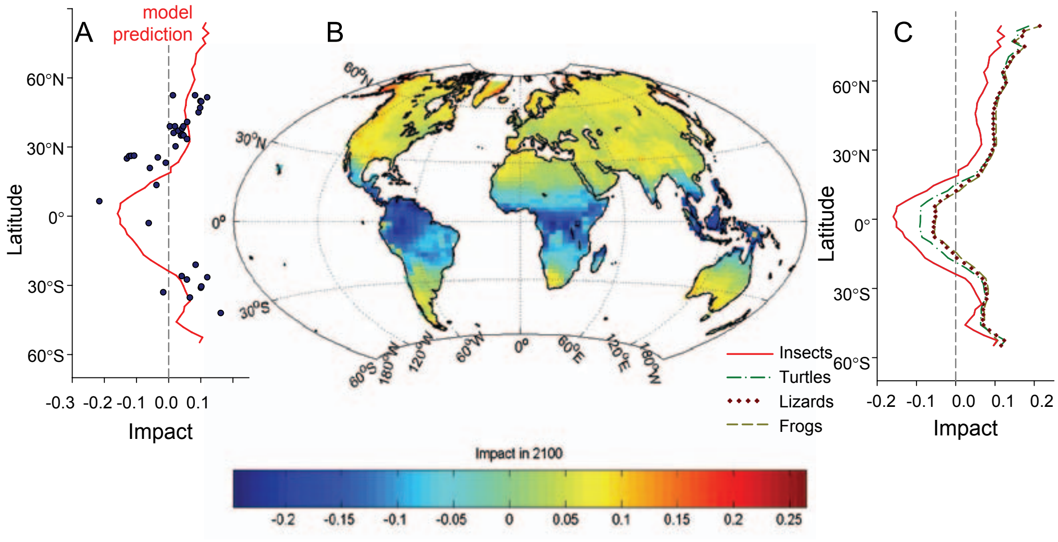
[122] Williams et al. (2007).

[123] Secretariat of the Convention on Biological Diversity (2009a).

A more physiological approach to assessing climatic vulnerability and resilience found that temperate terrestrial ectotherms (cold-blooded animals, mostly invertebrates) might benefit from higher temperatures, whilst tropical species, already close to their upper temperature tolerances, would be disadvantaged even though the amount of change to which they will be exposed is smaller (Figure 3.6).[124] More limited data for vertebrate ectotherms (frogs, lizards and turtles[125]) demonstrated a similar pattern indicating a higher risk to tropical species from climate change. In temperate regions, insect crop pests and disease vectors would be amongst those likely to benefit from higher temperatures (with negative implications for ecosystem services, food security and human health), particularly if their natural predators are disadvantaged by climate change.

Figure 3.6: Projected impact of projected future warming (for 2100) on the fitness of terrestrial ectotherms[126]



Latitudinal impacts of climate change, based on thermal tolerance. A) and B), insect data; map shows negative impacts in blue, positive impacts in yellow/red. C), comparison of latitudinal change in thermal tolerance for insects with more limited data for turtles, lizards and frog.

In general, vulnerability to climate change across species will be a function of the extent of climate change to which they are exposed relative to the species' natural adaptive capacity. This capability varies substantially according to species biology and ecology, as well as interactions with other affected species. Species and ecosystems most susceptible to decline will be those that not only experience high rates of climate change (including increased frequency of extreme events), but also have low tolerance of change and poor adaptive capacities.[127]

Given their importance in the carbon cycle, the response of forest ecosystems to projected climate change is a critical issue for natural ecosystems, biogeochemical feedbacks and human society.[128] Key unresolved issues include the relative importance of water availability, seasonal temperature ranges and variability, the frequency of fire and pest abundance, and constraints on migration rates. Whilst tropical forests may be at risk, recent high resolution modelling has given some cause for optimism,[129] in that losses in one region may be offset by expansion elsewhere.

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[124] Deutsch et al. (2008).

[125] Additional issues arise for turtles since their sex ratio can depend on the temperature during egg incubation. Several populations of marine turtles are already female biased, and ultra-bias (jeopardising population survival) could be caused by a further 1°C of warming [Hawkes et al. (2007)].

[126] Deutsch et al. (2008).

[127] Dawson et al. (2011).

[128] Bonan (2008).

[129] Zelazowski et al. (2011).

3.2.3 Projected impacts of climate change and ocean acidification on marine ecosystems

The marine environment is also vulnerable to climate change, with the additional stress of ocean acidification. Although, future surface temperature changes (with the exception of the Arctic) may not be as high as on land (Figure 3.2), major poleward distributional changes have already been observed; for example, involving population movements of hundreds and thousands of kilometres by fish[130] and plankton[131,132] respectively in the North East Atlantic. Increases in marine pathogenic bacteria have also been ascribed to climate change.[133]

For temperate waters, increases in planktonic biodiversity (in terms of species numbers) have recently occurred in response to ocean warming.[134] Such changes do not, however, necessarily result in increased productivity nor benefits to ecosystem services, e.g., fisheries. In the Arctic, the projected loss of year-round sea ice this century[135] is likely to enhance pelagic biodiversity and productivity, but will negatively impact charismatic mammalian predators (polar bears and seals). The loss of ice will also increase the biological connectivity between the Pacific and Atlantic Oceans, with potential for major introductions (and novel interactions) for a wide variety of taxa via trans-Arctic exchange.[136]

Marine species and ecosystems are also increasingly subject to an additional and yet closely linked threat: ocean acidification. Such a process is an inevitable consequence of the increase in atmospheric CO_2: this gas dissolves in sea water, to form carbonic acid; subsequently, concentrations of hydrogen ions and bicarbonate ions increase, whilst levels of carbonate ions decrease.

By 2100, a pH decrease of 0.5 units in global surface seawater is projected under SRES scenario A1FI,[137] corresponding to a 300% increase in the concentration of hydrogen ions. This may benefit small-celled phytoplankton (microscopic algae and cyanobacteria), but could have potentially serious implications for many other marine organisms, including commercially-important species that are also likely to be subject to thermal stress.[138] Fish sensory perception, and hence behaviour, may also be affected.[139] However, responses by a wide range of taxa can be highly variable, with some species showing positive or neutral responses to lowered pH. For marine invertebrates, differences in sensitivity can occur between populations and within life cycles,[140] and seem closely linked to metabolic activity[141] and food availability. Overall, effects are likely to be negative: a meta-analysis[142] of 73 studies showed that laboratory survival, calcification and growth were all significantly reduced when a wide range of organisms was exposed to conditions likely to occur in 2100 under conditions of unmitigated climate change (Figure 3.7).

For a recent overview of ocean acidification and its physiological and ecological impacts, see Gattuso & Hansson.[143] Actions to address ocean acidification have recently been reviewed by the CBD.[144]

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[130] Perry et al. (2005).

[131] Beaugrand et al. (2002).

[132] Perry et al. (2005).

[133] Vezzuli et al. (2012).

[134] Beaugrand et al. (2010).

[135] Boé et al. (2009).

[136] Greene et al. (2008).

[137] Caldeira & Wickett (2005).

[138] Secretariat of the Convention on Biological Diversity (2009d).

[139] Munday et al. (2009).

[140] Dupont et al. (2010).

[141] Melzner et al. (2009).

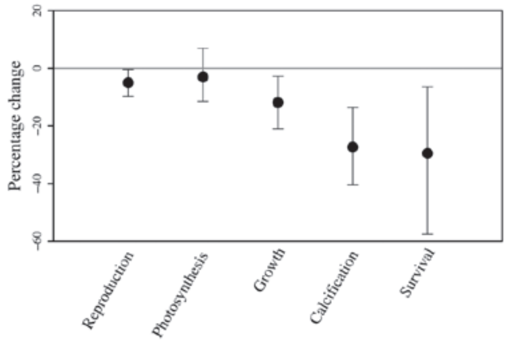
[142] Kroeker et al. (2010).

[143] Gattuso & Hansson (2011).

[144] Secretariat of Convention on Biological Diversity (2012b).

The threshold for "dangerous" ocean acidification has yet to be defined at the intergovernmental level, in part because its ecological impacts and economic consequences are currently not well quantified.[145,146] An atmospheric CO_2 stabilization target of 450 ppm could still risk large-scale and ecologically-significant impacts. Thus, at that level: 11% of the surface ocean would experience a pH fall of >0.2 relative to pre-industrial levels; only 8% of present-day coral reefs would experience conditions considered optimal for calcification, compared with 98% at pre-industrial atmospheric CO_2 levels;[147] and around 10% of the surface Arctic Ocean would be aragonite-undersaturated for part of the year[148] (increasing metabolic costs for a wide range of calcifying organisms). Potentially severe local impacts could occur elsewhere in upwelling regions and coastal regions,[149] with wider feedbacks.[150]

Figure 3.7: Meta-analysis of experimental studies on effect of pH change projected for 2100



Effect of pH decrease of 0.4 units on reproduction, photosynthesis, growth, calcification and survival under laboratory conditions for a wide taxonomic range of marine organisms. Mean effects and 95% confidence limits calculated from log-transformed response ratios, here re-converted to a linear scale. Redrawn[151] with original lead author's permission[152].

Both cold water and tropical corals seem likely to be seriously impacted by ocean acidification; however, the latter are especially vulnerable since they are also subject to temperature stress (coral bleaching), coastal pollution (eutrophication and increased sediment load) and sea-level rise. Population recovery time from bleaching would be prolonged if growth is slowed due to acidification (together with other stresses), although responses are variable and dependent on local factors.[153] The biodiversity value of corals is extremely high, since they provide a habitat structure for very many other organisms; they protect tropical coastlines from erosion; they have significant biotechnological potential; and they are highly-regarded aesthetically. More than half a billion people are estimated to depend directly or indirectly on coral reefs for their livelihoods.[154]

3.3 THE ROLE OF BIODIVERSITY IN THE EARTH SYSTEM AND IN DELIVERING ECOSYSTEM SERVICES

The biosphere plays a key role in the Earth system, especially as part of the global cycles of carbon, nutrients and water, thereby providing ecosystem services of immense human value. Interactions between species, ecosystems and a very wide range of other natural and human-driven processes must therefore also be considered when assessing the impacts of climate change (and geoengineering) on biodiversity. The conservation and restoration of natural

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[145] Turley et al. (2010).

[146] Cooley & Doney (2009).

[147] Cao & Caldeira (2008).

[148] Steinacher et al. (2009).

[149] Feely et al. (2010).

[150] Gehlen et al. (2011).

[151] Williamson & Turley (2012).

[152] Kroeker et al. (2010).

[153] Pandolfi et al. (2011).

[154] TEEB (2009).

terrestrial, freshwater and marine biodiversity are essential for the overall goals of both the CBD and UNFCCC, not only on account of ecosystems' active role in global cycles but also in supporting adaptation to climate change.

Carbon is naturally captured and stored by terrestrial and marine ecosystems, through biologically-driven processes. The amount of carbon in the atmosphere, ~750Gt, is much less than the ~2,500 Gt C stored in terrestrial ecosystems;[155] a further 1,000 Gt C occurs in the upper layer of the ocean, and an additional ~37,000 Gt C is stored in the deep ocean, exchanging with the atmospheric over relatively long time scales. On average ~160 Gt C exchange annually between the biosphere (both ocean and terrestrial ecosystems) and atmosphere. Proportionately small changes in ocean and terrestrial carbon stores, caused by changes in the balance of exchange processes, might therefore have large implications for atmospheric CO_2 levels. Such a change has already been observed: in the past 50 years, the fraction of CO_2 emissions that remains in the atmosphere each year has slowly increased, from about 40% to 45%, and models suggest that this trend was caused by a decrease in the uptake of CO_2 by natural carbon sinks, in response to climate change and variability.[156]

42. It is therefore important to improve our representation of biogeochemical feedbacks (mostly driven by plants and microbes, on land and in the ocean) in Earth system models—not just climate models—in order to understand how biodiversity may influence, and be influenced by, human activities. The range of non-climatic factors important in this context, as direct and indirect drivers of biodiversity change, and the range of ecosystem goods and services that are involved are summarised in Figure 1.1.

3.4 PROJECTED SOCIO-ECONOMIC AND CULTURAL IMPACTS OF CLIMATE CHANGE, IN BIODIVERSITY CONTEXT

The scientific literature on the societal implications of projected climate change is vast, and a detailed assessment is inappropriate here. Nevertheless, a very brief overview of the socio-economic consequences of current trajectories (in the context of biological diversity and ecosystem processes) is necessary, to complete the conceptual picture of linkages between climate, biodiversity, non-marketed goods and services, and human well-being. Such considerations provide important context for the discussion of how geoengineering (with its own impacts) might be used to counteract climate change. Chapter 6 gives additional attention to CBD-relevant socio-economic and cultural aspects of geoengineering.

The Stern Review[157] estimated that, without action, the overall costs of climate change would be equivalent to a future annual loss of 5–20% of gross domestic product. Although that analysis was much discussed[158] and criticised by some economists, projected economic impacts of climate change of similar range and scale were identified in the IPCC Fourth Assessment Report (AR4, Working Group II). Table 3.1 summarises those findings on a regional basis, with emphasis on environmental impacts. The IPCC Fifth Assessment Report, AR5 now nearing completion, will provide additional, updated information, using improved projections (e.g., for sea level rise) and a wider range of impacts (e.g., including ocean acidification).

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[155] Ravindranath & Ostwald (2008).

[156] Le Queré et al. (2009).

[157] Stern (2006).

[158] Barker et al. (2008).

Table 3.1. Examples of some projected environmental impacts of climate change and their socio-economic implications for different regions (all with very high or high confidence). Information from IPCC AR4 Synthesis Report[159]

Africa	• By 2020, agricultural yields reduced by up to 50% in some countries, affecting food security and exacerbating malnutrition. 75–250 million people exposed to increased water stress. • By 2080, arid and semi-arid land likely to increase by 5–8%. • By 2100, sea level rise will affect low-lying coastal areas with large populations; adaptation costs could be at least 5–10% of Gross Domestic Product
Asia	• By 2050, decreased freshwater availability in Central, South,East and South-East Asia • Coastal areas, especially heavily populated regions in South, East and South-East Asia, at increased flooding risk from the sea (and, in some megadeltas, river flooding) • Associated increased risk of endemic morbidity and mortality due to diarrhoeal disease
Australasia	• By 2020, significant biodiversity loss in the Great Barrier Reef, Queensland wet tropics and other ecologically rich sites • By 2030, reduced agricultural and forest production over much of southern and eastern Australia, and parts of New Zealand, due to increased drought and fire. • By 2050, ongoing coastal development and population growth exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding.
Europe	• Negative impacts include increased risk of inland flash floods and more frequent coastal flooding and increased erosion (due to storminess and sea level rise). • Mountainous areas will experience glacier retreat, reduced snow cover and species losses of up to 60% by 2080 (under high emissions scenarios). • In southern Europe, reduced water availability, hydropower potential, summer tourism and crop productivity, together with increased health risks due to heat waves and wildfires.
Latin America	• By 2050, gradual replacement of tropical forest by savanna in eastern Amazonia; elsewhere semi-arid vegetation will tend to be replaced by arid-land vegetation. Associated risk of significant biodiversity loss through species extinction • Decreased productivity of many crops and livestock, with adversely affecting food security. • Hydrological changes are expected to significantly affect water availability for human consumption, agriculture and energy generation.
North America	• Moderate climate change is projected to increase yields of rain-fed agriculture by 5–20%, but with important variability among regions. Major challenges expected for crops near the warm end of their suitable range or which depend on highly utilised water resources. • Increased number, intensity and duration of heat waves during the course of the century, with potential for adverse health impacts. • Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution.
Polar regions	• Reductions in thickness and extent of glaciers, ice sheets and sea ice; changes in natural ecosystems include adverse effects on migratory birds, mammals and higher predators. • For human communities in the Arctic, impacts are projected to be mixed; detrimental impacts include those on infrastructure and traditional indigenous ways of life. • In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered.
Islands	• Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, threatening vital infrastructure that supports the livelihood of island communities. • Reduced water resources in many small islands, e.g., in the Caribbean and Pacific, may become insufficient to meet demand during low-rainfall periods. • Higher temperatures will increase frequency of coral bleaching and, for mid- and high-latitude islands, the risk of invasion by non-native species.

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[159] IPCC (2007a).

CHAPTER 4

POTENTIAL IMPACTS ON BIODIVERSITY OF CLIMATE GEOENGINEERING ACHIEVED BY SUNLIGHT REFLECTION METHODS

As summarized in Chapter 3, if anthropogenic greenhouse-gas emissions continue on current trajectories, the resultant projected climate change will pose an increasingly severe threat to biodiversity and ecosystem services, adding to the many factors already influencing biodiversity loss. Effective actions intended to reduce the magnitude of future climate change would therefore be expected to reduce its impacts on biodiversity. However, such measures may not fully achieve their intended benefits, and are also likely to have additional unintended consequences (Figure 2.1), that may offset (or augment) their intended effects. Thus, if a proposed geoengineering approach can be shown to be potentially feasible and effective in reducing the risks, costs and uncertainties of climate change, its projected positive impacts need to be considered alongside any projected further impacts of the geoengineering measure (mostly technique-specific), with their own risks, costs and uncertainties.

This chapter explores whether and how sunlight reflection methods (SRM) might be able to reduce climate-imposed threats to biodiversity and ecosystem services, including consideration of the uncertainties of those intended, beneficial impacts. It also examines the potential for unintended side effects of SRM. The projected positive and negative impacts that are common to all techniques involving reduction in incoming solar irradiance (as would result from space- or atmospheric-based SRM) are reviewed in section 4.1; technique-specific impacts for a wider range of approaches are reviewed in section 4.2. Carbon dioxide removal (CDR) techniques are examined in Chapter 5.

Most comparisons given here are in relation to a future world where the climate has changed and is impacting biodiversity due to inadequate efforts to reduce greenhouse-gas emissions. Limiting the future temperature increase to 2°C will be extremely challenging, and an increase of 3 to 5°C seems much more likely if current emission trajectories continue.

4.1 POTENTIAL IMPACTS ON BIODIVERSITY OF GENERIC SRM THAT CAUSES UNIFORM DIMMING

4.1.1 Potential reduction in temperature and other climatic effects from uniform dimming

Studies of the potential impacts of SRM have been primarily based on computer modelling, as discussed below. Observations of the natural world (e.g., volcanic eruptions, recent[160,161] and historical[162,163,164]) are also relevant, since these provide precedents for temporary changes in solar irradiance reaching the Earth's surface, of similar order of magnitude to proposed SRM interventions.

Several models have assumed that SRM is able to cause uniform dimming to counter the climate change projected from doubled[165,166] or quadrupled[167,168] CO_2, or for specific IPCC SRES scenarios.[169] This is a useful starting point;

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[160] Dutton & Christy (1992).

[161] Trenberth & Dai (2007).

[162] Miller et al. (2012).

[163] Oman et al. (2006).

[164] Oman et al. (2005).

[165] Caldeira & Wood (2008).

[166] Jones et al. (2010).

[167] Irvine et al. (2010).

[168] Schmidt et al. (2012).

[169] Jones et al. (2010).

however, the assumption of uniform dimming is only valid (and might still be unachievable) for space-based or stratospheric-based techniques where particular effort is made to achieve that goal. Reviews[170,171] of results from those idealised models have concluded that: i) it is theoretically possible to fully counteract, at the *global* scale, the radiative forcing due to increased anthropogenic greenhouse gases under such scenarios; and ii) the projected temperature changes due to greenhouse gas forcing can be greatly reduced for all areas of the planet. However, uniform dimming simulations are unable to fully restore surface temperatures to either current or pre-industrial conditions at the *regional* level, since the temperature gradients between the equator and both poles are reduced. As a result, the modelled SRM interventions leave either excess cooling in the tropics, or excess warming in high latitudes, or both, compared to existing conditions.

Water availability is at least as crucial as temperature for biodiversity, ecosystems and human well-being. Thus it is an important finding that the modelled cooling caused by uniform dimming is also apparently able to counteract most of the precipitation changes caused by increased atmospheric levels of greenhouse gases (previously presented in Figure 3.2). But not all of those precipitation changes are offset: models of the "SRM world" that fully counter anthropogenic radiative forcing consistently show a slowing of the hydrological cycle, with up to a 2% decrease in global mean precipitation compared to the current climate. This may be most pronounced over land and/or in equatorial regions, among the most biodiverse regions.

Thus the overall conclusion of several groups, working with different models, is that uniform dimming, if achievable, could reduce the worst negative impacts of unmitigated climate change, yet is also likely to lead to significant geographical redistribution of such climatic effects.[172,173,174,175,176,177,178]

The speed with which SRM would be expected to reduce temperatures, once deployed at the global scale, is a unique attribute of these techniques. While SRM would start reducing temperature immediately after global deployment, in a similar way to volcanically-induced cooling,[179] it would take decades (or longer) for emissions cuts or CDR deployment to lower global temperatures. This means that space- or stratospheric-based SRM is the only approach developed to date[180] that might allow a rapid reduction in temperatures, should that be considered necessary.

As indicated above, if the cooling from SRM were realized as simulated by (idealised) models, many of the projected impacts of unmitigated climate change on biodiversity would be much reduced. However, there is scope for further modelling work, since many uncertainties remain. Thus existing model outcomes cannot yet be used to confidently predict the totality of effects, comprising not only which areas are projected to benefit (fully, partially or maybe not at all, compared with unmitigated control) from reduced changes in temperature and precipitation under SRM deployment, but also the magnitude and relative importance—or unimportance—of other, unintended effects on biodiversity, ecosystems and their services.

The uncertainties associated with comparisons of regional climate changes in a high CO_2 world with and without SRM are inherent in the complexity of the climate system itself, affecting the ability of models to fully represent all the interacting physical and biogeochemical processes at the scale needed for regional climate projections. It

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[170] Rasch et al. (2008).

[171] Vaughan & Lenton (2011).

[172] Matthews & Caldeira (2007).

[173] Robock et al. (2008).

[174] Caldeira & Wood (2008).

[175] Ricke et al. (2010).

[176] Lunt et al. (2008).

[177] Schmidt et al. (2012).

[178] Pongratz et al. (2012).

[179] Dutton & Christy (1992).

[180] Relatively rapid cooling might also be possible from cirrus cloud manipulation; however, the practicalities of that techniques have yet to be investigated. The most rapid temperature reduction realistically achievable through mitigation is estimated to be ~1°C in 50 years, based on combined actions on CO_2, methane and black carbon [Shindell et al. (2012)].

is therefore unsurprising that different regional results are provided by different global climate models: as inter-comparison exercises for climate models (without SRM) have demonstrated,[181] relatively small differences in model structure, parameterisations and start-up conditions can generate a diversity of regional climate projections for the same emission scenarios. In some regions, the results of several models converge, increasing confidence that regional projections are correct—although that may be because they may all share the same deficiency (e.g. omitting a feedback factor, due to inadequate knowledge of the processes involved). However, in other regions, there is either less or no agreement.

Inter-comparisons between models that include SRM simulations are currently underway,[182,183] and preliminary results from one four-model experiment (based on quadrupling CO_2 and uniform dimming) have recently been published,[184] broadly confirming the main conclusions discussed above. Recognising that full climate restoration is unlikely to be achievable (even with sophisticated application of non-uniform dimming, targeting specific regions[185]), recent papers have proposed SRM approaches that might nevertheless minimize the overall effects of adverse impacts,[186] based on different social objectives—egalitarian, utilitarian or ecocentric,[187] albeit at a relative crude level.

However applied, SRM would introduce a new dynamic between the heating effects of greenhouse gases and the cooling effects of sunlight reduction. There are no known palaeo-precedents for the radiative impacts of high greenhouse gases to be balanced by reduced light quantity; thus the stability of that combination is uncertain, and it is not clear what specific environmental challenges an "SRM world" would present to particular species and ecosystems, either on a short-term or long-term basis, as discussed below in greater detail.

4.1.2 Projected impacts of uniform dimming on hydrological and nutrient cycles

As noted above, modelling to date has mostly focussed on the global and regional temperature and precipitation changes likely to result from idealised SRM deployment compared to a high CO_2 world. However, for biodiversity, ecosystems and their services, relative precipitation changes and temporal patterns in precipitation delivery are much more important than absolute amounts. Thus, for an arid region, a change in quantity or timing of around 5–10 cm yr^{-1} could be critical, yet such a change would be insignificant for areas annually receiving several metres of precipitation. Furthermore, precipitation minus evaporation (P-E) is a much more useful metric of biologically-available water than is precipitation alone,[188] with soil moisture the key hydrological variable for healthy terrestrial ecosystems. Additional relevant processes affecting soil and plant water loss (evapotranspiration) include total insolation, the response of plants to increased CO_2 (affecting stomatal opening), and the different projected changes in the distribution of different ecosystems in response to different emission scenarios.

The combined response of these processes to SRM-induced solar dimming is currently highly uncertain, and there is likely to be considerable regional variability. Whilst it has been calculated that SRM might be able to reduce the overall P-E change due to global warming by ~75%[189] (compared to doubled CO_2), soil moisture in the tropics under SRM is still likely to be significantly less than at present.[190,191] Changes in P-E and soil moisture have major

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[181] IPCC (2007b).

[182] Kravitz et al. (2011).

[183] Robock et al. (2011).

[184] Schmidt et al. (2012).

[185] Even if such sophistication were possible, we would never know exactly how the naturally-dynamic climate system would have evolved in the absence of SRM; e.g. as a consequence of natural decadal variability in climatic processes, that may partly be due to highly uncertain changes in the 'solar constant'.

[186] Ban-Weiss &.Caldeira (2010).

[187] Moreno-Cruz et al. (2012).

[188] Running & Kimball (2006).

[189] Ban-Weiss &.Caldeira (2010).

[190] Bala et al. (2008).

[191] Matthews & Caldeira (2007).

implications for terrestrial ecosystems since this is a key parameter determining net primary production (NPP),[192] with consequences for the carbon cycle[193] and a wide range of biogeochemical feedbacks. P-E is also a crucial factor for agriculture, the frequency of forest fires;[194] and freshwater quantity and quality.[195]

SRM that aims to achieve uniform dimming could have both predictable and unknown side effects on the atmospheric cycling of nutrients, their deposition[196] and recycling processes, in soil and in the ocean. Relative to unmitigated climate change, the recycling of soil nutrients could be expected to be slowed, since this process is highly temperature dependent. However, it is not yet known to what degree SRM might be able to counteract the overall changes to nutrient cycles that might occur in a high CO_2 world.

4.1.3 Projected impacts of uniform dimming on species and ecosystems

Reducing temperature through deployment of idealised SRM would, if achievable, benefit those species and ecosystems identified in Chapter 3 as being particularly vulnerable to the negative impacts of increased temperature due to unmitigated climate change; e.g., endemic, isolated populations ("stranded" species or on islands), and polar and mountain ecosystems. Long-lived species which are poor at adapting to climate change (e.g. non-mobile species, such as many trees, and others that reproduce slowly), are also likely to benefit from SRM in comparison to unmitigated climate change, as are species with temperature-regulated sex determination. However, species that are particularly poor at adapting to climate change are also those most at risk from sudden SRM termination (Section 4.1.5).

There are many uncertainties relating to the ability of existing species and ecosystems to adapt to living in novel environments resulting from rapid global climate change. This is true both for a world of unmitigated climate change (high temperatures, altered precipitation patterns, increased CO_2 concentrations) and for a world where radiative forcing due to high levels of greenhouse gases is masked by SRM (more diffuse light, altered precipitation patterns, high CO_2 concentrations).

Overall, *if* i) the world behaves the way that it does in most global climate models developed to date; ii) uniform or near-uniform global dimming is achievable, and iii) there are no serious additional adverse side effects, *then* SRM-induced (uniform) dimming would greatly reduce the impacts of climate change on biodiversity relative to a high greenhouse gas world. Nevertheless, climate model predictions have their limitations (being unable to exactly match changes in the real world, particularly at fine spatial and temporal scales, i.e. regionally and annually); and there is inevitably some risk of unexpected, as well as unintended, side effects.

Global-scale SRM necessarily involves "unknown unknowns", since it is unlikely that all potential risks can be identified through smaller-scale deployments.[197] Furthermore, the comparison with "unmitigated climate change" necessarily covers a range of potential scenarios, although (as pointed out in Chapter 3) current trajectories indicate that global warming of at least 3–5°C by 2100 is now very likely.

4.1.4 Impacts of high CO_2 under SRM

SRM does not seek to reduce the atmospheric concentrations of anthropogenic CO_2, and the process of ocean acidification will therefore continue. As a result, marine biodiversity will be increasingly exposed to the adverse impacts of decreasing pH (Section 3.2.3). Nevertheless, there may be significant second order effects.[198] One unintended, additional negative impact would be more CO_2 dissolving in the ocean if its surface temperature has

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[192] Zhao & Running (2010).

[193] Van der Molen et al. (2011).

[194] Cochrane & Laurance (2008).

[195] Oki & Kanaer (2006).

[196] Kravitz et al. (2009).

[197] MacMynowski et al. (2011).

[198] Williamson & Turley (2012).

been reduced by SRM, in comparison to unmitigated climate change. However, that is likely to be countered by the avoidance of additional biogenic CO_2 in the atmosphere (as much as 100 ppm by 2100, under an A2 SRES scenario) as a feedback response to global warming, due to temperature-driven changes in the productivity and decomposition of terrestrial biomass,[199] particularly affecting Arctic regions.[200]

SRM will not address the effects of high CO_2 concentrations on terrestrial ecosystems, such as favouring some plant groups over others.[201] However, high CO_2 can have beneficial effects on plant productivity, reducing water stress,[202] and such positive impacts could be expected to continue under SRM.

4.1.5 Rate of environmental change and the termination effect

It is not just the magnitude, nature and distribution of environmental changes (from climate change or from solar geoengineering) that will affect biodiversity and ecosystem services, but also the rate at which the changes take place. In general, the faster an environment changes, the greater the risk to species.[203] SRM, if effective, could slow, halt or even reverse the pace of global warming much more quickly than mitigation measures (within months, versus decades or longer), notwithstanding potential side effects. Therefore, it could either be deployed as an "emergency response[204,205]" in order to counter imminent threats, or more gradually to shave the peaks off more extreme warming, in order to allow more time both for adaptive measures and natural adaptation,[206] and for effective mitigation measures to be implemented.

However, there is an additional issue to consider when evaluating the general effects of SRM on biodiversity and ecosystem services: the so-called "termination effect".

Atmospheric-based SRM techniques would only offset global warming as long as they are actively maintained. Whilst abrupt discontinuation would be unplanned, there is inevitably risk of such an eventuality, due to political instabilities or policy changes at either the national or international level; for example, in response to the occurrence of regionally-severe extreme events. Such events would undoubtedly be perceived as due to the SRM action (with consequences for public acceptability and international legal compensation), even if direct attribution could not be scientifically proven. Such cessation of SRM that had been deployed for some time would, in the absence of effective stabilization or reduction of atmospheric greenhouse gas concentrations, result in increased rates of climatic change: all the warming that would have otherwise taken place (either over just a few years or several decades) is projected to take place over a much shorter period.[207]

Under such circumstances, the rapid warming due to SRM termination would almost certainly have large negative impacts on biodiversity and ecosystem services, with potentially severe socio-economic implications[208] and these effects would be more severe than those resulting from gradual climate change. Most plants, animals and their interactions are likely to be affected, since current rates of anthropogenic climate change are already altering, or are projected to alter, community structure,[209] biogeochemical cycles,[210] and fire risk.[211]

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[199] Matthews et al. (2009).

[200] Schuur et al. (2008).

[201] Collatz et al. (1998).

[202] Long et al. (2004).

[203] Chevin et al. (2010).

[204] Solar Radiation Management Governance Initiative (SRMGI) (2011).

[205] Rapid cooling due to full-scale SRM deployment could also itself have negative impacts for biodiversity, as well as potentially triggering climatic instabilities.

[206] Secretariat of the Convention on Biological Diversity (2009a).

[207] Matthews & Caldeira (2007).

[208] Goes et al. (2012).

[209] Walther et al. (2002).

[210] Zepp et al. (2003).

[211] Golding & Betts (2008).

For the above reason (and because of ocean acidification effects), it is important that SRM should not be regarded as an alternative to strong emission reductions, in order to stabilize, and preferably reduce, the levels of greenhouse gases in the atmosphere. SRM might, however, be considered as a supplementary action.

4.2 POTENTIAL IMPACTS OF SRM ON BIODIVERSITY AT THE TECHNIQUE-SPECIFIC LEVEL

Thus far, this chapter has addressed the general effects of space- or atmospheric-based SRM on biodiversity, based on uniform dimming; as noted, such a change in the Earth's radiative energy budget may not be achievable in practice. Below, the potential benefits and drawbacks associated with three specific techniques—stratospheric aerosol injection, cloud brightening and surface albedo enhancement—are considered, on the basis that these are the options most frequently proposed, and are each theoretically capable of counteracting either all or most of the radiative forcing from greenhouse gases.[212] Important technique-specific considerations include the height above the Earth's surface where the sunlight reflection occurs, and whether there may be additional physico-chemical interactions. The potential positive and negative impacts of space-based reflectors[213,214,215] are expected to be similar to those theoretically indicated by models for uniform-dimming SRM described above.

4.2.1 Potential impacts on biodiversity of stratospheric aerosol injection

In addition to the positive and negative impacts of idealised SRM already described, the climatic effects of geoengineered stratospheric sulphate aerosol will depend on where (injection altitude and locality) and how (injection technique and timing) this technique is deployed, with significant effects of both factors on aerosol microphysics and behaviour, including the radius, radiative impact and longevity of the aerosols.[216] Furthermore, this proposed technique could affect precipitation acidity, stratospheric ozone depletion, and the overall quantity and quality of light reaching the biosphere, with subsequent effects on biodiversity and ecosystem services. Some, but not all, of these unintended negative impacts might be avoided if aerosols other than sulphates were to be used for this approach. Other particles that have been suggested include electrostatic or magnetic nano-particles,[217] potentially with relatively long atmospheric lifetimes; there is also the possibility of designing a particle with specific attributes.[218] However, they might bring with them their own particular risks—together with additional public acceptability issues.

Increased precipitation acidity

Use of sulphate aerosols for SRM would, to some degree, increase the acidity of precipitation ("acid rain"), with consequent impacts on ecosystems. However, the size of this effect is considered to be small, since the quantities of sulphur estimated to be needed for this form of SRM are ≤10% of the current global deposition, and possibly as little as 1%.[219] Furthermore, sulphur deposition would be more widely distributed than is currently the case from anthropogenic sulphur emissions, and buffering processes mean than ocean acidification is unlikely to be significantly worsened.[220]

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[212] Vaughan & Lenton (2011).

[213] Seifritz (1989).

[214] Angel (2006).

[215] McInnes (2010).

[216] Niemeier et al. (2011).

[217] Keith (2010).

[218] Oral presentation by Ben Kravitz at Planet under Pressure conference, London, 27 March 2012.

[219] Kravitz et al. (2009).

[220] Hunter et al. (2011).

Ozone depletion and increased UV radiation

If stratospheric sulphate injection were to be used for SRM, there is evidence that this could result in increased ozone depletion, primarily in polar regions in spring. This effect was observed[221] after the 1991 Mount Pinatubo eruption. However, the consequences of decreased ozone (in terms of allowing additional ultra violet (UV) radiation to reach the Earth's surface) could be at least partly offset by UV scattering and attenuation by the sulphate aerosol itself. If surface UV were to significantly increase, some species would be affected more than others. Certain plants possess a protective layer on the upper surface of their leaves, making them less susceptible to UV damage. The ecological effects of any increased UV radiation will also depend on which spectral form (UVA, UVB and UVC) is most affected.

An additional uncertainty is the appropriate comparison to be made with regard to future conditions, since projections of stratospheric ozone in 50–100 years time are subject to assumptions regarding societal behaviour (the future effectiveness of the Montreal Protocol, or other measures that might be introduced), as well as climate-induced changes in atmospheric chemistry.[222]

Changes in the nature and amount of light reaching ecosystems

Stratospheric aerosols would decrease the amount of photosynthetically active radiation (PAR) reaching the Earth; they would also increase the amount of diffuse (as opposed to direct) short-wave solar irradiation. For terrestrial ecosystems, these processes would have opposing ecological effects, with the net impact likely to differ between species and between ecosystems. The net impact may also depend on the percentage reduction in PAR, and the absolute levels under current conditions; these vary latitudinally and are also subject to spatial variability in cloud cover.

Thus, the net efficiency of carbon fixation by a forest canopy is increased when light is distributed more uniformly throughout the canopy, as occurs with diffuse light. Diffuse light penetrates the canopy more effectively than direct radiation because direct light saturates upper sunlit leaves but does not reach shaded, lower leaves. The negative effects of a (small) reduction in total PAR might be less than the positive effects of the increase in diffuse radiation giving a net improvement in photosynthetic efficiency, hence an overall increase in terrestrial primary production. Crop species may also benefit[223] although inter-species differences are likely, as a function of canopy structure. There may also be additional hydrological effects driven by the effects of the diffuse/direct ratio on evapotranspiration.[224] There is evidence for such responses following the Mount Pinatubo eruption,[225] and during the "global dimming" period (1950–1980).[226,227]

However, the magnitude and nature of such effects on biodiversity are currently not well understood, and their wider ecological significance is uncertain. Even if gross primary production (GPP) were to increase, GPP is not necessarily a good proxy for biodiversity: increases in GPP could be due to a few plant species thriving in more diffuse light. Furthermore, for ecosystems where total light availability is the major growth-limiting factor, the negative impacts of total radiation decrease could be greater than any benefits provided by the increase in diffuse radiation.

A further complication is that while diffuse light is better at penetrating a multi-layered canopy, sunflecks (bursts of strong light which penetrate the canopy and reach ground level) would be less intense with diffuse light as opposed to direct light.[228]

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[221] Tilmes et al. (2008).

[222] McKenzie et al. (2011).

[223] Zheng et al. (2011).

[224] Oliveira Pet al. (2011).

[225] Gu et al. (2003).

[226] Mercado et al. (2009).

[227] Wild (2009).

[228] Montagnini & Jordan (2005).

Analyses of effects of large-scale, aerosol-based SRM on marine photosynthesis have not been carried out; however, primary production in the upper ocean is closely linked to the depth of light penetration, that is greatest for direct sunlight.[229] Thus, ocean productivity could be expected to decrease under SRM in comparison to present-day values. However, the comparison to unmitigated climate change is not straightforward, since many other factors would also then be involved.

The potential effects on animals of the (relatively small) changes in total solar irradiance and its direct/diffuse ratio that would result from SRM using stratospheric aerosols have yet to be investigated. Bees and other insects that use polarized light for navigation may be particularly sensitive; whilst they are still able to detect celestial polarization patterns under cloudy skies,[230] year-to-year variability in early summer sunshine can have a significant effect on honey production.[231]

4.2.2 Potential impacts on biodiversity of cloud brightening

Cloud brightening involves increasing the concentration of cloud-condensation nuclei (CCN) in the troposphere (lower atmosphere), to increase the reflection back to space of short-wave solar radiation.[232] The technique is effectively limited to ocean areas,[233,234] particularly the southern hemisphere, where CCN abundance is naturally low. Whilst deployment locations could (in theory) be chosen to spatially maximize beneficial effects,[235] the large-scale application of this technique seems likely to cause strong regional or local atmospheric and oceanic perturbations[236] with potentially significant impacts on terrestrial and marine biodiversity and ecosystems.

Cloud brightening, if effective, could be expected to reduce local radiative forcing by up to 40 $W\ m^{-2}$ in tropical areas. Persistent local/regional cooling on that scale could affect regional weather systems of high ecological and societal importance, such as the West African Monsoon and the El Niño Southern Oscillation. These complex systems, and their year-to-year variability, are not well-represented in current global climate models; comparisons with future, unmitigated climate change scenarios are therefore highly uncertain.

A reduction in solar radiation at the ocean surface would be expected to reduce global evaporation and hence precipitation elsewhere.[237] Increased numbers of cloud droplets could also suppress precipitation.[238] An idealised model that assumed that cloud droplet size could be reduced uniformly over all the global ocean has indicated that such an "intervention" could counteract most of the temperature and precipitation changes caused by doubling CO_2, although with an (unexpected) slight residual increase in precipitation over land, compared to the pre-industrial climate, for double CO_2 plus CCN increase.[239] This model is, however, unrealistic in many of its assumptions.

In addition to these uncertain local, regional and global effects of cloud brightening (with potential for both positive or negative effects on terrestrial biodiversity), the relatively dramatic changes in light intensity and temperature near to the sites of deployment are also likely to affect ocean productivity. Increases in primary production are, however, more likely than decreases, since the ocean areas most suitable for cloud brightening deployment are mostly strongly stratified, with photosynthesis constrained by nutrient availability rather than lack of light. Strong

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[229] Morel (1991).

[230] Pomozi et al. (2001).

[231] Holmes (2002).

[232] Latham (1990).

[233] Latham et al. (2008).

[234] Latham et al. (2012).

[235] Rasch et al. (2009).

[236] Jones et al. (2010).

[237] Vaughan & Lenton (2011).

[238] Albrecht (1989).

[239] Bala et al. (2010).

local cooling could be expected to increase upper ocean mixing and nutrient re-supply, with subsequent effects on biodiversity and ecosystems.

The possibility that CCN abundance could also be enhanced biologically, particularly in the Southern Ocean, has been suggested,[240] but this approach is not generally considered to be either realistic or effective.[241]

4.2.3 Potential impacts on biodiversity of surface albedo enhancement

Land surface

The reflectivity (albedo) of the land surface could be increased by whitening the built environment (e.g. roofs and roads);[242] developing crops, grasses or shrubs with more reflective foliage;[243,244] or covering "unused" land surface (e.g. deserts) with reflective material.[245] These techniques are likely to have varying degrees of climatic effectiveness, cost-effectiveness and achievability.

In general, surface albedo changes are less effective than those above or within the atmosphere, since the reflected irradiance has to travel twice through the Earth's atmosphere before it is returned to space, with energy (heat) losses on both inward and outward journeys.[246] Thus such changes would have to be deployed over very large areas to have a significant effect on the global climate. Assuming that the albedo of *all* the Earth's land surface could be changed, significant inter-hemispheric climate effects occur in model simulations[247] due to the asymmetric inter-hemispheric distribution of land and ocean. Although unrealistic, such results indicate that (as for cloud brightening) the climatic effects of the technique are location-sensitive. While a high degree of localised cooling could potentially benefit ecosystems that are experiencing the adverse consequences of climate change, the "patchy" nature of the cooling might change local systems as much, or possibly more, than the global warming that the schemes are seeking to address.

Whitening the built environment could potentially reduce energy use for air conditioning and provide other local benefits.[248] It cannot, however, be considered as a viable geoengineering technique, since the maximum possible change in radiative forcing (with all urban surfaces becoming white) has been estimated to counteract <5% of the forcing from anthropogenic greenhouse gases.[249] A realistically achievable areal coverage would be at least an order of magnitude less.

For croplands, grasslands and savannah regions, the maximum global-scale effect of albedo change may be potentially much higher than for urban areas, but little serious attention has been given to how this might be achieved. The albedo of crops is likely to be manageable,[250] to some degree, yet selection for significant changes in leaf colour or micro-structures to increase albedo by 25–40% is likely to have other physiological consequences, with implications for crop productivity, harvested food quality, and the biodiversity of agricultural areas. Such issues have yet to be addressed. Whilst GM (genetic modification) technologies could be used to accelerate the development of high-albedo strains, additional issues would then be raised. Even if developed, the large-scale deployment of high albedo crops would not be straightforward, with additional ecological and socio-economic risks arising from increased dependence on monocultures. The feasibility of replacing at the scale required (several million km^2) the current

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[240] Wingenter et al. (2007).

[241] Woodhouse et al. (2008).

[242] Akbari et al. (2009).

[243] Hamwey (2007).

[244] Singarayer & Davies-Barnard (2012).

[245] Gaskill (2004).

[246] Lenton & Vaughan (2009).

[247] Bala & Nag (2011).

[248] Taha (2008).

[249] Vaughan & Lenton (2011).

[250] Ridgwell et al. (2009).

vegetation of semi-natural grasslands, shrublands and savannah with species or varities of higher albedo is even more questionable. If it could be done, the potential implications for biodiversity, ecosystems and their services are likely to be very high.

Non-biological means have been proposed to increase the reflectivity of (stable) desert regions, by covering them with a polyethylene/aluminium membrane.[251] The proponent of that scheme considered such areas to be expendable, on the basis that they are largely uninhabitated and sparsely vegetated. Nevertheless, deserts are not devoid of natural life, nor people: both would be highly impacted if such an approach were to be implemented at a climatically-significant scale, with significant negative ecological effects.[252] Desert dust also makes an important contribution to marine productivity, providing the main source of iron to most of the global ocean.[253]

Water surface

It has been proposed that the albedo of the surface ocean—and potentially other large water bodies, such an inland seas—might be enhanced through the introduction of microbubbles ("bright water") on the basis that microbubbles can be effective at enhancing reflectivity at parts per million levels.[254]

The feasibility of this scheme at the scale required is highly questionable.[255] If it were possible, there would be major biodiversity and biogeochemical implications. Not only would there be impacts of decreased light penetration and temperature changes on phytoplankton, but the microbial composition of the sea surface microlayer[256] would change, and air-sea exchange rates of CO_2 and other gases (highly sensitive to sea surface properties, including bubbles[257]) would also be affected.

Maintaining year round sea-ice cover in the Arctic would be the most effective and ecologically benign form of ocean albedo management. Unfortunately, that option seems increasingly unlikely under current climate change trajectories.[258]

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[251] Gaskill (2004).

[252] The Royal Society (2009).

[253] Jickells et al. (2005).

[254] Seitz (2011).

[255] Robock (2011).

[256] Cunliffe et al. (2011).

[257] Woolf (2005).

[258] Meier et al. (2007).

CHAPTER 5

POTENTIAL IMPACTS ON BIODIVERSITY OF CARBON DIOXIDE REMOVAL GEOENGINEERING TECHNIQUES

5.1 GENERAL FEATURES OF CDR APPROACHES

5.1.1 Reducing the impacts of climate change

By removing carbon dioxide (CO_2) from the atmosphere, CDR techniques are intended to reduce the concentration of the main causal agent of anthropogenic climate change. In addition, they are expected to ameliorate ocean acidification (Figure 2.1).

Any reductions in the negative impacts of climate change and ocean acidification on biodiversity (as summarized in Chapter 3) that might be achieved by effective and feasible CDR techniques would therefore be expected to have positive impacts on biodiversity, in a way that is far more certain than for SRM. However, as noted in Chapter 2: (i) these beneficial effects are generally slow-acting; (ii) the climatic conditions resulting from a specific atmospheric CO_2 value may be different if CO_2 is falling (as a result of a CDR measure) from the conditions previously experienced at the same CO_2 value when it was rising;[259] and (iii) several CDR techniques are of only modest or doubtful effectiveness,[260,261] with few (if any) considered realistically capable of fully offsetting current anthropogenic carbon emissions.

In addition, any positive effects from reduced impacts of climate change and/or ocean acidification due to reduced atmospheric CO_2 concentrations may be offset (or, in a few cases, augmented) by additional, unintended impacts on biodiversity of the particular CDR technique employed. Such additional impacts are summarised in Table 5.1, and are reviewed on a technique-specific basis in sections 5.2 -5.7 below.

5.1.2 Carbon sequestration (removal and storage)

The term "carbon sequestration" was (provisionally) defined by the tenth meeting of the Conference of the Parties to the CBD[262] as "the process of increasing the carbon content of a reservoir/pool other than the atmosphere". However, in a geoengineering context this usage is ambiguous, since no temporal constraints are included. It is therefore preferable to clearly recognise that carbon sequestration (through CDR geoengineering) necessarily involves two steps:

i) removal of CO_2 from the atmosphere; and

ii) long-term storage of the captured carbon, taking it out of circulation for a climatically-significant period (e.g., at least 10 years, and preferably > 100 years).

These processes occur naturally, but the former does not necessarily lead to the latter. Thus most of the products of either terrestrial or marine photosynthesis are recycled annually or on shorter timescales by plant, animal or microbial respiration. Effective sequestration requires that both steps can be demonstrated. Nevertheless, the term is sometimes used as the descriptor for only the latter, storage component,[263] contrasting to the CBD's definition above that seems to focus only on the initial removal.

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[259] Chadwick et al. (2012).

[260] Vaughan & Lenton (2011).

[261] McLaren (2011).

[262] Footnote to CBD decision X/33, paragraph 8(w).

[263] In legal and/or financial usage, sequestration involves secure holding and access restrictions, e.g. of assets.

Table 5.1: Classification of CDR techniques and summary of additional impacts relevant to biodiversity (other than climatic benefits via reduced radiative forcing). See text for discussion of available information on effectiveness and feasibility.

Technique		**Location of side effects**		**Ameliorates ocean acidification (OA)*?**	**Nature of potential additional impacts** *Some of these are very uncertain; all are highly scale-dependent*
		Capture	Storage		
1. Ocean fertilization	Direct external fertilization	– Ocean –		Relocates OA effects from ocean surface to ocean interior	Changes to phytoplankton productivity and diversity, food-webs and biogeochemical cycling; increased anoxia and acidification in deep sea
	Up/downwelling modification	– Ocean –			
2. Enhanced weathering	Ocean alkalinity	– Ocean** –		Yes, but risk of local excess alkalinity	Habitat destruction from mining and transport on land; high energy use; local impacts of excess alkalinity at sea
	Spreading of base minerals	– Land*** –		Yes	Habitat destruction from mining and transport; high energy use; effects on soil structure and fertility; increased soil albedo
3. Terrestrial ecosystem management	Afforestation	– Land –		Yes	Negative and positive impacts of land use change
	Reforestation	– Land –		Yes	Generally positive impacts on forest ecosystems
	Soil carbon enhancement	– Land –		Yes	Mostly positive impacts of soil carbon enhancements
4. Biomass	Biomass production	Land	N/A	Yes	Land-use/habitat change; potential for nutrient depletion
	Biofuels with CCS	N/A	Sub-surface	OA amelioration achieved via CO_2 removal (covered above)	*Above,* plus estimated small risk of leakage from CCS storage
	Charcoal storage		Land		*Above* , plus mostly benign but uncertain impacts on soil water retention and fertility; effects on N_2O emissions; decreased albedo
	Ocean biomass storage		Ocean	Local leakage risk	*Above,* plus damage to benthic environments
5. Direct air capture		Either	N/A	Yes	Minor land cover changes; water and energy use; pollution risks
6. Carbon storage	Ocean CO_2 storage	N/A	Ocean	Severe local OA impacts	Damage to deep sea ecosystems, via severe local ocean acidification
	Geological carbon reservoirs		Sub-surface	Low leakage risk	Estimated small risk of leakage

* "Yes" in this column indicates that amelioration of ocean acidification is expected to be directly proportional to absolute or relative reduction achieved in atmospheric CO_2.

** As indicated in right-hand column, ocean alkalinity will also have unintended, indirect impacts on land.

*** Spreading of alkaline minerals will eventually have impacts (expected to be mostly positive) on shelf seas and ocean through river run-off.

In some biologically—and chemically—driven CDR processes these two steps are very closely linked; for example, in ocean fertilization techniques, and for afforestation, reforestation and soil carbon enhancement. In such cases, the impacts of the CDR technique on biodiversity are almost entirely limited to either the environmental system (marine or terrestrial) where the technique is carried out. In other cases, the steps are discrete, and various combinations of carbon removal and storage options are possible. Thus CDR processes that initially involve land biomass production could subsequently involve carbon storage in the ocean as crop residues; or carbon burial in soil as charcoal (potentially with some energy extraction); or use of the carbon directly as biofuel with the resultant CO_2 removed at source and stored either in sub-surface reservoirs or the deep ocean. In all these cases, each step will have different and additive potential impacts on biodiversity, and both marine and terrestrial environments may be affected.

In the case of enhanced weathering, there will be the indirect impacts of large-scale mining and processing of minerals, and their transport, in terrestrial environments (with associated energy and water implications) as well as the direct impacts of the measure in the ocean and/or on the land.

5.1.3 Impact on ocean acidification

While removal of CO_2 from the atmosphere should reduce ocean acidification (based on a near-linear relationship between atmospheric CO_2 and surface ocean hydrogen ion concentration, at constant temperature),[264] this positive impact may be compromised.[265] For example, if the CO_2 leaks into the ocean from geological storage sites or as a result of decomposition of ocean stored biomass, or if the net effect of the CDR measure is to transfer CO_2 from the atmosphere to the ocean interior. Technique-specific effects on ocean acidification are discussed in greater detail under sections 5.2–5.7 below, as far as they are known.

5.1.4 Potentially vulnerable biodiversity

Ocean-based approaches and potentially vulnerable marine biodiversity

The unintended impacts of ocean-based CDR will vary greatly according to techniques. Whilst one approach—ocean iron fertilization—has been relatively well investigated through small-scale experiments and models (with several reviews[266,267]), most other interventions remain theoretical and their effectiveness is unproven.

The behaviour of marine ecosystems when subject to large-scale, long term perturbations is inherently difficult to model and predict due to the complex interactions between marine physical, chemical and biological processes. Even under strong mitigation scenarios, unintended CDR impacts will be superimposed on climatically-driven physical changes (temperature, circulation and mixing; also changes in ice cover and river inputs), operating over a wide range of spatial and temporal scales. Furthermore, several CDR techniques use the deep sea, seafloor or sub-seafloor for long term carbon sequestration,[268] potentially affecting species and ecosystems that seem likely to be particularly vulnerable, yet are not well known.[269] For example, many deep sea multicellular organisms are long-lived, relatively immobile and produce few offspring.[270] If such populations were to be severely impacted at the local/regional level, recolonization and community recovery in the deep ocean may take decades to centuries, compared to months to years in shallow waters.[271]

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[264] The Royal Society (2005).

[265] Williamson & Turley (2012).

[266] Secretariat of the Convention on Biological Diversity (2009c).

[267] Wallace et al. (2010).

[268] IPCC (2005b).

[269] Costello et al. (2010).

[270] Gage & Tyler (1991).

[271] Smith & Demopoulos (2003).

The deep sea and its sub-seafloor sediments also contain high abundances and diversity of prokaryotes (bacteria and archaea),[272,273] responsible for longterm element re-cycling. Several of these groups have high biotechnological potential.[274] However, marine microbes in deep sea sediments are not well studied: the overwhelming majority of such taxa are undescribed, and their role in delivering ecosystem services is currently poorly understood.

Other than at vent sites, the abundance of non-microbial benthic organisms generally decreases with depth, probably associated with the diminishing flux of food. However, species diversity can be high between 2000 and 3000 m depth, with each species having a low population size.[275] The fauna living in the water column is generally less diverse than that on the sea floor, due to physical mixing (slow, but operating on a global scale) and the relative uniformity of vast volumes of water in the deep ocean.

Most experimental studies on CO_2 (and pH) sensitivity of benthic and sediment-dwelling organisms have been carried on shallow-water species.[276] Cold-water corals currently living close to carbonate saturation horizons (2000m in the North Atlantic; 50-600m in the North Pacific) are likely to be especially vulnerable to CDR-enhanced deepwater pH changes.[277] Those species living at greater water depths already experience relatively low pH (< 7.4, cf ~8.1 in the upper ocean),[278] that will vary according to episodic inputs of organic material from the upper ocean.[279] Within sediments, pH can vary by more than 1.7 units within the top few millimetres or centimetres,[280] with deeper values being relatively insensitive to changes in the overlying seawater.

Land-based approaches and potentially vulnerable terrestrial biodiversity

Land-based CDR potentially covers a range of proposals, although (as noted in Chapter 2) there is not yet consensus regarding the inclusion within geoengineering of several approaches, such as bio-energy carbon capture and storage, and changes in forest cover and land use. In many cases, such methods replicate natural processes or reverse past anthropogenic changes to land cover and land use. Here, techniques are considered as CDR geoengineering if carried out for the purpose of carbon removal and storage, and deployed (collectively) at sufficient scale to achieve a significant climatic effect.

The level of information concerning many of the land-based CDR approaches, as broadly defined above and in section 2.1, is relatively well-developed. For example, reforestation and restoration activities reverse previous human-induced land-use changes, and the implications of these activities on biodiversity, ecosystem services, surface albedo, and local/regional hydrological cycles are reasonably well known. There have been several field-based assessments to measure the impacts of biochar on crop yield, nutrient cycles, water availability and other factors (see 5.6.2 below); nevertheless, many uncertainties remain.

Studies to date on land-based CDR approaches can only provide limited information on effectiveness, feasibility and safety for geoengineering deployments. That is because the scale of intervention to significantly affect climate would be several orders of magnitude greater than what has been investigated thus far.

Because of the range of land-based CDR techniques considered here, it is difficult to identify which terrestrial ecosystems and species will be most vulnerable to potential negative impacts. However, in discussions on biofuel production, Parties to the CBD identified the following four vulnerable components of terrestrial biodiversity that warranted particular consideration: primary forests with native species; rare, endangered, threatened and endemic species; high biodiversity grasslands; and peatlands and other wetlands.[281]

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[272] Fry et al. (2008).

[273] Lipp et al. (2008).

[274] Bull & Stach (2007).

[275] Snelgrove & Smith (2002).

[276] Andersson et al. (2011).

[277] Turley et al. (2007).

[278] Joint et al. (2011).

[279] Gooday (2002).

[280] Widdicombe et al. (2011).

[281] Secretariat of the Convention on Biological Diversity (2009b).

The projected impacts on biodiversity of individual CDR approaches are considered below

5.2 DIRECT OCEAN FERTILIZATION

Ocean fertilization involves enhancing the supply of nutrients to the marine environment with the aim of increasing the uptake of CO_2 in the oceans through biological processes and the subsequent long-term storage of a portion of the additional organic carbon in the deep sea. Fertilization may be directly achieved through the addition of nutrients from external sources; it may also be indirectly achieved by modifying ocean upwelling/downwelling, as discussed below (5.3).

Most attention has been given to iron, an element lacking in some ocean areas (primarily the Southern Ocean and equatorial Pacific), yet only required in small quantities as a micro-nutrient by phytoplankton and other marine organisms. Other proposed approaches include the addition of macro-nutrients such as nitrogen and phosphorus, in very much greater amounts.

There have been 13 field experiments on iron-based ocean fertilization over the last 20 years, at the scale of 50–500 km^2, and two on macro-nutrient additions. Although not designed for geoengineering purposes, these studies have addressed several of the uncertainties concerning the impacts of ocean fertilization on biodiversity.[282,283] They have also shown (together with associated modelling) that this is a technique of limited effectiveness for long term carbon sequestration, since most of the enhanced carbon uptake is returned to the atmosphere relatively rapidly,[284] rather than being transported and stored in the deep ocean or in sea-floor sediments. Several issues relating to technical feasibility have yet to be resolved, and the costs of monitoring and verification of long-term sequestration (with assessment of whether negative impacts might be occurring locally or elsewhere) seem likely to be high.

Changes in marine biodiversity, ecosystem services and marine bio-resources

For ocean fertilization to work, biological primary production (photosynthesis by algae and bacteria) needs to increase; this will inevitably involve changes in phytoplankton community structure and diversity,[285,286] with implications for the wider food-web. Such effects can be considered either positive or negative from a biodiversity perspective. Whilst the duration of those changes will depend on the fertilization method and treatment frequency, the desired outcome would be to closely mimic or enhance natural phytoplankton blooms, typically lasting a few weeks.

More significant and longer-term changes are, however, likely if ocean fertilization is sustained, and carried out on a climatically-significant scale. Such changes may include an increased risk of harmful algal blooms, involving toxic diatoms.[287,288] In addition, if the supply of organic matter to deep sea sediments were significantly enhanced, that could be expected to result in greater densities and biomass of benthos.[289]

Iron-induced increases in marine productivity and carbon uptake will only occur in those ocean regions where iron is currently lacking yet macro-nutrients are abundant, primarily the Southern Ocean and equatorial Pacific. However, increases in net primary productivity in these regions will be offset (to some degree) by decreases in other areas (Figure 5.1) due to use of upper ocean macro-nutrients as part of the fertilization process.[290]

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[282] Secretariat of the Convention on Biological Diversity (2009c).

[283] Wallace et al. (2010).

[284] The highest estimate of longterm removal (≥ 50%) in a field experiment is by Smetacek et al. (2012) [Document published after the main preparation of this Expert Group report; however, it is not considered to justify any change to the key messages presented here].

[285] Boyd et al. (2007).

[286] Boyd et al. (2004).

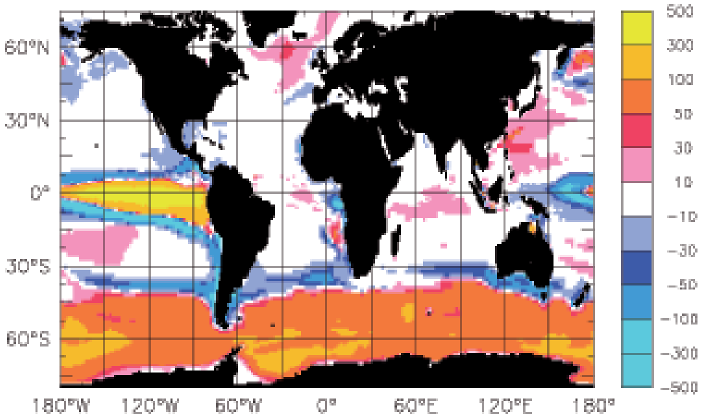
[287] Trick et al. (2010).

[288] Silver et al. (2010).

[289] Wolff et al. (2011).

[290] Gnanadesikan & Marinov (2008).

Figure 5.1. Changes in primary production after 100 years of global iron fertilization[291]



Projected increases (red, orange and yellow) and decreases (blue) in vertically integrated primary productivity (gC/m²/yr) after 100 years of global iron fertilization.

Increases in marine productivity (and associated CO_2 removal from the atmosphere) on a much wider spatial scale could, in theory, be achieved if biologically-available nitrogen (N) or phosphorus (P) were added to the ocean instead of iron (Fe); such an approach has been proposed.[292]

Whilst no large-scale N addition experiments have been carried out, the two experiments with P additions in P-deficient waters did not result in the expected productivity enhancements,[293] presumably because other nutrients were also limiting. Thus (as on land) the addition of a range of macro- and micro-nutrients would almost certainly be necessary to stimulate substantive increases in marine production in most of the global ocean, currently nutrient limited—with the implication that, for geoengineering purposes, many thousands of millions of tonnes of fertilizer are likely to be needed every year to achieve discernible climatic effects. Such considerations greatly reduce the cost-effectiveness and sustainability of ocean fertilization based on external macro-nutrients.

Fish stocks might, however, benefit from any increase in phytoplankton (and zooplankton) that could be achieved from ocean fertilization, whether by Fe, N, P or other nutrients. Field Fe-based studies to date have been too small and too short to test such ideas; nevertheless, caution would be needed, since fish production could also decrease in far field areas where primary production is reduced (Figure 5.1), and in response to altered water quality (increased anoxic zones and lower pH) in mid and deep water.

Effects on ocean acidification and other biogeochemical changes

Although ocean fertilization may slow near-surface ocean acidification, it would increase acidification of the deep ocean. The benefits of the former effects seem unlikely to be great: a maximum pH offset of 0.06 units has been calculated for fully-global iron fertilization[294] (i.e. less than the pH change that has occurred in the upper ocean in the past century), with the maximum global reduction in atmospheric CO_2 estimated to be ~33 ppm after 100 years of global deployment.[295]

Nevertheless, if successful, ocean fertilization would increase biogeochemical cycling in surface layers. One expected consequence would be enhanced production and remineralisation of sinking particles, with associated potential additional production of methane (CH_4) and nitrous oxide (N_2O).[296] If released in any quantity to the atmosphere, these greenhouse gases could significantly reduce the (modest) effectiveness of ocean fertilization as a

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[291] Aumont & Bopp (2006).

[292] Jones (2011).

[293] Thingstad et al. (2005).

[294] Cao & Caldeira (2010).

[295] Aumont & Bopp (2006).

[296] Law (2008).

geoengineering technique. Whilst enhanced dimethyl sulphide (DMS) emissions from plankton might be considered a "beneficial", unintended outcome of ocean fertilization, due to albedo effects,[297] the scale (and even sign) of this response is uncertain, and the overall linkage between DMS and climate is now considered relatively weak.[298]

5.3 MODIFICATION OF UPWELLING AND DOWNWELLING

Artificial upwelling is an ocean fertilization technique that has been proposed to bring deep water (from 200–1000 m) naturally rich in a range of nutrients to the surface, through some type of pipe, to fertilize the phytoplankton[299]. Limited field experiments have been carried out in the Pacific.[300,301]

The intended effects are essentially the same as for externally-adding nutrients, as above and will therefore not be repeated here. However, there is a major problem with the concept, as the nutrient-rich water brought up to the surface also contains high concentrations of dissolved CO_2 derived from the decomposition of organic material. The release of this CO_2 to the atmosphere[302,303] would counteract most (if not all) of the potential climatic benefits from the fertilization of the plankton.

Upwelling in one area necessarily also involves downwelling elsewhere. Modifying downwelling currents to carry increased carbon into the deep ocean by either increasing the carbon content of existing downwelling or by increasing the volume of downwelling water has also been proposed as a possible geoengineering approach, without necessarily involving enhanced biological production.

While the view of some authors[304] is that "modifying downwelling currents is highly unlikely to ever be a cost-effective method of sequestering carbon in the deep ocean", lower-cost structural approaches have recently been proposed, with the claim that the downwelling would stimulate adjacent upwelling, increasing primary production and carbon drawdown, and benefitting fisheries.[305] In order to estimate the number of such structures necessary to achieve global climate impact, the hydrodynamics and biogeochemistry of such systems would need further attention. However, such an approach is likely to require coverage of a significant proportion of the ocean surface, since—as for other CDR techniques—the geoengineering requirement is for long-term sequestration of anthropogenic carbon, not stimulating carbon cycling per se. In particular: i) if the increased phytoplankton growth is stimulated by nutrients from deeper water, such water will also contain higher CO_2, thus net drawdown of atmospheric CO_2 is unlikely to be achieved; ii) there is considerable variability in the timescale of carbon re-cycling in the ocean interior, determining the rate of return of additional, biologically-fixed CO_2 to the atmosphere and iii) enhancement of biological production at the scale required for climatic benefits is likely to significantly deplete mid-water oxygen, resulting in increased CH_4 and N_2O release.

Because of these complications, the overall effectiveness of any upwelling/downwelling modification is questionable. Furthermore, high costs are likely to be involved in achieving reliable data on any long term carbon removal (needed for international recognition of the effectiveness of the intervention), and in quantifying potentially counter-active negative impacts, over large areas (ocean basin scale) and long time periods (10–100 years).

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[297] Wingenter et al. (2007).

[298] Quinn & Bates (2011).

[299] Lovelock & Rapley (2007).

[300] Maruyama et al. (2011).

[301] White et al. (2010).

[302] Oschlies et al. (2010).

[303] Yool et al. (2009).

[304] Zhou & Flynn (2005).

[305] Salter (2009).

5.4 GEOCHEMICAL SEQUESTRATION OF CARBON DIOXIDE

CO_2 is naturally removed from the atmosphere by the weathering (dissolution) of carbonate and silicate rocks, forming bicarbonates and other compounds. However, the process of natural weathering is very slow: CO_2 is consumed at less than one hundredth of the rate at which it is currently being emitted.[306] It has therefore been proposed that, in order to combat climate change, the natural process of weathering could be artificially accelerated. There is a range of proposed techniques that include releasing calcium carbonate or dissolution products of alkaline minerals into the ocean, or spreading abundant silicate minerals such as olivine[307] over agricultural soils—as discussed below.

5.4.1 Enhanced ocean alkalinity

This proposed approach is based on adding alkaline minerals (e.g., carbonate or silicate[308] rock) or their dissolution products to the ocean in order to chemically enhance ocean storage of CO_2; it also expected to buffer the ocean to decreasing pH, and thereby help to counter ocean acidification.[309]

It has been proposed that dissolution products of alkaline minerals could be released into the ocean through a range of techniques that include: i) CO_2-rich gases dissolved in sea water to produce a carbonic acid solution that is then reacted with a carbonate mineral to form calcium and bicarbonate ions;[310,311,312] ii) addition to the ocean of bicarbonate ions produced from the electrochemical splitting of calcium carbonate (limestone);[313] and iii) addition of magnesium and calcium chloride salts from hydrogen and chlorine ions produced from the electrolysis of sea water to form hydrochloric acid which is then reacted with silicate rocks.[314]

For deployment for geoengineering purposes, all of these techniques would require very large volumes of feedstock minerals, abundant (non-carbon) energy, water, and extensive associated operational infrastructure. Most proposals envisage the addition of material through a pipeline into the sea or indirectly through discharge into a river: hence constraining their application to coastal zones, and limiting the potential for rapid dilution (thereby increasing the risk of local negative impacts on ecosystems).

Other proposals involve the direct addition of limestone powder[315] or calcium hydroxide[316] to the ocean from ships, thereby increasing flexibility with the sites of application and also potentially achieving much higher dilution rates (therby minimizing short-term pH spikes). Note that the manufacture of calcium hydroxide requires energy and releases CO_2 (that would need to be captured and safely stored), although the overall process is theoretically capable of net uptake.

Such processes undoubtedly could have high long term effectiveness, i.e. on geological timescales. However, for geoengineering purposes, the maximum potential effectiveness of generic enhanced alkalinity techniques (in terms of their radiative forcing) has been estimated[317] as very low, at ≤ 0.03 W m^{-2}. This value is less than 1% of the

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[306] Uchikawa & Zeebe (2008).

[307] Schuiling & Krijgsman (2006).

[308] The weathering of calcium carbonate ($CaCO_3$) by CO_2 mostly produces bicarbonate ions and calcium ions; the weathering of magnesium silicate (olivine; Mg_2SiO_4) mostly produces bicarbonate ions, magnesium ions, and silicic acid (H_4SiO_4). In theory, the latter is more efficient, absorbing four molecules of CO_2 for each molecule of magnesium silicate, with potential sequestration of 0.34 tonnes of carbon for each tonne of olivine.

[309] Kheshgi (1995).

[310] Rau & Caldeira (1999).

[311] Caldeira & Rau (2000).

[312] Rau (2011).

[313] Rau (2008).

[314] House et al. (2007).

[315] Harvey (2008).

[316] Cquestrate (http://www.cquestrate.com/).

[317] Vaughan & Lenton (2011).

forcing required to counteract anthropogenic climate change. In part this likelihood of very low effectiveness is due to the very large volume of the ocean (1.3 billion km^3): substantive changes to the carbonate chemistry of a significant proportion of that volume need to be made to have any drawdown effect on atmospheric CO_2.

Impacts of local excess alkalinity on marine biodiversity

While the theoretical chemistry of the processes of enhancing ocean alkalinity is relatively straightforward, the impacts on those processes on biodiversity (if the technique were to be deployed) are much more uncertain. In particular, the biological effects of temporarily enhanced Ca_2^+ ions and dissolved inorganic carbon are not adequately known.

It could be expected that the initial local spatial and temporal pH spike might be harmful to biodiversity (and hence, potentially, ecosystems and their services). However, this impact is transient and could be minimized through rapid dilution and dispersion and, in the case of particulate material, by controlling the dissolution rate of the substance through its particle size.

There are large unknowns associated with enhanced ocean alkalinity, due to limited knowledge of effects on atmospheric CO_2 and potential biological impacts. In particular, no field experiments have been carried out, and there are a limited number of theoretical papers available. Furthermore, as already noted, it is questionable whether any of the approaches above can be scaled-up sufficiently to make a difference to the global carbon budget in a cost-effective way. Nevertheless, local use of enhanced alkalinity techniques may provide a means of counteracting the worst effects of ocean acidification for specific high-value marine ecosystems, e.g. coral reefs.

5.4.2 Land-based enhanced weathering

Closely similar to the techniques discussed above, it has been proposed that the natural process of land-based weathering could be artificially accelerated; for example, by reacting silicate rocks with CO_2 to form carbonates, bicarbonates and other products. One proposed method is to spread finely-ground silicate minerals such as olivine over agricultural soils and river catchments.[318] It has been estimated that this approach could globally sequester up to 1 Gt C yr^{-1}, using at least 3–4 Gt yr^{-1} of olivine (for comparison, current coal production is ~6 Gt yr^{-1}).

The method would be most effective in the humid tropics. If the Amazon and Congo basins could both be fully treated with olivine at an application rate of ~300 g m^2 yr^{-1}, their combined carbon sequestration potential has been calculated[319] as 0.6 Gt C yr-1. However, river pH would estimated to rise to 8.2 (currently 5.7–7.8) and the additional delivery of biologically-available silicon could increase the regional-scale abundance of diatoms in the ocean. The latter effect could potentially increase atmospheric CO_2 drawdown through ocean fertilization effects.[320]

No field studies have been published to date to quantify CO_2 uptake rates by land-based enhanced weathering, although direct measurements of chemical changes, with associated carbon uptake, have been made for magnesium carbonate minerals in mine waste.[321]

Impacts on biodiversity

The addition of alkaline rock dust, e.g. olivine, to low pH, nutrient-deficient soils may (under certain conditions) increase the productivity of those soils, thereby reducing the incentive to convert previously non-agricultural land into agricultural land. However, positive impacts cannot be assumed for all soil types, and, in order to have a significant effect on the Earth's climate, large-scale mining, processing and transport activities would necessarily be

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[318] Schuiling & Krijgsman (2006).

[319] Köhler et al. (2010).

[320] Oral presentation by Peter Köhler at Planet under Pressure conference, London, 27 March 2012.

[321] Wilson et al. (2009).

involved. Such additional impacts would potentially exacerbate habitat degradation and loss, for climatic benefits that are currently relatively uncertain (at the timescale required).

Whilst there is the possibility of modest positive impact on planetary albedo, a relatively high proportion of the Earth's land surface would need to be significantly lightened to achieve additional climatic benefits by that means (section 4.2.3).

As raised in the previous section, effects of land-based enhanced weathering would not be limited to the terrestrial environment, with rivers, coastal seas and the open ocean also potentially impacted if the techniques were to be applied at a climatically-significant scale.[322] The likely impacts of increased river pH (enhanced alkalinity) on freshwater biodiversity have yet to be investigated in a geoengineering context. The liming of acidified lakes and rivers provides some relevant data, and in Norway such treatment has generally been considered as ecologically-beneficial.[323] However, that treatment has been carried out to restore the pH of rivers to their historic baselines, rather than changing them to a novel state.

5.5 RESTORATION, AFFORESTATION, REFORESTATION, AND THE ENHANCEMENT OF SOIL CARBON

Although not always viewed as geoengineering per se, familiar methods such as afforestation, reforestation, and the enhancement of soil carbon can play a small but significant role in moderating climate change[324] through increasing carbon storage in natural and managed ecosystems (forests, plantations and agricultural lands).

Afforestation involves the direct and intentional conversion of land that has not been forested (for at least 50 years, for the purposes of the first commitment period of the Kyoto Protocol) into forested land, through planting, seeding and/or the promotion of natural seed sources by humans. Reforestation involves similar techniques, but is carried out on land that was previously forested but converted to non-forested land at a certain point in time (before 31 December 1989, for the purposes of the first commitment period of the Kyoto Protocol). Since both afforestation and reforestation result in increased forest cover, their potential impacts on biodiversity and ecosystem services are discussed collectively below. Restoration of some other ecosystems (marine as well as terrestrial), while making significant contributions to biodiversity, may also make additional though smaller contributions to reducing atmospheric CO_2.

A related means of ecosystem carbon storage is the enhancement of soil carbon. This is achieved by improving land management practices; for instance, preventing captured CO_2 from reaching the atmosphere, and altering livestock grazing patterns so as to increase root mass in the soil.

Impacts on biodiversity

The impacts on biodiversity of ecosystem carbon storage depend on the method and scale of implementation. If managed well, this approach has the potential to increase or maintain biodiversity. However, if managed badly, it may result in the reduction of the distribution of certain biomes; the introduction of invasive alien species; inappropriate land use conversion (e.g., from natural, mixed grassland to monoculture forest); and subsequent loss of species. Since afforestation, reforestation and land use change are already being promoted as climate change mitigation options, much guidance has already been developed. For example, the CBD has developed guidance to maximize the benefits of these approaches to biodiversity, such as the use of assemblages of native species, and to

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[322] Köhler et al. (2010).

[323] Fiellheim & Raddum (2001).

[324] The Royal Society (2009).

minimize the disadvantages and risks[325,326,327] such as the use of monocultures and potentially invasive species. The CBD is also developing advice for the application of REDD+ biodiversity safeguards (reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries).

In order to maximize biodiversity benefits, ecosystem storage of carbon should be based on an environmental impact assessment including impacts related to biodiversity and native species. Interventions should also incorporate resilience to anticipated climate change, and should prioritize climatically-appropriate native assemblages of species. Where such recommendations have not been followed (e.g., in reforestation projects using non-native species), the result has often been monoculture plantations which are unable to support viable population of endemic species.[328]

Impacts on ecosystem services

Increased soil carbon can increase the amount of water retained in the soil, thereby increasing the resilience of ecosystems and potentially mitigating the water-depleting effects of climate change in arid areas. In addition, increased soil carbon has the potential to enhance crop productivity. This may reduce the incentive to convert previously non-agricultural land into agricultural land, and could therefore help to safeguard biodiversity. As demonstrated by a watershed-scale study in Oregon, USA, increasing carbon storage through the introduction of land-use policies can benefit a wide range of ecosystem services.[329] Moreover, several regional studies have demonstrated that benefits to ecosystem services such as water regulation, biodiversity conservation, and agriculture, can result from integrated land-use planning that delivers enhanced CO_2 sequestration.[330]

However, while increased soil water retention (as a result of increased soil carbon) may generally have positive effects, in some areas, increased water retention could lead to more anoxic conditions, increasing CH_4 and N_2O emissions. Moreover, enhanced plant productivity does not necessarily produce positive ecosystem impacts, if fast growing species are favoured. This could lead to shifts in ecosystem composition, interactions between species, and changes within food webs.

Risks and uncertainties

Large-scale increases in forest cover can have an impact on both planetary albedo and the hydrological cycle, and can create a protecting buffer for neighboring ecosystems against floods and other environmental perturbations. Newly created forests are also likely to emit volatile organic compounds (VOCs), which increase the concentration of cloud condensation nuclei and therefore affect cloud formation. However, the combined effects of increased forest cover on the hydrological cycle,[331] planetary albedo and cloud cover, and subsequent impacts on biodiversity and ecosystem services, are currently not well understood.[332] This is an area where the need for further research and assessment has been identified.[333]

Other key uncertainties relate to which soil types are most suitable for carbon enhancement, to avoid adverse side effects (e.g. anoxic conditions and methane release). It is also currently unclear how a soil carbon change might affect the community of species dependent on a particular soil type, and whether biodiversity benefits would ultimately increase or decrease.

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[325] Secretariat of the Convention on Biological Diversity (2009a).

[326] Secretariat of the Convention on Biological Diversity (2003).

[327] CBD COP decision VI/22 Annex and X/33 paragraph 8(p).

[328] Ramanamanjato & Ganzhorn (2001).

[329] Nelson et al. (2009).

[330] The Royal Society (2001).

[331] Arora & Montenegro (2010).

[332] Anderson et al. (2011).

[333] Russell et al. (2012).

5.6 BIOLOGICAL CARBON CAPTURE AND STORAGE IN LAND BIOMASS

As already noted, land-based biomass approaches to CO_2 removal involve two steps: biomass production and biomass storage or disposal.

5.6.1 General issues on biomass production

Biomass-based approaches are based on the assumption that biomass production is either carbon neutral or results in very low greenhouse-gas emissions. However, recent work[334,335] shows that this assumption can be seriously flawed and that biomass production, if not well-managed, may incur a carbon debt for several decades or centuries.

Habitat loss

Production of biomass for carbon sequestration on a scale large enough to be climatically significant would likely entail large changes in land use leading to the significant loss of biodiversity and habitats directly, or indirectly as biomass production displaces food crops, which subsequently leads to encroachment into natural areas. These effects are similar to those resulting from expansion of biofuels.[336,337,338] For example, a recent assessment of global biochar potential (see section 5.6.2*)* indicates that the capture of 12% of annual anthropogenic CO_2 emissions would require 556 million hectares of dedicated biomass plantations, much of it through the conversion of tropical grasslands.[339] In addition to the impacts on biodiversity, these land use changes would entail net greenhouse-gas emissions due to land use change.[340,341] Biomass production on previously degraded areas, if well-managed, may deliver biodiversity benefits; however, even here, greater benefits in terms of both biodiversity and net greenhouse gas reductions may be achieved through restoration of natural habitats on these lands. [342]

The environmental consequences of an ambitious global cellulosic biofuels programme up to 2050 have been modeled.[343] The study looked at two scenarios: one in which there were no restrictions on deforestation and in which any land would be available for biofuel production as long as it was economically viable (deforestation scenario), and the other in which the conversion of natural forests and other "unmanaged land" was limited to recent regional land conversion rates (intensification scenario). The study concluded that the more optimistic intensification scenario would see the loss of 3.4 million km^2 of grasslands currently used for grazing, 38% of the natural forest cover and 38% of wooded savannah in sub-Saharan Africa based on 2000 figures. In Latin America, the same scenario would be associated with the loss of 20% of natural forests and savannah.

Other impacts on biodiversity

Proposals for carbon sequestration of carbon as crop residues in the ocean (section 5.6.3) envisage the removal of some 30% of crop residues from agricultural systems.[344] This is likely to have negative impacts on productivity, biodiversity, and soil quality.

There are clear trade-offs between optimizing land for bioenergy crop yield and for biodiversity benefits; where monocultures of non-native species are employed in the production of biofuels the projected impacts on biodiversity

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[334] IAASTD: http://www.agassessment.org/docs/SR_Exec_Sum_280508_English.htm.

[335] Searchinger et al. (2009).

[336] Righelato & Spracklen (2007).

[337] Searchinger et al. (2008).

[338] Fargione et al. (2008).

[339] Woolf et al. (2010).

[340] Searchinger et al. (2008).

[341] Fargione et al. (2008).

[342] Righelato & Spracklen (2007).

[343] Melillo et al. (2009).

[344] Strand & Benford (2009).

are negative. If, however, native assemblages of species are planted on degraded land and managed in a sustainable manner, benefits may be positive.

Bioenergy Carbon Capture and Storage (BECCS)

Bioenergy carbon capture and storage (BECCS) combines existing or planned technology for bioenergy/biofuels and for carbon capture and storage (CCS).[345,346] It involves harvesting biomass, using it as a fuel, and sequestering the resulting CO_2.

Issues related to bioenergy production are covered above. Issues related to chemically-based carbon capture and storage are addressed in section 5.7.

5.6.2 Charcoal production and storage (biochar)

CDR based on biochar involves the production of black carbon (charcoal) from land plant biomass, usually through pyrolysis (decomposition in a low- or zero-oxygen environment), and its longterm storage in soils or elsewhere, potentially for thousands of years.[347]

Land-use issues related to the production of biomass for charcoal production are covered above (section 5.6.1), while issues related to biochar storage in soils are addressed here.

Charcoal production and storage can potentially help slow the increase in atmospheric CO_2 since it prevents the natural process of biomass decomposition by micro-organisms, which returns carbon to the atmosphere. Biochar is very much more stable and resistant to such decomposition,[348] due to the bonds between its carbon atoms being much stronger than those in plant matter. However, assumptions regarding the longevity and benefits of black carbon are challenged by the variable results from field trials, indicating that impacts on soil carbon and soil carbon sequestration may be unpredictable and not always positive, even over a short time-span.[349,350,351,352]

Impacts of charcoal storage in soils on biodiversity and ecosystems

There is a wide variety of raw materials (feedstocks) for creating charcoal—such as wood, leaves, food waste and manure—and various conditions under which pyrolysis can take place. These variations, combined with the diversity of soil types to which biochar can be added, provide the main explanation why the impacts of biochar on soils, crop yields, soil microbial communities and detritivores can be highly variable.[353,354,355] In addition, the impacts of biochar on mycorrhizal fungi are not yet fully understood.[356]

As with increased soil (organic) carbon, discussed above, biochar can increase soil water retention, thereby enhancing the resilience of ecosystems and potentially mitigating the water-depleting effects of climate change in arid areas. However, while this property may have positive effects in some areas, in other areas increased water retention could lead to more anoxic conditions. Moreover, the large-scale deposition of biochar in suitable terrestrial locations is

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[345] Gough & Upham (2011).

[346] Lenton (2010).

[347] Spokas (2010).

[348] Cheng et al. (2008).

[349] Major et al. (2010).

[350] Steiner et al. (2008).

[351] Major et al. (2010).

[352] Steiner et al. (2007).

[353] Amonette & Joseph (2009).

[354] Lehmann et al. (2006).

[355] Asai et al. (2009).

[356] Warnock et al. (2007).

likely to require considerable transport, burying and processing, which could compromise the growth, nutrient cycling and viability of the ecosystems involved.[357]

There is a great deal of uncertainty surrounding the impacts of biochar on biodiversity and ecosystem services due to a lack of published research on biochar. Compounding this limitation is the fact that many field trials have relied on charcoal produced by wildfires rather than by the modern method of pyrolysis proposed for biochar geoengineering.[358]

Two other unintended impacts warrant mention. First, biochar application may decrease soil N_2O emissions, thereby potentially providing additional benefits.[359] Second, if used on light-coloured soils, biochar can decrease albedo, at least on a seasonal basis.[360] Whilst unlikely to have a climatically significant effect, the potential for that additional, negative, impact should nevertheless also be taken into account if very large-scale use of biochar is proposed for geoengineering purposes.

5.6.3 Ocean storage of terrestrial biomass

Ocean biomass storage (for example, the CROPS proposal: Crop Residue Oceanic Permanent Sequestration), involves the deep ocean sequestration of terrestrial crop residues on or in the seabed.[361,362] These proposals suggest that up to 0.6 Gt C (30% of global annual crop residues of 2 Gt C) could be available sustainably, deposited in an annual layer 4m deep in an area of seabed of ~1,000 km^2. However, an annual sequestration rate < 1 Gt C/yr would only make a modest contribution to slowing climate change.[363] Potentially, charcoal (biochar), timber or other organic remains could also be deposited on the seabed, if suitably ballasted. Nevertheless, it seems unlikely that deposition on the seabed would be the most effective use of such materials; e.g., it would seem more effective to obtain at least some energy from them, via a BECCS approach.

It should be noted that this technique would seem to be covered by the existing category of wastes "Organic material of natural origin" in Annex I of the London Protocol and "Uncontaminated organic material of natural origin" in Annex I of the London Convention.[364] That does not mean such disposal is prohibited; however, an appropriate regulatory framework would seem to be in place.

Impacts on biodiversity

Where crop residues are deposited as ballasted bales, it is likely that there will be significant physical impact (although of a relatively local nature) on the seabed due to the sheer mass of the material. In addition, there may be wider chemical and biological impacts through reductions in oxygen and potential increases in H_2S, CH_4, N_2O and nutrients arising from the degradation of the organic matter.

The degradation of crop residue bales is likely to be slow due to the ambient conditions of low temperature and limited oxygen availability; the apparent lack of a marine mechanism for the breakdown of ligno-cellulose material; and the anaerobic conditions within the bales.[365] While it can be argued that potential impacts could be reduced if deposition occurred in areas of naturally high sedimentation, such as off the mouths of major rivers (e.g., Mississippi),[366] many such areas are already susceptible to eutrophication and anoxia from existing anthropogenic,

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[357] The Royal Society (2009).

[358] Shackley & Sohi (2011).

[359] Clough & Condron (2010).

[360] Genesio et al. (2012).

[361] Metzger & Benford (2001).

[362] Strand & Benford (2009).

[363] Lenton & Vaughan (2009).

[364] International Maritime Organization (IMO) (2010).

[365] Strand & Benford (2009).

[366] Strand & Benford (2009).

land-derived nutrient inputs. These effects are likely to be worsened if increased use of inorganic fertilizer is needed to replace the nutrients removed in the crop residues.

The type of packaging would also be significant when assessing potential impacts as its permeability to water and gases has the potential to influence the flux of substances into near-seabed water. If the bales are buried within the sediment, then such impacts are likely to be significantly reduced. Additional manipulations would, however, almost certainly have cost implications.

The addition of significant amounts of organic matter to the deep sea floor could lead to greater densitiy and biomass of benthic organisms over a long period in the locations where the crop residues are deposited: a perturbation from the natural state.

The limited knowledge of ecosystem services from the deep sea combined with limited understanding of the impacts of ocean biomass storage lead to a lack of understanding about its impacts on ecosystem services. However, if done in the shallower end of the water depths suggested (1000–1500 m), its impacts on ecosystem services could be more significant since this is now within the range of deep sea fisheries. Whilst the area directly affected could be relatively restricted (on a global scale), larger-scale and longer-term indirect effects of oxygen depletion and deep-water acidification could be regionally significant if there is cumulative deposition of many gigatonnes of organic carbon to the seafloor, and most of this is eventually decomposed.

There are large unknowns due to limited knowledge as indicated above. No field experiments have been carried out and only a few peer-reviewed papers on the proposed technique have been published. Furthermore, while there is a lot of knowledge about the impact of organic enrichment on continental shelf environments, it is unclear whether this is easily translated into the very different deep sea environment.

5.7 CHEMICALLY-BASED CARBON DIOXIDE CAPTURE AND STORAGE

5.7.1 CO_2 capture from ambient air

Direct CO_2 capture is an industrial process that removes the gas from exhaust streams or ambient air, producing a pure CO_2 stream for use or disposal.[367,368] Three main technologies are being explored for achieving this: i) adsorption of CO_2 onto solids; ii) absorption into highly alkaline solutions; and iii) absorption into moderately alkaline solutions with a catalyst. The technical feasibility of air capture technologies is in little doubt and has already been demonstrated; for example, in the commercial removal of CO_2 from air for use in subsequent industrial processes. However, no large-scale geoengineering prototypes have yet been tested.

Capturing CO_2 from the ambient air (where its concentration is 0.04%) is more difficult and energy intensive than capturing CO_2 from exhaust streams of power stations where the CO_2 concentration is about 300 times higher. The main problem is the high energy cost.[369] Thus the process would need to be powered by a non-carbon fuel source (e.g. solar or nuclear energy) otherwise as much (or more) CO_2 would be produced than was captured.

A recent study[370] re-assessed the energetic and financial costs of capturing CO_2 from the air, considering that these issues placed the viability of this approach in doubt. There is also some risk of pollution from the manufacture of the sorbents involved (e.g. NaOH, produced by the chloralkali process) when manufactured at the very large scale that would be necessary for effective geoengineering. Such approaches are discussed in Chapter 6 of the IPCC Special Report on Carbon Dioxide Capture and Storage.[371]

Subsequent storage of the captured CO_2 is necessary, as considered below (section 5.7.2).

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[367] Keith et al. (2006).

[368] Keith (2009).

[369] Zeman (2007).

[370] House et al. (2011).

[371] IPCC (2005a).

Land and water requirements

Negative impacts on biodiversity through habitat loss due to land-use conversion would be relatively small for air capture systems, since they are expected to have a land-use footprint that is hundreds (or thousands) of times smaller per unit of carbon removed than that of biomass-based approaches.[372]

However, some proposed methods of air capture have a relatively high requirement for fresh water, which is already a scarce resource in most of the world. Furthermore, the disposal of captured CO_2, and the potential for leakage, might also impact terrestrial and marine ecosystems, as discussed below.

5.7.2 CO_2 storage techniques

CO_2 that has been extracted from the atmosphere by direct air capture (or from other geoengineering processes, e.g. the CCS part of BECCS) must be stored on a long term basis, with the quantities involved limiting such storage to either the ocean interior or sub-surface geological reservoirs. Such approaches are discussed comprehensively in Chapter 6 of the IPCC Special Report on Carbon Capture and Storage.[373]

Ocean CO_2 storage

The main variants of ocean CO_2 storage involve either adding CO_2 to middle/deep ocean waters or putting CO_2 in depressions in the seabed to form lakes/pools.[374,375] It has also been suggested to deposit solid CO_2 blocks in the sea;[376] inject liquid CO_2 a few hundred metres into deep-sea sediments at greater than 3,000 m depth,[377] displace the methane by CO_2 in methane hydrates on continental margins and in permafrost regions;[378] or discharge liquid CO_2 mixed with pulverized limestone at an intermediate depth of greater than 500 m in the ocean.[379] However, the economic viability of these methods has not been assessed, and none would permanently sequester the CO_2 since it will eventually return to the atmosphere over century-to-millennial time scales depending on where it was introduced.[380] So whilst they could help in buying time, it would be at the expense of future generations.

Disposal of CO_2 into the water column, on or in the seabed (other than in sub-seabed geological formations), is not permitted under the global instruments of the London Protocol 1996 and is explicitly ruled out under the regional OSPAR Convention covering the north East Atlantic region. The situation under the London Convention 1972 is currently unclear.

Impacts on biodiversity and ecosystem services

Ocean CO_2 storage will necessarily alter the local chemical environment, with a high likelihood of biological effects. Knowledge available for surface oceans indicates that effects on mid-water and deep benthic fauna/ecosystems is likely on exposure to pH changes of 0.1 to 0.3 units, primarily in marine invertebrates and possibly in unicellular organisms.[381] Calcifying organisms are the most sensitive to pH changes; they are however naturally less abundant in deep water, particularly if calcium carbonate saturation is already <1.0 (i.e. $CaCO_3$ dissolves, unless protected).

Total destruction of deep seabed biota that cannot flee can be expected if lakes of liquid CO_2 are created. The scale of such impacts would depend on the seabed topography, with deeper lakes of CO_2 affecting less seafloor area for

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[372] The Royal Society (2009).

[373] IPCCC (2005a).

[374] Nordhaus (1975).

[375] Marchetti (1977).

[376] Murray et al. (1996).

[377] House et al. (2006).

[378] Park et al. (2006).

[379] Golomb & Angelopolous (2001).

[380] Ridgwell et al. (2011).

[381] Gattuso & Hansson (2011).

a given amount of CO_2. However, pH reductions would still occur in large volumes of water near to such lakes,[382] and mobile scavengers are likely to be attracted (and themselves deleteriously affected) by the scent of recently-killed organisms.[383]

Ecosystem services from the deep seabed are generally of an indirect nature, relating to nutrient cycling and long term climate control. However, all deep water does eventually return to the surface and/or mix with the rest of the ocean. The use of the deep sea for large-scale CO_2 storage will therefore eventually reduce ocean pH as a whole, with potential effects greatest in upwelling regions (currently highly productive and supporting major fisheries).

The chronic effects of direct CO_2 injection into the ocean on ecosystems over large ocean areas and long time scales have not yet been studied, and the capacity of ecosystems to compensate or adjust to such CO_2 induced shifts is unknown. Several short-term and very small field experiments (litres) have, however, been carried out, e.g., on meiofauna,[384] and peer-reviewed literature on potential CO_2 leakages from geological sub-sea storage[385] is also relevant.

CO_2 storage in sub-surface geological reservoirs

CO_2 storage in sub-surface geological reservoirs is already being implemented at pilot-scale levels, and has been used industrially as part of enhanced oil recovery. Based in part on this experience, the risks are generally regarded as low. However, leakage from such reservoirs could have locally significant biodiversity implications.[386] It is expected that, where CO_2 storage in sub-seabed geological formations is authorized (by permit) under the London Protocol, information on the leakage and potential impacts will be reported and amassed over time.

There is potentially reduced risk of leakage from sub-surface reservoirs if the CO_2 is injected into basalt[387,388] or other minerals rich in calcium and/or magnesium[389] with which it would react—in a similar way to the enhanced weathering reactions described in section 5.4. With pure CO_2, the reactions are expected to be relatively rapid, limited by the porosity of the rock. This process is currently being tested at commercial scale.[390]

5.8 SEQUESTRATION OF GREENHOUSE GASES OTHER THAN CARBON DIOXIDE

CDR techniques necessarily focus on the removal of CO_2 from the atmosphere. Nevertheless, there could be significant climatic benefits if other greenhouse gases, particularly methane (CH_4) and nitrous oxide (N_2O) could also be removed.[391] Techniques are understood to be under development, but have not yet been reported in peer reviewed literature.

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[382] IPCC (2005a).

[383] Tamburri et al. (2000).

[384] Barry et al. (2004).

[385] IPCC (2005a).

[386] Wilson et al. (2003); Oruganti & Bryant (2009).

[387] Goldberg et al. (2008).

[388] Goldberg et al. (2010).

[389] Matter & Keleman (2009).

[390] Matter et al. (2009).

[391] Boucher & Folberth (2010).

CHAPTER 6

SOCIAL, ECONOMIC, CULTURAL AND ETHICAL CONSIDERATIONS OF CLIMATE-RELATED GEOENGINEERING

6.1 INTRODUCTION

Climate change is likely to have serious impacts on biodiversity, ecosystems and associated ecosystem services. The social, economic and cultural implications of unmitigated climate change and continued degradation of ecosystems should not be underestimated (Chapter 3). Furthermore, the social, economic and cultural considerations regarding geoengineering have significant inter- and intra-generational equity issues.

Geoengineering proposals have proved to be highly controversial, with a wide divergence of opinions about potential risks and benefits. All new technologies or techniques are embedded in a wider social context and have social, economic and cultural impacts that might become apparent only once they have been employed. However, geoengineering raises issues beyond technical scientific assessments due to its intentionality, and the inter- and intra-generational equity issues associated with its potential impacts. The controversies surrounding nuclear power, genetically modified organisms (GMOs) and nano-technologies have shown the importance of connecting scientific research to its wider social context.

The Conference of the Parties to the CBD, through its decision X/33 requested the Executive Secretary to identify social, economic and cultural considerations associated with the possible impacts of geoengineering on biodiversity. In this chapter, we discuss those issues, together with the role of indigenous groups and local communities in the context of geoengineering and biodiversity. Initial sections deal with social, economic and cultural issues that are relevant for geoengineering in general,[392] in order to put geoengineering technologies in a wider social context, and to highlight social, political, economic and cultural issues that ought to be of interest for the Parties to the CBD. The second part of the chapter has an explicit focus on potential social concerns associated with different geoengineering proposals and technologies and their impacts on biodiversity.

6.2 AVAILABLE INFORMATION

Assessing the social, economic and cultural impacts of geoengineering technologies as they relate to biodiversity is an important, yet difficult, task considering the current state of knowledge and the lack of peer-reviewed literature on the topic. It has also been questioned whether peer-reviewed literature can adequately reflect indigenous knowledge; knowledge which is often as much a process of knowing as it is a thing that is known, and so does not lend itself to the practice of documentation.[393,394] This is a major concern considering the role indigenous and local communities play in actively managing ecosystems, sometimes through an active application of local ecological knowledge that has evolved over long periods through co-management processes and social learning.[395]

Some work on this matter has been conducted within the framework of CBD activities on biodiversity and climate change, including a workshop on opportunities and challenges of responses to climate change for indigenous and local communities, their traditional knowledge and biological diversity (March 2008, Helsinki),[396] as well as through the consideration of the role of traditional knowledge innovations and practices during the second

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[392] These initial sections could be considered as beyond the explicit mandate of the group, but are included to put the technologies in a wider social context, as well as responding to comments on a draft of this report.

[393] Agrawal (1995).

[394] Berkes (2008).

[395] Berkes et al. (2004).

[396] Secretariat of the Convention on Biological Diversity (2008).

Ad hoc Technical Expert Group on Biodiversity and Climate Change;[397] however, further work remains to be done. In addition, there is a growing literature on social dimensions of geoengineering[398,399,400] including examples of social perceptions from historic efforts to engineer the climate and other large-scale planetary processes.[401] Issues related to geoengineering ethics, governance and socio-political dimensions have also been discussed within the geoengineering research community, as exemplified by the "Oxford Principles"[402] and the subsequent "Asilomar Principles".[403]

It should also be noted that there is very little information available about the perspectives from indigenous peoples and local communities, especially among developing countries within geoengineering discussions.[404] The CBD Secretariat has initiated a process to bring in the views of indigenous communities, and the results are presented in a separate report.[405]

6.3 GENERAL SOCIAL, ECONOMIC AND CULTURAL CONSIDERATIONS

There are a number of social, economic and cultural considerations from geoengineering technologies that may emerge, regardless of the specific geoengineering approach considered. These considerations are not necessarily unique for geoengineering, but have clear parallels to on-going discussions on social dimensions of climate change, emerging technologies, and complex global risks. It should be re-stated that this is not intended to be a complete all-encompassing analysis of costs and benefits, but should rather be seen as social, economical and cultural issues of potential concern. In addition, social perceptions of risks in general, are highly differentiated across social groups, are highly dynamic,[406] and pose particular socio-political challenges in settings defined by complex bio-geophysical interactions.[407,408] This complicates any projection of how the general public, non-governmental organizations and governments would perceive any experimentation and deployment of geoengineering technologies.

6.3.1 Ethical considerations

Humanity is now the major changing force on the planet, reflected in the proposal to define the Anthropocene[409] as a new geological epoch driven by human activities. This shift has important repercussions, not only because it forces us to consider multiple and interacting global environmental changes,[410,411] but also because it opens up difficult discussions on whether it is desirable to move from unintentional modifications of the Earth system, to an approach where we intentionally try to modify the climate and associated bio-geophysical systems to avoid the worst outcomes of climate change. Hence, the very fact that the international community is presented with geoengineering as a potential option to be further explored is a major social and cultural issue.

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[397] Secretariat of the Convention on Biological Diversity (2009a).

[398] Banerjee (2009).

[399] Victor et al. (2009).

[400] Galaz (2012).

[401] Fleming (2006).

[402] Rayner et al. (2009).

[403] Asilomar Scientific Organizing Committee (ASOC) (2010).

[404] However, public engagement initiatives have been piloted in the developed world, as a means of gauging public opinions on geoengineering, e.g. Ipsos MORI (2010).

[405] Secretariat of the Convention on Biological Diversity (2012a).

[406] Kasperson et al. (1988).

[407] Galaz et al. (2011).

[408] Mercer et al. (2011).

[409] Crutzen (2002).

[410] Rockström et al. (2009a).

[411] Steffen et al. (2011).

Geoengineering poses numerous ethical challenges.[412,413,414,415,416,417] The successful governance of geoengineering also requires the international community to resolve the conflicting objectives of avoiding the adverse effects of global climate change whilst also avoiding the risks and uncertainties of geoengineering.

Public engagement is an important part of this process, providing guidance on the research and input to policy-making. Although the need for such dialogue is widely recognised,[418,419,420] and some upstream public engagement on geoengineering has been trialled,[421,422] current discussions on geoengineering are often based on technical approaches whose implications are not readily understood nor easily assessed.[423] There is a growing discussion and literature on ethical considerations related to geoengineering, including issues of "moral hazard"[424] (whereby attention to geoengineering reduces the effort given to mitigation); the potential for the opposite effect;[425] intergenerational issues of submitting future generations to the need to maintain the operation of the technology or suffer accelerated change;[426] the possibility that development and uses of geoengineering techniques are perceived to be threatening by governments;[427] as well as the question of whether it is ethically permissible to remediate one pollutant by introducing another.[428]

6.3.2 Unintended consequences and technological lock-in

Technological innovation has in very many ways helped to transform societies and improve the quality of life, but not always in a sustainable way.[429] Failures to respond to early warnings of unintended consequences of particular technologies have been documented.[430] The possibility of unintended side effects in the large-scale application of geoengineering techniques is a frequent concern in the literature and wider debate, especially for SRM methods (Chapter 4). The concept of "technologies of hubris" has been introduced, calling for a better balance between the idea that technology can solve problems and the concern that technological approaches may not be the best option for addressing social and ethical issues.[431]

An additional concern is the possibility of technological, political and social "lock in"—the possibility that the development of geoengineering technologies also result in the emergence of vested interests and increasing social momentum. It has been argued that this path dependency could make deployment more likely, and/or limit the reversibility of geoengineering techniques.[432,433,434]

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[412] Betz (2011).

[413] Bunzl (2009).

[414] Gardiner (2006).

[415] Gardiner (2010).

[416] Jamieson (1996).

[417] Hamilton (2011).

[418] Kahan et al. (2011).

[419] Mercer et al. (2011).

[420] Poumadère et al. (2011).

[421] Ipsos MORI (2010).

[422] Parkhill & Pidgeon (2011).

[423] Ipsos MORI (2010).

[424] Robock (2008).

[425] Millard-Ball (2012).

[426] Gardiner (2011).

[427] Fleming (2010).

[428] Hale & Dilling (2011).

[429] Westley et al. (2011).

[430] Harremoës et al. (2002).

[431] Jasanoff (2003).

[432] The Royal Society (2009).

[433] Arthurs (1989).

[434] Geels (2004).

It is important that research on geoengineering does not itself contribute to that "lock in". To minimize that risk, it is essential that any such research is fully transparent, open-minded and objective (i.e., without prejudice to the desirability or otherwise of geoengineering implementation), and preferably carried out on an international basis.

6.3.3 Governance and legal considerations

Issues related to geoengineering governance and regulation have gained increased prominence in the literature.[435,436,437] It should be noted that the challenges for regulation and governance of geoengineering include the variety of evolving technologies as well as their different stages of development—ranging from theory to modelling, to sub-scale field testing, and large scale deployment.[438] Governance structures also need to provide different functions ranging from ensuring transparency, participation, containing risks, the coordination of science, bridging the science-policy divide, and create structures to secure funding.[439]

These issues, along with precautionary principle/approach and human rights approaches, are discussed in more detail in the study on the regulatory framework of climate-related geoengineering relevant to the Convention on Biological Diversity presented in Part II of this volume, and are therefore not explored in detail here.

6.3.4 Societal distribution considerations

The large-scale application of geoengineering would raise a number of questions regarding the distribution of resources and impacts within and amongst societies and across time. First, access to natural resources is needed for several geoengineering techniques. Competition for limited resources can be expected to increase if geoengineering technologies emerge as a competing activity for land or water use. For example, possible competition for land as a result of land based albedo changes, or land based CDR will reduce land available for other uses such as the production of food crops, medicinal plants or the exploitation of non-timber forest products. These competing demands for land use can increase social tensions unless addressed by national and local institutions.[440] In addition, changes in land use may impact local communities and indigenous people's cultural and spiritual values of natural areas, sacred groves and water shades.[441]

These issues could also be relevant in the marine environment where experimentation or deployment of geoengineering proposals such as ocean fertilization could impact traditional marine resource use.[442,443] The use of the deep water as reservoirs for storage of CO_2 or biomass, as well as for ocean fertilization, would also use ocean space. To the extent that most of these activities would happen on the high seas, they are unlikely to raise significant distributional issues as a social consideration.

Enhanced weathering on land however will have clear local impacts as it requires large mining areas and associated transport infrastructure. In addition, the mineral resources required will only be available in certain locations, therefore reducing the opportunity for choosing between alternative sites. Based on historical experience, large mining activities could have serious social impacts. In addition, land space is needed for weathering to happen.

Second, the distribution of *impacts* of geoengineering is not likely to be even or uniform as are the impacts of climate change itself. Regarding impacts on climate, this appears to be mainly an issue arising from SRM. Regarding

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[435] Macnaghten & Owen (2011).

[436] Reynolds (2011).

[437] Solar Radiation Management Governance Initiative (2011).

[438] Blackstock et al. (2011).

[439] Bodansky (2011).

[440] Trumper et al. (2009).

[441] United Nations Forum on Forests (UNFF) (2011).

[442] Glibert (2008).

[443] IMO (2007).

other impacts, CDR could have local and possibly also regional *impacts* that could raise distributional issues. Such impacts are explored below in this chapter. Where distributional effects arise, this raises questions about how the uneven impacts can be addressed for instance through proper governance mechanisms.

Third, as with climate change, geoengineering could also entail intergenerational issues. As a result of possible technological "lock-in", future generations might be faced with the need to maintain geoengineering measures in general in order to avoid impacts of climate change. This mainly has been identified as an issue for SRM. However, it is also conceivable that CDR techniques entail similar "lock-in" effects depending on emission trajectories. Conversely, it could be argued that *not* pursuing further research on geoengineering could limit future generations' options for reducing climate risk.

6.3.5 Political considerations

There are also a number of social and political considerations to bear in mind especially when considering SRM. Establishing agreement on the desirability and governance for international action will be extremely difficult, and countries and societies will also have to deal with the possibility of unilateral deployment of geoengineering. In cases in which geoengineering experimentation or interventions have (or are suspected to have) transboundary effects or impacts on areas beyond national jurisdiction, geopolitical tensions could arise regardless of causation of actual negative impacts, especially in the absence of international agreement.[444,445,446]

Furthermore, some civil society organizations have expressed opposition to geoengineering experiments and deployment.[447,448,449] Tensions could also increase in cases where geoengineering technologies are combined with other emerging and controversial technologies, such as biotechnology (e.g. albedo-enhanced crops) and nanotechnology (e.g. "designer aerosols" for SRM), and where those involved are perceived to have ulterior motives. Polarization of the debate could prove detrimental to political decision-making.[450]

6.4 SPECIFIC SOCIAL, ECONOMICAL AND CULTURAL CONSIDERATIONS OF GEOENGINEERING TECHNOLOGIES AS THEY RELATE TO BIODIVERSITY

As discussed in Chapter 3, climate change is expected to result in altered ecosystems consisting of new assemblages of species,[451] and therefore affect biodiversity in ways that are relevant for all sort of local uses of land-based and marine ecosystems, and their associated ecosystem services. Reducing the impacts of climate change through geoengineering interventions may *in theory* address the loss of ecosystems upon which traditional knowledge is based. On the other hand, deployment of geoengineering interventions may itself alter ecosystems (see examples below), resulting in this impact being offset or eclipsed.[452] This however, is highly dependent on the geoengineering technology of interest, how it is deployed, and the institutions (local and national) in place.

In addition to the social considerations that generally arise from geoengineering, in this section we briefly elaborate social, economical and cultural considerations that result specifically from geoengineering's impacts on biodiversity.

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[444] The Royal Society (2009).

[445] Barrett (2008).

[446] Blackstock & Long (2009).

[447] ETC Group (2011).

[448] Parkhill & Pidgeon (2011).

[449] Poumadère et al. (2011).

[450] Bodle (2012).

[451] Williams & Jackson (2007).

[452] Matthews & Turner (2009).

6.4.1 Geoengineering, indigenous and local communities and stakeholders

CBD Decision X/33 calls for the integration of the views and experiences of indigenous and local communities and stakeholders into the consideration of the possible impacts of geoengineering on biodiversity and related social, economic and cultural considerations. Integrating such views is important as indigenous peoples and local communities, especially in developing countries, tend to be among the populations whose livelihoods are most reliant upon biodiversity resources. In addition, disadvantaged users of ecosystems and their associated ecosystem services, are at constant risk of losing out in conflicts related to local resources, have less of a voice in decision-making at all levels, and may have fewer opportunities to engage in regulatory and other policy forums to support their interests.[453,454]

The issue here is as much about physical resources, as about cultural uses and worldviews associated with ecosystems and their management. Forest taboo systems in Madagascar[455] and the unique cultural features of Balinese water temples[456] are just two examples.

All forms of environmental change—resulting from geoengineering or not—have local implications for livelihoods and ecosystem services. In fact, the Second Ad hoc Technical Expert Group on Biodiversity and Climate Change concluded that indigenous people will be disproportionately impacted by climate change because their livelihoods and cultural ways of life are being undermined by changes to local ecosystems.[457] As such, if geoengineering can reduce the negative impacts of climate change, without effecting more environmental change than that which is avoided, geoengineering could contribute to the preservation of traditional knowledge, innovations and practices.

However, there is considerable uncertainty regarding the impacts of any environmental change on indigenous peoples and local communities since these changes are difficult to predict with current modelling capabilities.[458] Furthermore, there is the risk that SRM geoengineering, could effect change more rapidly than unmitigated climate change itself.[459]

In order to ensure that the impacts of geoengineering on indigenous peoples and local communities are adequately considered and addressed, there is a role for such stakeholders in various phases of geoengineering research, ranging from theory and modelling, technology development, subscale field-testing; and potential deployment. The participation of indigenous peoples and local communities could hence be included in all parts of research development, especially in cases where technological interventions are projected to have impacts for biodiversity and ecosystem services.

Guidelines for the consideration of the views and knowledge of indigenous peoples and local communities have already been proposed by the Second Ad hoc Technical Expert Group on Biodiversity and Climate Change with regards to climate change.[460] These guidelines (see box 1) may be useful to consider by scientists and national governments alike when assessing the social, economic and cultural impacts of geoengineering.

As noted above, the CBD Secretariat has initiated a separate process to bring in the views of indigenous communities, and the results are presented in a separate report.[461]

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[453] Trumper et al. (2009).

[454] Millennium Ecosystem Assessment (2005b).

[455] Tengö et al. (2007).

[456] Lansing (2006).

[457] Secretariat of the Convention on Biological Diversity (2009a).

[458] Robock et al. (2010).

[459] The Royal Society (2009).

[460] Secretariat of the Convention on Biological Diversity (2009a).

[461] Secretariat of the Convention on Biological Diversity (2012a).

Box 1: Activities to promote the consideration of the views of indigenous peoples and local communities consistent with Article 8(j) of the Convention:

• Promote the documentation and validation of traditional knowledge, innovations and practices. Most knowledge is not documented and has not been comprehensively studied and assessed. Therefore there is need to enhance links between traditional knowledge and scientific practices.	• Revitalize traditional knowledge, innovations and practices on climate change impacts on traditional biodiversity based resources and ecosystem services through education and awareness-raising, including in nomadic schools.	• Explore uses of and opportunities for community-based monitoring linked to decision-making, recognizing that indigenous people and local communities are able to provide data and monitoring on a whole system rather than single sectors based on the full and effective participation of indigenous and local communities.

6.4.2 Social, economic and cultural considerations of sunlight reflection methods (SRM)

As discussed in Chapter 4, SRM is only expected to partly, not fully, prevent undesirable climate change, with implications for ecosystem productivity and associated livelihoods. Any shifts of temperature and changes to the hydrological cycle might affect local and indigenous communities, especially those dependent on provisioning ecosystem services such as food and energy. Cultural services such as ceremonies that follow planting and harvesting seasons in most rain fed agricultural regions (e.g., Nigeria and Ghana[462]) could also be affected by any changes in hydrological regimes. Whilst such impacts are expected to be less than for unmitigated climate change, there is an ethical difference in that they are the consequence of deliberate action.

In theory, SRM might be able to counteract the adverse impacts of climate change to a greater extent in some regions[463] (e.g., the Arctic[464,465]) than others; thus such approaches *might* be tailored to preserve threatened traditional livelihoods. However, there are many uncertainties regarding the impact of SRM on the climate system, and hence on food security, ecosystem productivity and associated issues. For example, as discussed in Chapter 4, whether there might be increases in plant productivity due to the increase in diffuse insolation; whether the the albedo of crop leaves[466] can be increased without affecting crop yields; and what changes SRM would cause to regional precipitation patterns and extreme events, with the likelihood of substantive impacts on rainfed agriculture and traditional pastoral livelihoods.

Stratospheric aerosols could also: i) adversely affect ground-level astronomical observation; ii) interfere with satellite-based remote sensing of Earth, and iii) make skies whiter (less blue). However, such effects have not been investigated in detail, and their magnitude may be slight.[467]

6.4.3 Social, economic and cultural considerations of land-based CDR techniques

The non-climatic consequences of land based CDR are highly technique-specific, as discussed in Chapter 5, with corresponding variability in socio-economic impacts via ecosystem productivity and associated livelihoods. Some approaches could, in theory, increase ecosystem productivity[468] and food production; e.g. through increased carbon and nutrient content in soils.[469] It is, however, less certain whether such unintended benefits could be sustained, and whether the intended benefits could be of sufficient magnitude to significantly counteract anthropogenic climate change.[470]

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[462] IITA (2010).

[463] Ban-Weiss & Caldeira (2010).

[464] Latham et al. (2008).

[465] Rasch et al. (2009).

[466] Ridgwell et al. (2009).

[467] Solar Radiation Management Governance Initiative (2011).

[468] Woodward et al. (2009).

[469] The Royal Society (2009).

[470] Vaughan & Lenton (2011).

The large-scale implementation of direct air capture of CO_2 ("artificial trees", although unlikely to be tree-like structures) could compromise locally significant features or degrade culturally significant landscapes, with possible parallels to the debate over wind farms. Such methods might also be associated with operational noise, depending on the deployment arrangements. Concerns have also been raised about the energy and (fresh)water requirements of this approach, with the possibility that the latter might adversely affect water security, whilst negatively impacting local freshwater biodiversity.

Large-scale afforestation involves landscape changes that are likely to have both positive and negative impacts on biodiversity, ecosystems services and their uses. In addition to implications for competing land uses, altered landscapes affect hydrological regimes (evapo-transpiration and water run-off) and may also cause habitat fragmentation and/or loss. Some of these concerns could also apply to reforestation.

It has been suggested that some land based CDR techniques could make use of genetic modification of organisms or monoculture hybrid crop breeding.[471] The potential benefits obtained by such approaches would need to be carefully assessed in the context of any potential negative impacts on traditional crop varieties and non-target species, including those of cultural or medicinal importance. Where such approaches are considered in a geoengineering context, the safe handling of such materials would be expected to follow the provisions set out in the Cartagena Protocol on Biosafety.[472]

6.4.4 Social, economic and cultural considerations of ocean based CDR techniques

The non-climatic impacts of ocean-based CDR are similarly technique-specific, and also may involve regional disparities—and considerable uncertainties. The consequences of enhanced ocean alkalinity for marine species of economic and cultural importance are highly uncertain, since this technique has not been tested in field experiments. Whilst it could assist in counteracting ocean acidification, it would be a high-risk strategy to carry out field trials adjacent to coral reefs.

The consequences of ocean fertilization for marine communities in the upper ocean are somewhat better known;[473,474] however, impacts on fisheries due to changes in marine food chains are uncertain, and could be positive in some areas and negative in others. If carried out on a very large scale, ocean fertilization would have far-field effects that are inherently difficult to predict, so distant ecological and human communities could be affected and the overall effectiveness of the technique would be very difficult to assess. Whilst there is also a suggested risk of toxic blooms, land-based nutrient inputs are likely to continue to be the main cause for concern in that regard, at least for shelf seas and coastal waters.

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[471] Shiva (1993).

[472] Cartagena Protocol on Biosafety. http://bch.cbd.int/protocol/.

[473] Wallace et al. (2010).

[474] Secretariat of the Convention on Biological Diversity (2009c).

CHAPTER 7

SYNTHESIS

This study has: introduced the range of proposed geoengineering techniques (Chapter 2); reviewed the projected impacts of likely climate change on biodiversity (Chapter 3); considered the impacts of specific geoengineering techniques on biodiversity (Chapters 4 and 5); and discussed associated socio-economic and cultural issues (Chapter 6). Based on that information, this chapter provides a short summary of the drivers of biodiversity loss under the scenarios of (1) continuation of current trends of increasing energy use; (2) rapid and substantive reduction in greenhouse-gas emissions; and (3) the deployment of geoengineering techniques to address climate change, against a baseline scenario of (1), i.e. taking little or insufficient action to reduce anthropogenic climate change. Intermediate and alternative scenarios are also possible.

The chapter also includes remarks on the importance of scale, and highlights key areas where further knowledge and understanding is required.

7.1 CHANGES IN THE DRIVERS OF BIODIVERSITY LOSS

As noted in Chapter 1, the main direct drivers of biodiversity loss are habitat conversion, over-exploitation, the introduction of invasive species, pollution and climate change.

For terrestrial ecosystems, the largest driver of biodiversity loss at the global scale has been, and continues to be, land use change. In the ocean, over-exploitation has been the major cause of ecosystem degradation, with loss of top predators (fish and marine mammals). For both environments, climate change is rapidly increasing in importance as a driver of biodiversity loss. However, the relative importance of different drivers of loss vary between ecosystems, and from region to region.

The baseline scenario (1) described in Chapter 3 considers the climatic consequences of continued anthropogenic greenhouse-gas emissions, without urgent action to achieve a low-carbon economy at the global scale. Under those conditions, global temperature increases of 3 to 5°C are projected by 2100, posing an increasingly severe range of threats to biodiversity and ecosystem services not only as a result of changes in temperature, but also in precipitation, water availability, sea level and the associated phenomenon of ocean acidification. The impacts are exacerbated by the other anthropogenic pressures on biodiversity (such as over-exploitation; habitat loss, fragmentation and degradation; the introduction of non-native species; and pollution) since these reduce the opportunity for gradual ecosystem shifts, population movements and genetic adaptation. In addition, climate change is likely to increase some of the other drivers; for example, by providing additional opportunities for invasive alien species (e.g., mixing of Pacific and Atlantic marine plants and animals).

Under this baseline scenario of taking insufficient action to address climate change, the climate change driver will increase substantially.

Under scenario (2) of addressing climate change through a rapid and substantive reduction in greenhouse-gas emissions, there would be a transition to a low-carbon economy in both the way we produce and use energy, and in the way we manage our land. Measures to achieve that effect could include: increased end-use efficiency; the use of renewable energy technologies alongside nuclear and carbon capture and storage; and ecosystem restoration and improved land management. These measures would substantially reduce the adverse impacts of climate change on biodiversity, although significant further climate change is now considered unavoidable. Generally, most other impacts on biodiversity, mediated through other drivers, would be small (e.g., use of nuclear power to replace fossil fuels) or positive (e.g., avoided deforestation, ecosystem restoration). Although some of the climate change mitigation measures have potential negative side-effects on biodiversity (e.g., bird kill by wind farms; disruption of freshwater ecosystems by hydropower schemes) these can be minimized by careful design. Overall, strong climate change mitigation measures are expected to be beneficial for biodiversity, and for the provision of ecosystem services.

Under this scenario, the climate change driver would be very much reduced. Land use change would also likely be significantly reduced relative to the baseline scenario. Pollution and invasive species are expected to be somewhat reduced compared to the baseline, while there are few reasons to expect significant differences in over-exploitation.

A third scenario (3) involves deploying geoengineering techniques to counteract climate change in the absence of substantive emission reductions. Under such a scenario, some of the negative impacts of climate change on biodiversity could be reduced, provided that the geoengineering techniques prove to be feasible and climatically-effective. At the same time, most geoengineering techniques would have additional impacts on biodiversity, that may be either negative or positive. The totality of effects on biodiversity will vary depending on the techniques employed, and many aspects are, and will remain, difficult to predict. All geoengineering techniques are associated with significant risks and uncertainties.

Under this scenario, the climate change driver would be expected to be significantly reduced (compared to the baseline scenario of taking minimal action) for some or all aspects of climate change and/or their impacts. For several techniques (e.g., surface albedo and afforestation) there would be increases in land use change compared to the baseline scenario, though this driver could be unaffected for some other techniques. For some techniques (e.g., afforestation) there might be an increased risk from invasive species compared to the baseline, although this risk could be minimized through good design. Some other techniques (e.g., stratospheric aerosols, ocean fertilization) may lead to a small increase in pollution compared to the baseline. There are no reasons to expect significant differences in over-exploitation compared to the baseline scenario.

7.2 THE QUESTION OF SCALE AND ITS IMPLICATIONS FOR FEASIBILITY AND IMPACTS OF GEOENGINEERING TECHNIQUES

The study describes a large range of potential impacts of geoengineering techniques on biodiversity and identifies the large uncertainties associated with many of these. To be effective in counter-acting anthropogenic climate change, geoengineering techniques need to be deployed on a large scale, either individually, or in combination. In most cases the risks associated with the techniques are highly dependent on the scale at which they are deployed. Several of the techniques (e.g., whitening of the built environment; afforestation; biomass production) are benign at a small scale, but scaling up is either difficult or impractical (e.g., spatial extent of the built environment is limited) or may be associated with greatly increased negative effects (afforestation—as opposed to reforestation—or biomass production on a very large scale is likely to have significant adverse effects on biodiversity via land-use change).

The scaling issue is particularly important for CDR techniques, since none on their own seem capable of counteracting more than a small proportion of current CO_2 emissions. The technique that is potentially the most climatically effective (direct air capture) would also seem to be the least cost-effective.

7.3 GAPS IN KNOWLEDGE AND UNDERSTANDING

The report recognizes many areas where knowledge is very limited. These include: (1) the overall effectiveness of some of the techniques, based on realistic estimates of their scalability; (2) how the proposed geoengineering techniques can be expected to affect weather and climate regionally and globally; (3) how biodiversity, ecosystems and their services are likely to respond to changes in climate, both with and without geoengineering; (4) the unintended, non-climatic effects of different proposed geoengineering techniques on biodiversity; and (5) the social and economic implications of climate change and potential geoengineering interventions, particularly with regard to geo-political acceptability, governance and the potential need for international compensation in the event of there being “winners and losers”. Additional research in these areas would reduce uncertainties and improve evidence-based decision-making, without compromising the overall policy need to achieve rapid reductions in greenhouse-gas emissions.

In addition, there is very limited understanding among stakeholders of geoengineering concepts, techniques and their potential positive and negative impacts on biodiversity. Not only is there much less information available on geoengineering than for climate change, but there has been little consideration of the issues by local communities, indigenous peoples, marginalized groups and other stakeholders, especially in developing countries. Since these communities play a major role in actively managing ecosystems that deliver key climatic services, the lack of knowledge of their perspective is a major gap that requires further attention.

ANNEX I

SUMMARY OF SELECTED DEFINITIONS OF CLIMATE-RELATED GEOENGINEERING

1. **Convention on Biological Diversity —decision X/33**
   Technologies that deliberately reduce solar insolation or increase carbon sequestration from the atmosphere on a large scale that may affect biodiversity (excluding carbon capture and storage from fossil fuels when it captures carbon dioxide before it is released into the atmosphere).
   www.cbd.int/climate/doc/cop-10-dec-33-en.pdf

2. **Intergovernmental Panel on Climate Change —Fourth Assessment Report**
   Technological efforts to stabilize the climate system by direct intervention in the energy balance of the Earth for reducing global warming.
   www.ipcc.ch/pdf/glossary/ar4-wg3.pdf

3. **Intergovernmental Panel on Climate Change —Third Assessment Report**
   Efforts to stabilize the climate system by directly managing the energy balance of the Earth, thereby overcoming the enhanced greenhouse effect.
   www.ipcc.ch/pdf/glossary/tar-ipcc-terms-en.pdf

4. **The United Kingdom of Great Britain and Northern Ireland House of Commons Science and Technology Committee**
   Activities specifically and deliberately designed to effect a change in the global climate with the aim of minimising or reversing anthropogenic (that is, human made) climate change.
   www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/22102.htm

5. **The United States House of Representatives Committee on Science and Technology**
   The deliberate large-scale modification of the Earth's climate systems for the purposes of counteracting [and mitigating anthropogenic[475]] climate change.
   Hearing on 5 November 2009—Geoengineering: Assessing the Implications of Large-Scale Climate Intervention

6. **The Royal Society (U.K.)**
   The deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change.
   Geoengineering the Climate: Science, Governance and Uncertainty. September 2009

7. **The National Academy of Science (U.S.A.)**
   Options that would involve large-scale engineering of our environment in order to combat or counteract the effects of changes in atmospheric chemistry.
   http://books.nap.edu/openbook.php?record_id=1605&page=433

8. **The Australian Academy of Science**
   A branch of science which is focused on applying technology on a massive scale in order to change the Earth's environment.
   www.science.org.au/nova/123/123key.html

9. **The ETC Group (Non-Governmental Organization)**
   Geoengineering is the intentional, large-scale technological manipulation of the Earth's systems, including those related to climate.
   www.etcgroup.org/en/node/5217

10. **The Asilomar Conference Report: Recommendations on Principles for Research into Climate Engineering Techniques**
    Deliberate steps to alter the climate, with the intent of limiting or counterbalancing the unintended changes to the climate resulting from human activities.
    www.climateresponsefund.org/images/Conference/finalfinalreport.pdf

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[475] Added in the Report by the Chairman of the Committee on Science and Technology 'Engineering the Climate: Research Needs and Strategies for International Coordination—October, 2010'.

ANNEX II

ADDITIONAL INFORMATION ON OPTIONS FOR DEFINITIONS OF CLIMATE-RELATED GEOENGINEERING

The Expert Group gave careful attention to the definition of geoengineering, not only because the consideration of definition options was included in the group's mandate, but also because this issue was fundamental for planning and implementing its main work (assessment of impacts requires initial identification of causative agents). The following wording was agreed:

- *A deliberate intervention in the planetary environment of a nature and scale intended to counteract anthropogenic climate change and its impacts.*

This is a relatively broad definition, recognising that geoengineering covers a wide spectrum of approaches, and that additional information on what is or is not covered by the term may be needed when the definition is applied for more specific technical, operational or legal purposes. Section 2.1 of the study discusses the scope and implications of the above definition.

The development of the definition by the Expert Group was based on five principles, all routinely used by lexicologists: i) usage (corpus linguistics), on the basis that it would be inappropriate for the CBD definition of geoengineering to differ significantly from the meaning currently assumed for the term by the "wider world"; ii) clarity, aiming to avoid any ambiguity in the definition overall or in any component of it that might give problems in interpretation, either within or between languages; iii) purpose, since the generality (or specificity) of a formal definition is relevant to its intended application; iv) brevity, on the basis that succinctness is preferable to superfluity, providing that essential meaning is expressed; and v) etymological consistency, although accepting that the meaning of words can evolve, depending on usage and purpose ("Earth manipulation" can be considered a good match to the greek and latin roots of geoengineering, although other transliterations are possible).

The first of the above criteria—usage—was considered to be of particular importance. For evidence of wider application, the CBD Secretariat provided the Expert Group with ten formal and informal definitions of geoengineering by national and international science organisations and other bodies (these definitions are given in Annex I). Members of the group also investigated additional online usage and identified more than 200 scientific publications, mostly produced within the past five years, that had "geoengineering" in either the title, abstract or as a key word. These publications provided the basis for the Expert Group's study, and many (but not all) are cited in the report.

The definition of geoengineering developed by the Expert Group, together with related text, was subject to two rounds of peer review involving CBD Parties and international experts. All comments on the definition (~15) were assessed and taken into account before the wording provided above was finalised. This formulation was considered robust and fit for purpose as a general descriptor of geoengineering for use by the CBD.

The scientific rationale for the Expert Group's definition is summarised in Table 1 below. In this Table, the initial basis for grouping different geoengineering approaches is whether they achieve their effect on the Earth's climate system by increasing outgoing energy (i.e. lessening the greenhouse effect, primarily by removing greenhouse gases), or by decreasing incoming energy (by reflecting sunlight), or by spatially redistributing that energy. Subsequent sub-grouping is similar, but not an exact match, to the structure of the report. Table 1 includes several geoegineering techniques that are speculative, not discussed in the report.

In principle, the CBD's definition of geoengineering could specify a subset of techniques, for example those that would seem to have the greatest likelihood of implementation; those that are considered to be novel or "technological"; those that have highest risk of adverse trans-boundary effects; or those that are likely to have the greatest impacts on biodiversity and ecosystems. However, given the large number of proposed techniques,[476] the wide ranges of scales for deployment and for impacts, and the lack of detailed understanding of direct and indirect consequences, it is extremely unlikely that any such distinctions can be drawn unambiguously.

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[476] For example, see Isomäki (2011).

Table 1. A proposed taxonomy of climate geoengineering techniques, based on the definition developed by the CBD Expert Group on Geoengineering Impacts ("deliberate intervention in the planetary environment of a nature and scale intended to counteract anthropogenic climate change and its impacts")

Reductions of greenhouse gas emissions, e.g. by at-source carbon capture and storage (CCS), are excluded from the definition. Techniques and processes that are considered to be geoengineering need to be at sufficient scale for significant climatic impact, and carried out with that intention. This structure potentially covers all specific techniques relating to changes in the Earth's energy budget, but not all those that have been proposed are listed here. Note that: i) BECCS stands for bio-energy carbon capture and storage, considered as geoengineering because of its carbon capture from the atmosphere; ii) bracketed techniques and approaches are mostly speculative and may be unrealistic; they were not given detailed attention in the report; iii) techniques marked with an asterisk (*) are storage-only.

Techniques that increase energy loss from the Earth's climate system [through change in output of long-wave radiation (heat)]	Removal of greenhouse gases from the atmosphere: negative emission techniques	Carbon dioxide removal: CDR	Carbon dioxide	Biological CO_2 capture and carbon storage	Ocean fertilization
					Afforestation/reforestation
					Enhanced soil carbon
					Biomass production, incl BECCS
					Ocean storage of land biomass
				Chemical/ geochemical CO_2 air capture and storage	Increased ocean alkalinity
					Land-based enhanced weathering
					Direct chemical air capture of CO_2
					CO_2 storage in ocean*
					Geological CO_2 storage - sub-surface*
		Methane		(CH_4 removal from atmosphere)	
		Other green-house gases		(Removal of other greenhouse gases, e.g. N_2O or H_2O)	
	Other means of enhanced heat escape	(Reduction in cirrus cloud cover)			
		(Removal of black carbon from atmosphere)			

Techniques that decrease energy gain by the Earth's climate system [through change in input of short-wave radiation (light)]	Sunlight reflection methods or solar radiation management: SRM	(Space-based increased reflection, e.g. via space mirrors)	
		Increase in stratospheric aerosols	
		Cloud brightening: Increased cloud reflectivity	
		Increased surface reflectivity	Land surface, e.g. crops, desert, buildings
			Ocean surface/inland seas

Techniques that redistribute energy within the Earth's climate system	(Via increased ocean heat storage, e.g. by enhanced downwelling, or by actions to promote sea-ice formation, e.g. blocking Bering Strait to restrict water flow in Arctic Ocean)

ANNEX III

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PART II

THE REGULATORY FRAMEWORK FOR CLIMATE-RELATED GEOENGINEERING RELEVANT TO THE CONVENTION ON BIOLOGICAL DIVERSITY

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CONTENTS

KEY MESSAGES

1. **The Conference of the Parties to the Convention on Biological Diversity, taking into account *the possible need for science based global, transparent and effective control and regulatory mechanisms*, requested a study to be undertaken on gaps in such existing mechanisms for climate-related geoengineering relevant to the Convention on Biological Diversity** (decision X/33, paragraph 9 (m)). This request was made in the context of the CBD decision on geoengineering which provides guidance for Parties and other Governments to ensure, "*in the absence of science based, global, transparent and effective control and regulatory mechanisms for geoengineering*", that no climate-related geoengineering activities that may affect biodiversity take place, until certain conditions are met, with some exceptions for small scale research (decision X/33, paragraph 8(w)). (*Section 1.1)*[1]

2. **"Climate-related geoengineering" is a general term that encompasses several different geoengineering concepts, techniques or technologies.** The Conference of the Parties to the Convention on Biological Diversity, at its tenth meeting adopted a preliminary definition for climate-related geoengineering in 2010 and will further discuss the matter in 2012. In the study on the potential impacts on biodiversity, climate-related geoengineering is defined as a deliberate intervention in the planetary environment of a nature and scale intended to counteract anthropogenic climate change and/or its impacts through, *inter alia*, sunlight reflection methods or removing greenhouse gases from the atmosphere. However, there is no universal and uniform use of the term "geoengineering". Thus, the definition will need to be analysed for its suitability for governance in a normative context. (*Section 1.3*)

3. **The need for science-based global, transparent and effective control and regulatory mechanisms may be most relevant for those geoengineering concepts that have a potential to cause significant adverse transboundary effects, and those deployed in areas beyond national jurisdiction and in the atmosphere.** For example, injection of aerosols into the atmosphere would have transboundary effects that may be deleterious, while ocean fertilization would be carried out in areas that extend beyond national jurisdiction. Some activities such as afforestation, reforestation and terrestrial biomass production, when carried out within a single country, might be deemed to be adequately governed through domestic regulations. (*Section 1.3*)

4. **The existing regulatory framework includes general customary rules of international law and specific international treaties.** The rules of customary international law and other general principles of international law apply to all activities and therefore would, in principle, be relevant to geoengineering. In addition, some international treaties have provisions that may be relevant to particular categories of activities. (*Section 1.5*)

General rules of customary international law

5. **State responsibility describes the rules governing the general conditions under which a State is responsible for wrongful actions or omissions, and the resulting legal consequences**. Although the rules on State responsibility provide a general framework for addressing breaches of international law, they do not address under which conditions geoengineering activities would be permitted or prohibited. They require a breach on an obligation without defining these obligations. States are not as such responsible for acts for private actors. However, a State might have to address private actors in order to fulfil its own obligation. A State could be in breach of an obligation if it fails to take necessary measures to prevent effects caused by private actors. (*Section 2.1*)

6. **All States are under a general obligation to ensure that activities within their jurisdiction or control respect the environment of other States or of areas beyond national jurisdiction or control**. This duty to respect the environment does not mean, however, that *any* environmental harm, pollution, degradation or impact is generally prohibited. The duty prohibits a State from causing *significant transboundary* harm and obliges a State of origin to take adequate measures to control and regulate in advance sources of such potential harm. States have to exercise "due diligence" before carrying out potentially harmful activities. What constitutes "due diligence" would largely

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[1] Information in parentheses indicates where full details, with references, can be found in the main report.

depend on the circumstances of each case. Establishing State responsibility for any harm from a geoengineering activity would require that (i) the geoengineering activity can be attributed to a particular State and (ii) can be associated with a significant and particular harm to the environment of other States or of areas beyond national jurisdiction or control. (*Section 2.2*)

7. **States have the duty to carry out an environmental impact assessment for activities that may have a significant adverse impact in a transboundary context, in particular, on a shared resource**. Among others, the Convention on Biological Diversity includes a provision for environmental assessment in Article 14 that is referred to in its decision on geoengineering (decision X/33 8(w)). An environmental impacts assessment (EIA) is required in many domestic legal orders and the International Court of Justice has recently recognised that the accepted practice among States amounts to "a requirement under general international law". Thus, where there is a risk that a proposed industrial activity may have a significant adverse impact in a transboundary context, the requirement to carry out an environmental impact assessment applies even in the absence of a treaty obligation to this effect. However, this does not necessarily extend to a requirement to undertake strategic environmental assessments. (*Section 2.3*)

8. **The precautionary principle or approach is relevant but its legal status and content in customary international law has not yet been clearly established, and the implications of its application to geoengineering are unclear.** Under the Convention, the precautionary approach has been introduced recognizing that "where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat". This has been invoked in its decision on geoengineering which invites Parties and others to ensure (with some exceptions and until certain conditions are met) that no geoengineering activities take place (decision X/33 paragraph 8(w)). Under the London Protocol, Article 3.1 requires the application of the precautionary approach. Under the United Nations Framework Convention on Climate Change (UNFCCC), the precautionary approach is generally considered as intending to prevent States from postponing mitigation measures by referring to scientific uncertainty about climate change. However, an interpretation in support of geoengineering or pursuing further geoengineering research would not be evidently contrary to the wording. (*Section 2.4*)

9. **Other relevant general concepts include sustainable development, common but differentiated responsibilities, and concepts addressing international interest in the protection of areas beyond national jurisdiction and shared resources as well as issues of common concern such as biodiversity**. However the status of these concepts as customary international law is not clearly established. (*Section 2.6*)

Specific treaty regimes and institutions

10. **The Convention on Biological Diversity has adopted a decision on geoengineering that covers all technologies that may affect biodiversity.** The Convention contains many provisions that are relevant but not specific to geoengineering, including provisions on environmental assessment. Additional relevant guidance has been developed under the Convention. The CBD decision on geoengineering invites Parties and others to ensure (with some exceptions and until certain conditions are met) that no geoengineering activities take place (decision X/33 paragraph 8(w)). The decision refers specifically to "the precautionary approach and Article 14 of the Convention. While not expressed in legally binding language, the decision is important for a global governance framework because of the wide consensus it represents. The Parties to the Convention have also recognized that while science-based global transparent and effective control and regulatory mechanism for geoengineering may be needed, they may not be best placed under the Convention. The Convention on Biological Diversity has referred to and incorporated the work of the London Convention and its Protocol (LC/LP) on ocean fertilization in its own decisions, thus widening the application of this work beyond the smaller number of Parties to the LC/LP. (*Section 3.1*)

11. **The United Nations Convention on the Law of the Sea (UNCLOS) sets out the legal framework within which all activities in the oceans and seas must be carried out, including relevant geoengineering activities**, such as ocean fertilization, modification of downwelling and/or upwelling, maritime cloud albedo enhancement,

and altering ocean chemistry through enhanced weathering. Under the Convention, States have the general obligations to protect and preserve the marine environment and to take all measures necessary to prevent, reduce and control pollution of the marine environment from any source, including pollution by dumping. While States are allowed to pursue a range of activities under the "freedom of the high seas", these activities must be exercised in accordance with the provisions of UNCLOS and with due regard for the interests of other States. Rules and standards established under LC/LP are considered to be relevant for the implementation of UNCLOS. (*Section 3.2*)

12. **The London Convention and its Protocol (LC/LP) have provided detailed guidance on ocean fertilization, as well as carbon storage, and are considering wider application to other marine geoengineering activities within their mandate. Disposal of CO_2 in the water column or on the seabed is not allowed under the London Protocol**. The LC/LP are global instruments that address marine pollution from dumping of wastes and other matter at sea. In 2010 the Parties adopted the "Assessment Framework for Scientific Research Involving Ocean Fertilization". This non-binding Assessment Framework, which has been recognized by the Convention on Biological Diversity, guides Parties as to how proposals they receive for ocean fertilization research should be assessed and provides criteria for an initial assessment of such proposals and detailed steps for completion of an environmental assessment, including risk management and monitoring. The LP has also adopted amendments to regulate CO_2 sequestration in sub-seabed geological formations supported by a risk assessment and management framework and additional guidelines. (*Section 3.3*)

13. **The UNFCCC and Kyoto Protocol have not addressed geoengineering concepts as such or its governance.**[2] The objective of both instruments as stated in Article 2 of UNFCCC is to stabilize greenhouse-gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Under these instruments, guidance has been developed that address afforestation, reforestation and enhancement of soil carbon. Beyond these techniques, the obligations on Parties to take measures to limit emissions and protect carbon sinks do not promote or prohibit geoengineering measures as such. (*Section 3.4*)

14. **The Vienna Convention for the Protection of the Ozone Layer requires Parties, *inter alia*, to take measures to protect human health and the environment against likely adverse effects resulting from human activities that modify or are likely to modify the ozone layer. The Montreal Protocol requires Parties to phase down certain substances that deplete the ozone layer.** Activities such as aerosol injection could raise issues under these agreements, particularly if they involve a substance covered by the Montreal Protocol. The Vienna Convention defines "adverse effects" as changes in the physical environment or biota, including changes in climate, which have significant deleterious effects on human health or on the composition, resilience and productivity of natural and managed ecosystems, or on materials useful to mankind. (*Section 3.5*)

15. **The Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD) would only apply directly to geoengineering if it were used as a means of warfare.** The main substantial obligation is that listed parties "undertake not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to any other State Party". However, the Convention could be a possible source of ideas, concepts and procedures useful for addressing geoengineering. (*Section 3.6*)

16. **The deployment of shields or mirrors in outer space to reflect or block solar radiation would fall under Space Law.** The international legal regime regulating environmental aspects of outer space includes the Outer Space treaty, four other main treaties and several resolutions of the United Nations General Assembly. The Outer Space Treaty provides that experiments that "would cause potentially harmful interference with activities of other States" are subject to prior appropriate international consultation. Activities such as aerosol injection in the stratosphere would not be regarded as falling under the purview of space Law because they would be below 80 km. (*Section 3.7*)

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[2] However have addressed carbon capture and storage, which may have some relevance for CO_2 storage.

17. **The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) prohibits CO_2 storage in the water column or on the seabed and has developed rules and guidance for the storage of CO_2 in geological formations under the seabed.** The amendments allowing sub-surface CO_2 storage were adopted in 2007 but have not yet entered into force. (*Section 3.9*)

18. **The Convention on Long Range Transboundary Air Pollution (LRTAP) may be relevant for geoengineering concepts such as aerosol injection, which introduce sulphur or other substances into the atmosphere.** It is a regional convention covering most States in Europe and North America. Although the LRTAP Convention requires parties to make efforts at limiting, gradually reducing and preventing air pollution including long-range transboundary air pollution", the wording of these obligations and the definition of air pollution soften its content considerably. The same goes for the obligation on parties to develop policies and strategies for combating the discharge of air pollutants. These general obligations do not require specific legal measures to prevent air pollution or to restrict aerosol injection. Apart from this obligation, LRTAP requires the sharing of data on pollutants and stipulates procedural obligations that may apply to certain geoengineering activities. Several protocols under the LRTAP impose specific obligations to reduce sulphur emissions or transboundary fluxes, but at most only up to 2010. (*Section 3.10*)

19. The Antarctic treaty system would apply to geoengineering activities carried out in the Antarctic. (*Section 3.8*)

20. **Human rights law would be relevant if a particular geoengineering activity violates specific human rights.** Which human right could be impacted would depend on how a particular geoengineering activity would be carried out and which effects it might actually have. In addition, impacts on human rights might be justified in a particular case. Most human rights are not absolute and are subject to restrictions under certain conditions, e.g. that the restrictions are provided by law, address specific aims and are necessary to achieve a legitimate purpose. (*Section 3.11*)

21. **International institutions such as the United Nations General Assembly, United Nations Environment Programme (UNEP), World Meteorological Organization (WMO) and Intergovernmental Oceanographic Commission (IOC) of UNESCO are relevant to the governance of geoengineering**. The United Nations General Assembly has addressed ocean fertilization and could address additional issues related to geoengineering. It has also encouraged the further development of EIA processes. In 1980, UNEP developed guidelines on weather modification. The mandate of WMO covers meteorology, the atmosphere and hydrology and could, in principle, address sunlight reflection methods. It has issued non-binding guidance on weather modification. UNESCO's IOC has assessed the potential impact of ocean fertilization. In addition, depending on the impacts and activity in question, States might argue that geoengineering activities constitute a threat to or breach of the peace or aggression under Article 39 of the Charter of the United Nations. However, the current state of knowledge concerning geoengineering reveals a great deal of uncertainty. In any event, the Security Council has wide discretion in determining whether the requirements of Article 39 of the Charter of the United Nations are met and deciding on its response. (*Section 4.2; Section 4.4; Section 4.5; Section 4.6; Section 2.5*)

22. **Research is generally not specifically addressed under international law as distinct from the deployment of technology with known impacts or risks, apart from special rules in certain areas**. In a few cases, certain types of research might be prohibited, for instance if it would encourage nuclear weapons test explosions prohibited by the Partial Test Ban Treaty or the Comprehensive Nuclear-Test-Ban Treaty. While the CBD decision on geoengineering invites Parties and others to ensure (until certain conditions are met) that no geoengineering activities take place, it excludes from this limitation small scale scientific research studies that are conducted in a controlled setting, scientifically justified and subject to prior environmental impact assessments (decision X/33 paragraph 8(w)). UNCLOS has provisions that address marine scientific research. The LC/LP assessment framework on ocean fertilization provides guidance that is applicable to research studies. A major gap concerns sunlight reflection methods. (*Section 5.1; Section 5.2*)

Gaps in the current regulatory framework

23. **The current regulatory mechanisms that could apply to climate-related geoengineering relevant to the Convention on Biological Diversity do not constitute a framework for geoengineering as a whole that meets the criteria of being science-based, global, transparent and effective.** While the CBD decision on geoengineering provides a comprehensive non-binding normative framework, there is no legally-binding framework for geoengineering as a whole. With the possible exceptions of ocean fertilization experiments and CO_2 storage in geological formations, the existing legal and regulatory framework is currently not commensurate with the potential scale and scope of the climate related geoengineering, including transboundary effects. (*Section 6*)

24. **Some general principles of international law such as the duty to avoid transboundary harm, and the need to conduct an environmental impact assessment (EIA), together with the rules of State responsibility provide some guidance relevant to geoengineering.** However, they are an incomplete basis for international governance, because of the uncertainties of their application in the absence of decision-making institutions or specific guidance and because the scope and risks associated with geoengineering are so large-scale. As an overarching concept including several distinct concepts and technologies, geoengineering is currently not as such prohibited by international law. Specific potential impacts of specific geoengineering concepts might violate particular rules, but this cannot be determined unless there is greater confidence in estimates of such potential impacts. (*Section 6*)

25. **Some geoengineering techniques are regulated under existing treaty regimes, while others are prohibited**:

(a) **Disposal of CO_2 in the water column or on the seabed is not allowed under the LP**. It is also prohibited under OSPAR;
(b) **Ocean fertilization experiments are regulated under the LC/LP's provision on dumping and additional non-binding guidance including a risk assessment framework**; and
(c) **CO_2 storage in sub-surface geological formations is regulated under the LC/LP and the OSPAR Convention**. Further guidance has been developed under the UNFCCC based on IPCC assessments. (*Section 6.1*)

26. **Some other geoengineering techniques would be subject to general procedural obligations within existing treaty regimes, but, to date, no specific rules governing these particular techniques have been developed**:

(a) Storage of biomass in the ocean would be subject to the LC/LP and UNCLOS;
(b) Altering ocean chemistry through enhanced weathering would be subject to the LC/LP and UNCLOS;
(c) LRTAP might impose procedural obligations on the use of aerosols in the atmosphere; and
(d) Deployment of mirrors in space would be subject to space law (Outer Space Treaty). (*Section 6.1*)

27. **Most, but not all treaties, potentially provide for mechanisms, procedures or institutions that could determine whether the treaty in question applies to a specific geoengineering activity and address such activities**. In legal terms, the mandate of several major treaties or institutions is sufficiently broad to address some or all geoengineering concepts. However, this could lead to potentially overlapping or inconsistent rules or guidance. From a global perspective, the different regimes and institutions have different legal and political weight, depending, for instance, on their legal status, particular mandate or their respective levels of participation. (*Section 1.3; Section 6*)

28. **The lack of regulatory mechanisms for sunlight reflection methods is a major gap, especially given the potential for significant deleterious transboundary effects** of techniques such as stratospheric aerosols and maritime cloud albedo enhancement. In principle, existing institutions, such as the World Meteorological Organization have a mandate that could address such issues. (*Section 4.5; Section 6*)

29. **Most regulatory mechanisms discussed in the report were developed before geoengineering was a significant issue and, as such, do not currently contain explicit references to geoengineering approaches**. However, many of the treaties examined impose procedural obligations on geoengineering activities falling within their scope of application. Moreover, the international regulatory framework comprises a multitude of treaties, actual and potential customary rules and general principles of law, as well as other regulatory instruments and mechanisms

that could apply to all or some geoengineering concepts. As a minimum, it is suggested that States engaged in geoengineering field activities have a duty to inform other States prior to conducting them e.g., as required in the London Convention/Protocol Ocean Fertilization Assessment Framework. Few rules provide for public participation beyond the representation of the public by delegates, except for the usual rules on observer participation in treaty regimes and institutions. The treaties examined provide few *specific* rules on responsibility and liability, but the International Law Commission's articles on State responsibility provide general rules in cases where geoengineering would be in breach of an international obligation. (*Section 1.3; Section 6*)

CHAPTER 1

INTRODUCTION

1.1 MANDATE AND SCOPE

At the tenth meeting of the Conference of the Parties to the Convention on Biological Diversity, Parties adopted decision X/33, part of which addressed climate-related geoengineering and its impacts on the achievement of the objectives of the Convention.[3,4] The decision included a request that a study be undertaken on gaps in existing control and regulatory mechanisms for climate-related geoengineering relevant to the Convention on Biological Diversity (CBD). Specifically, in paragraph 9 (m) of decision X/33, the Parties requested the Executive Secretary of the Convention,

> Taking into account the possible need for science based global, transparent and effective control and regulatory mechanisms, subject to the availability of financial resources, to undertake a study on gaps in such existing mechanisms for climate-related geo-engineering relevant to the Convention on Biological Diversity, bearing in mind that such mechanisms may not be best placed under the Convention on Biological Diversity, for consideration by the Subsidiary Body on Scientific Technical and Technological Advice prior to a future meeting of the Conference of the Parties and to communicate the results to relevant organizations.

Accordingly, the study was prepared for the Secretariat, by a lead author with comments and additional contributions from a group of experts as well as the Secretariat.[5]

The study evaluates the global control and regulatory framework for climate-related geoengineering with regard to its current and potential coverage of issues relevant to the Convention. The report provides a summary of existing international regulatory frameworks and mechanisms as background material to inform further consideration of this issue under the Convention on Biological Diversity and to facilitate consideration of gaps in global control and regulatory frameworks.[6]

Preparation of the report was made possible thanks to the kind financial contribution of the Government of the United Kingdom of Great Britain and Northern Ireland.

1.2 CRITERIA FOR IDENTIFYING GAPS

In order to assess gaps in existing international regulatory mechanisms, the report examines the extent to which current mechanisms already address geoengineering, either explicitly or implicitly, and discusses gaps in terms of both scope, scale and coverage, based on criteria referred to in decision X/33 (paragraph 8 (w))[7]. The following provide some observations on how these criteria have been considered in this report:

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[3] To match wider usage, "geoengineering" is unhyphenated in this report except when quoting older CBD documents.

[4] See especially paragraphs 8 (w) and 8 (x) of decision X/33, and also paragraphs 9 (l) and 9 (m).

[5] The report was prepared by Ralph Bodle with contributions from Gesa Homan, Simone Schiele, and Elizabeth Tedsen. It was reviewed by a group of experts comprising the following, many of whom made additional contributions: Michael Shewchuk, Edward Kleverlaan, Dan Bondi-Ogolla, Gerardo Gúnera-Lazzaroni, Alexander Proelss, Elisa Morgera, Diana Bronson, Joshua Horton, Atty. Elpidio Ven Peria, René Coenen, Chris Vivian, and Lyle Glowka. The CBD Secretariat provided some further comments and editing (Jaime Webbe, Annie Cung and David Cooper). Others who provided input or comments are listed in annex IV below. Following peer review, the report was made available as document UNEP/CBD/SBSTTA/16/INF/29, then reformatted and edited for publication as Part II of CBD Technical Series No. 66; content has not been updated.

[6] A companion report, on geoengineering impacts on biodiversity, was prepared by a parallel group of experts in response to paragraph 9 (l) of decision X/33; it is presented as Part I of CBD Technical Series No. 66.

[7] With respect to control and regulatory mechanisms, these are: science based; global; transparent; and effective. The decision also refers to climate-related geo-engineering "relevant to the Convention on Biological Diversity".

- **"Relevant to the CBD"**: Because of the potentially wide-ranging effects of geoengineering, this study did not exclude any geoengineering technique on the grounds that it was not relevant for the CBD. In fact, the parallel group of experts that considered the impacts of geoengineering on biodiversity and related social, economic and cultural considerations identified potential impacts (positive and/or negative) from all currently proposed or modelled approaches to geoengineering.
- **"Global"**: This could include two sub-criteria:
    - Geographical or spatial scope of application of the regulatory mechanism (e.g., global, or regional);
    - Degree of participation, including the number of Parties (within the intended scope) and balance in representation (e.g., developed and developing countries, participation of least developed countries, small island developing States).
- **"Science-based"**: Role of associated scientific or technical bodies or mechanisms for provision of clear scientific information in considering and/or developing advice or guidelines for relevant research activities. (Note that in the case of some approaches to geoengineering, it is difficult to differentiate between large-scale scientific experiments and deployment and that, as such, close links with policy mechanisms are required.)
- **"Transparent"**: Due to the technical nature of geoengineering or confidentiality concerning the research, special attention must be paid to transparency of the decision-making process and the basis on which decisions are made. This is especially important for developing countries with fewer scientists involved in the research and fewer delegates at international meetings where this is discussed. Possible considerations include:
    - Ensuring that the rule or guidance is sufficiently clear for States to apply a case-by-case analysis of whether a geoengineering activity would be permitted or not;
    - Access to funding details, recognizing that private funding may be protected by other laws;
    - Facilitating clear mechanisms for consultation with any potentially affected countries;
    - Involving all major stakeholder groups in decision-making;
    - Informing all major stakeholder groups of potential and realized impacts;
    - Ensuring accountability for decisions.
- **"Effective"**: Whether a framework is effective depends on what it is supposed to achieve. Considerations could include:
    - In one sense, "effective" could mean that the framework meets its aims. For the purposes of this study, effectiveness could also refer to effectiveness in meeting the objectives of the CBD, in particular whether or not the framework is consistent with efforts towards the conservation and sustainable use of biodiversity and ensuring the equitable sharing of its benefits. Generally, existing frameworks and rules need to be evaluated in terms of their coverage of the geoengineering approaches currently being considered. In particular, there is a need to assess effectiveness in relation to particular technologies, materials, intent and impacts, all of which are relevant elements of geoengineering. An additional consideration could be that the framework is able to deal with evolving research and potential new geoengineering concepts.
    - Further considerations of effectiveness in this regard include (i) presence of mechanisms aimed at ensuring implementation, compliance with rules, decisions and other guidance, including non-legally-binding approaches where such approaches are most appropriate and (ii) the presence of a compliance mechanism.

It should be noted, throughout the analysis, that with the exception of recent developments under the LC/LP, the CBD, and the ENMOD treaty, the mechanisms discussed in the report were developed before geoengineering was a significant issue and, as such, do not currently contain explicit references to geoengineering approaches. Rather, the report considers, in addition to the above, a number of international instruments which could apply to certain geoengineering approaches. They could address, for instance:

- The substances used by various geoengineering technologies (e.g., sulphur compounds);
- The activity or technology (e.g., "dumping" of substances at sea);
- The area in which the activity takes place (e.g., the high seas or outer space);
- The purpose of an activity (e.g., military or hostile purposes).

1.3 DEFINITION OF GEOENGINEERING

There is no universal and uniform use of the term "geoengineering".[8] At the tenth meeting of the Conference of the Parties, the CBD included an interim definition as a footnote to paragraph 8 (w) of decision X/33.[9]

Subsequently, a parallel group of experts under the CBD was requested to develop proposals on definitions for the consideration of Parties during the sixteenth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice. Based on the definition used in decision X/33, and consistent with other widely used definitions, options for a concise definition were included in the following formulation:

> Climate-related geoengineering: a deliberate intervention in the planetary environment of a nature and scale intended to counteract anthropogenic climate change.[10]

The parallel group considered that the above definition would include both solar radiation management (SRM), also known as sunlight reflection methods, and carbon dioxide removal (CDR) techniques. It should be noted, however, that opinions differ as to the inclusion or exclusion of large scale mitigation activities such as afforestation, reforestation and biochar. Furthermore, different geoengineering approaches are in different states of readiness: some have already been experimented *in situ* (ocean fertilization, for instance) while others remain largely theoretical (most solar radiation management approaches) or at this stage appear to be technically possible but not economically viable or scalable (for instance air capture of CO_2).[11]

The wording of the two proposals noted above for a definition is quite broad. It would need to be analysed to what extent these definitions would be suitable for governance in a normative context, although such a discussion is beyond both the scope and mandate of this report.

The need for global science-based, transparent and effective control and regulatory mechanisms may be most relevant for those geoengineering concepts that have a potential to cause significant adverse transboundary effects, and those deployed in the atmosphere and in areas beyond national jurisdiction. For example, ocean fertilization would be carried out in areas beyond territorial waters, while injection of aerosols into the atmosphere would

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[8] Keith (2000), p. 248; Sugiyama and Sugiyama (2010), pp. 2–3; ETC Group (2010a), pp. 4–7.

[9] The footnote to paragraph 8 (w) of decision X/33 reads as follows:

> Without prejudice to future deliberations on the definition of geo-engineering activities, understanding that any technologies that deliberately reduce solar insolation or increase carbon sequestration from the atmosphere on a large scale that may affect biodiversity (excluding carbon capture and storage from fossil fuels when it captures carbon dioxide before it is released into the atmosphere) should be considered as forms of geo-engineering which are relevant to the Convention on Biological Diversity until a more precise definition can be developed. It is noted that solar insolation is defined as a measure of solar radiation energy received on a given surface area in a given hour and that carbon sequestration is defined as the process of increasing the carbon content of a reservoir/pool other than the atmosphere.

[10] See section 2.1 of Part I of this Technical Series document for additional discussion of definitions.

[11] See American Physical Society (2011), and United States Government Accountability Office (2011), p.20 ff.

have transboundary effects that may be deleterious. Activities such as afforestation, reforestation or other means of terrestrial biomass production, on the other hand, may be governed primarily through domestic institutions.

1.4 METHOD AND STRUCTURE

Geoengineering is a broad term comprising several different concepts. Except for the efforts under the LC/LP and the CBD, the international regulatory framework has not generally addressed geoengineering as such. The ENMOD treaty is also of relevance, although it was designed to deal with environmental modification techniques for a different purpose, namely military or any other hostile use. However, the international regulatory framework comprises a multitude of treaties, actual and potential customary rules and general principles of law, as well as other regulatory instruments and mechanisms, that could apply to all or some geoengineering concepts.[12]

Any of these rules could apply to any geoengineering concept if it falls within its scope of application. One approach would be to analyse for each geoengineering concept separately, which international rules could apply. Another approach would be to take the rules as a starting point and analyse to which geoengineering concept they could apply.

This study primarily follows the second approach, taking the rules as a starting point. It was not feasible within the scope of this study to go through every single rule of the whole of international environmental law or even international law as a whole. The study focuses on the international rules and mechanism that apply, or could reasonably apply, to geoengineering; choices were made based on experience and initial assessments.[13] The study draws on published literature and original research.[14]

The study also looked at international rules governing science and research, an area that has been frequently overlooked.

For the purpose of this study, references to “States” also include subjects of international law such as the European Union (EU).[15]

1.5 ELEMENTS OF THE CURRENT INTERNATIONAL REGULATORY FRAMEWORK

The main elements of the current international regulatory framework as discussed in this study include:

(a) International laws and other principles that are generally applicable to all States,[16] and that by virtue of their universal nature, are relevant to all geoengineering concepts; and

(b) Treaty regimes that may provide more specific norms as well as additional general norms applicable to the Parties to the regime.

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[12] For instance, at some stage geoengineering might be considered as environmental goods or services within the scope of the WTO. However, as the WTO is still in the process of defining environmental goods and services, this topic was not analysed by this study. In addition, the regulatory techniques regarding marine pollution, in particular oil pollution, and nuclear accidents, may be interesting in terms of aspects such as insurance and compensation schemes, but are not considered within the scope of this study.

[13] For instance, there does not seem to be a general rule in international law that establishes restrictions or conditions on the geoengineering concept of painting rooftops and other surfaces such as roads white or light-coloured. Generally, States appear free to do so if they wish. However, there could be international rules banning, for instance, the use of certain chemicals in white paint for health reasons. Although such rules might indirectly affect this geoengineering concept, this level of detail and remoteness remains outside the scope of this study.

[14] E.g., Bodle (2011).

[15] Following the entry into force of the Treaty of Lisbon, cf. Articles 1, 3(2) and 47 of the Treaty on European Union (TEU) and Article 216 of the Treaty on the Functioning of the European Union (TFEU); in accordance with Article 1 of the Treaty on European Union, the European Union (EU) replaced and succeeded the European Community (EC), which had entered into treaties prior to the Treaty of Lisbon.

[16] Customary international law may not bind all States in the case of a persistent objector.

Some aspects of the current international legal framework constitute binding rules within the meaning of Article 38 of the Statue of the International Court of Justice. Binding rules include treaties, customary law, and general principles of law. Other aspects are not legally binding but nonetheless provide guidance to States.

Modern treaties often establish institutions and procedures in order to ensure implementation. This usually includes quasi-legislative bodies such as a Conference of the Parties or other Governing Body of the treaty which meets regularly and which has the mandate to decide on details not set out in the treaty and expert bodies which offer interpretations of treaty articles. Decisions taken by such quasi-legislative bodies are, as such, not binding unless the treaty so provides. However, the distinction between binding and non-binding has become difficult to draw in treaty regime practice and decisions of the Governing Body may be referred to as an aid when interpreting the provisions of a treaty. Governing Body decisions decide on technical details that are unresolved by the treaty, and specify how Parties are to implement and develop the regime. In practice, Parties usually implement the decisions even if they are not legally enforceable, as Parties consider the matters dealt with in the decision a practical necessity.

Apart from existing rules and guidelines, it is important to keep in mind that many international regimes and institutions have a potential mandate that would allow them to address geoengineering, or some aspects of the topic, even if they have not done so to date.

Additional guidance may be provided by relevant institutions, e.g. the UNEP 1980 guidelines on weather modification.[17]

In addition, there are other aspects that could be of interest or relevance, regardless of their legal status. These could include, for instance, self-organized standards by the scientific community[18] or recommendations by relevant civil society organizations.[19]

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[17] Provisions for Co-operation between States in Weather Modification, Decision 8/7/A of the Governing Council of UNEP, 29 April 1980.

[18] Rayner et al. (2009).

[19] E.g., Open Letter to the Climate Response Fund and the Scientific Organizing Committee, 4 March 2010 (http://www.etcgroup.org/sites/www.etcgroup.org/files/publication/pdf_file/AsilomarENG190310.pdf).

CHAPTER 2

GENERALLY APPLICABLE INTERNATIONAL LAW AND PRINCIPLES

There are some overarching rules of international law that are common legal ground and apply to all States, and that might apply to any concepts currently discussed as "climate-related geoengineering".

The fundamental pillars of international law include State sovereignty on the one hand and the maintenance of international peace, security and cooperation (or "good-neighbourliness")[20] on the other.

Treaties (see Chapter 3 below) apply only to those States that are Party to them. Moreover, since there is no specific treaty on geoengineering, the regulatory scope of potentially applicable treaties is limited to their material scope. In contrast, customary law applies to all States regardless of whether they are a Party to, and bound by, a particular treaty.[21] Some aspects of customary law, reviewed here, have a scope that is relevant, or may be relevant, to geoengineering concepts in general.

The legal meaning of "principles" is not clear or agreed in international law. However, for the purpose of this study, the question of whether classification as a "principle" has specific legal implications is not decisive. It may be more useful to focus on the distinction between binding and non-binding rules and principles and on interpreting their specific content in each case. However, the concept of "principles" is relevant in practice, even if its implications are not fully agreed.[22]

The following identifies rules and principles that could apply to geoengineering as part of a governance framework. However, the status of some concepts as *legal* principles or rules is disputed. In addition, the precise meaning of some concepts may be unclear.

2.1 STATE RESPONSIBILITY AND LIABILITY OF PRIVATE ACTORS

State responsibility describes the rules governing the general conditions under which a State is responsible for wrongful actions or omissions, and the resulting legal consequences. The rules on State responsibility presuppose a breach of an international obligation by a State. However, they do not define the requirements of the obligation which is said to have been breached. Instead, they deal with the consequences of such a breach. In this sense, the International Law Commission (ILC) uses the term "secondary rules".

The rules on State responsibility were codified and developed by the International Law Commission's articles on responsibility of States for internationally wrongful acts (annex to UNGA resolution 56/83 of 12 December 2001), which for the most part reflect customary law. The rules relevant to this study are customary law, although some other concepts in the draft articles on State responsibility may not be universally accepted.

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[20] See Articles 2 and 74 of the Charter of the United Nations.

[21] Except for so-called "persistent objectors".

[22] The two concepts of *ius cogens* (or *jus cogens*) and obligation *erga omnes* also exist as two distinct categories of obligations, *ius cogens* being more narrow than obligations *erga omnes*. Generally speaking, a *ius cogens* rule describes a peremptory norm—"a norm accepted and recognized by the international community of States as a whole as a norm from which no derogation is permitted and which can be modified only by a subsequent norm of general international law having the same character" (article 35 of VCLT). However, there are very few rules that are likely to be universally recognized as *ius cogens* (they include, for instance the prohibition of genocide or slavery). An obligation *erga omnes* is an obligation of a State towards the international community as a whole (as opposed to individual States), and all States can be held to have a legal interest in its protection. Details on the legal implications of these concepts have been under debate for a long time. This study suggests that the two concepts of *ius cogens* and obligations *erga omnes* do not have practical relevance for geoengineering at this stage.

Previous drafts of the articles on State responsibility had introduced the concept of "international crimes", which included serious breaches of certain environmental obligations. However, that concept was subsequently dropped and does not appear in the final outcome of the ILC's work.[23]

It is also notable that "a State may be responsible for the effects of the conduct of private parties, if it failed to take necessary measures to prevent those effects."[24]

The rules on State responsibility do not define the obligations relating to geoengineering in the sense of determining which activities are permitted or prohibited. Instead, they provide a basic legal framework for geoengineering activities that breach international law. In the absence of specific rules, the rules on State responsibility provide a general framework that sets out the legal consequences of geoengineering activities that breach international obligations.

State responsibility does not as such require fault or negligence of the State. The conduct required or prohibited and the standards to be observed depend on the obligation in question. A regulatory regime may consider developing specific rules and standards for all or particular geoengineering activities in this regard.

The consequences of State responsibility include legal obligations to cease the activity, to offer appropriate assurances and guarantees of non-repetition, if circumstances so require, and to make full reparation for the injury caused.[25] In view of the diverse geoengineering concepts and their potentially extensive and global impacts, a regulatory regime may consider specific legal consequences flowing from breaches of international obligations regarding geoengineering.

There is no uniform terminology in international law on the meaning of "liability". In this study, the term "liability" refers to legal obligations on private actors—in contrast to the concept of and rules on State responsibility.

States are not as such responsible for acts of private actors. However, a State might have to address private actors in order to fulfil its own obligation.[26] A State could be in breach of an obligation if it failed to take necessary measures to prevent effects caused by private actors (see above on State responsibility). The extent to which a State has to address private actors in order to fulfil its own obligation depends on the obligation in question. For instance, the duty to prevent transboundary harm (see below) requires the State to exercise due diligence. A State may be failing to exercise due diligence and thus be in breach of this obligation if it fails to exercise any legal or factual control over its private actors regarding transboundary harm.

In addition, a State can be under an explicit and specific obligation to address private actors. Specifically, international law can impose a duty on States to provide, in their internal law, that non-State actors are liable for certain acts. (For instance, the 2010 Nagoya-Kuala Lumpur Supplementary Protocol on Liability and Redress to the Cartagena Protocol on Biosafety requires States to address private actors through domestic rules on liability.) However, there is no general obligation on States to do this.

There are also international compensation schemes where non-State actors pay into a pool (e.g., oil pollution compensation schemes). However, there is no general obligation on States to do this.

Given the potential impact of such activities, the existing obligations on States might be insufficient in requiring States to address private actors.

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[23] In its work on State responsibility, the International Law Commission had considered whether a breach of a *ius cogens* rule should be referred to as a separate category of "international crime", as opposed to mere "international delicts". In the 1970s it proposed that an international crime should include "a serious breach of an international obligation of essential importance for the safeguarding and preservation of the human environment, such as those prohibiting massive pollution of the atmosphere or of the seas". However, it subsequently dropped the concept of international crimes.

[24] ILC, on draft articles on responsibility of States for internationally wrongful acts, with commentaries, in UN Doc. A/56/10 (Report of the International Law Commission on the work of its fifty-third session (23 April-1 June and 2 July-10 August 2001); p. 39.

[25] Articles 30 and 31 of the draft articles on State responsibility.

[26] Cf. article 139 of UNCLOS.

2.2 PREVENTION OF TRANSBOUNDARY HARM TO THE ENVIRONMENT

All States are under a general obligation to ensure that activities within their jurisdiction or control respect the environment of other States or of areas beyond national jurisdiction or control. Listed as Principle 2 of the Rio Declaration,[27] and as Article 3 of the Convention on Biological Diversity, the rule has become customary international law.[28] A State in breach of this rule could be held responsible by other States under the customary rules of State responsibility.

The duty to respect the environment of other States or of areas beyond national jurisdiction or control does not mean that any environmental harm, pollution, degradation or impact is for that reason generally prohibited.[29]Although the rule has long been established, it has so far very rarely been the subject of disputes which could have clarified its precise content. In the case of an alleged breach of the duty to not harm the environment, establishing responsibility of a State for geoengineering would require several elements:

- The geoengineering activity would have to be attributable to the State in question. Depending on the particular geoengineering activity and its scale, attribution to a State might be possible using global information systems and technology such as satellite observation.
- The particular geoengineering activity would have to cause a particular harm to the environment of other States or of areas beyond national jurisdiction or control. The causal link would most likely be very difficult to establish. For instance, alleged environmental harm could include changes in precipitation patterns,[30] followed by floods or droughts. A potential claimant State would have to establish a causal link between the particular geoengineering activity and changes in precipitation, as well as between those changes in precipitation patterns and specific environmental harm.[31] Procedural obligations regarding transparency, and global observation and monitoring systems, could play an important role in this respect.

In view of the extent of the potential damage, reversing the burden of proof is being discussed on the basis of the precautionary principle/approach (see also section 2.4 below). For instance, a State to which a geoengineering activity is attributable would have to rebut the assumption that it changed the earth's albedo and that this caused the alleged environmental harm. In the recent *Pulp mills on the river Uruguay* case, the International Court of Justice (ICJ) accepted that a precautionary approach "may be relevant" in the interpretation and application of the treaty in question. However, the court also stated that "it does not follow that it operates as a reversal of the burden of proof".[32] The wording of the court is not clear as to whether this applies to the specific case or generally excludes a reversal. Some national laws and cases do make this shift in the burden of proof. For example, in Australia, the case of *Telstra Corp v Hornsby Shire Council*[33] applied the precautionary principle to this effect. It was found that where there is a threat of serious or irreversible environmental damage and there is the requisite degree of scientific uncertainty, the precautionary principle will be activated and "a decision-maker must assume the threat of serious or irreversible environmental damage is … a reality [and] the burden of showing that this threat … is negligible

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[27] 31 ILM 876 (1992); cf. Principle 21 of the preceding 1972 Declaration of the UN Conference on the Human Environment (Stockholm Declaration), 11 ILM 1416 (1972).

[28] ICJ, Legality of the Threat or Use of Nuclear Weapons (Advisory Opinion—General Assembly), ICJ Rep. 1996, 22, para. 29; ICJ, Case concerning the Gabcikovo-Nagymaros Project (*Hungary v. Slovakia)*, ICJ Rep. 1997, 7, para. 53; ICJ, *Case concerning pulp mills on the river Uruguay (Argentia v. Uruguay)*, judgment of 20 April 2010, para. 193 www.icj-cij.org. Note that the ICJ's formulation is "activities within their jurisdiction *and* control".

[29] Cf. Birnie/Boyle/Redgwell (2009) p. 142.

[30] Policy Statement of the American Meteorological Society on geoengineering the climate system, adopted by the AMS Council on 20.07.2009, http://www.ametsoc.org/policy/2009geoengineeringclimate_amsstatement.html.

[31] Bodle (2010), p. 103.

[32] ICJ, *Pulp mills on the river Uruguay,* para. 164.

[33] New South Wales Land and Environment Court, 2006.

effectively reverts to the proponent …" The approach of the European Union (EU) to pesticide regulation[34] is another example of where this shift of burden of proof has occurred, since it requires pesticides to be proven safe before being registered for use.

It has recently been stated that the duty to respect the environment of other States or of areas beyond the limits of national jurisdiction enshrined in the "no harm" concept "entails prohibitive and preventive steering effects on States. In its prohibitive function, it forbids any State from causing significant transboundary environmental harm. According to this view, in its preventive function, the 'no harm' concept obliges every State of origin to take adequate measures to control and regulate in advance sources of potential significant transboundary harm."[35] While a State will generally not be in breach of the obligation relevant here unless it fails to apply due diligence,[36] the fact remains that if a significant damage occurs, the responsible State can, depending on the circumstances, arguably be obliged to pay compensation. Having said that, the prohibitive function of the obligation concerned is inappropriate to prevent the occurrence of environmental damage. This is why the situation of likeliness of environmental harm, which could become particularly relevant with regard to geoengineering, is addressed by the preventive function of the "no harm" concept, embodied in the principle of prevention.[37] In this respect, the ICJ clarified, in the Pulp Mills case, that "the principle of prevention, as a customary rule, has its origins in the due diligence that is required of a State in its territory."[38] Which diligence is "due", however, depends on the circumstances of the particular case, which leaves considerable legal uncertainty.

The obligation not to cause transboundary environmental harm and the rules on State responsibility do not explicitly distinguish between research and deployment with regard to technologies. It could be considered whether the level of diligence required is different. International coordination could provide guidance in this regard.

States can avoid State responsibility by relying on "circumstances precluding wrongfulness", such as self-defence or force majeure.[39] One of these recognized circumstances is necessity as "the only way for the State to safeguard an essential interest against a grave and imminent peril". This relates to some arguments made in favour of geoengineering. For instance, a State causing transboundary environmental harm by geoengineering might argue that it is severely affected by climate change and claim distress or necessity as a legal defence. On the other hand, the defence would arguably be excluded for States that contributed to climate change and thus to the state of necessity (Article 25 (2) (b) of the draft articles on State responsibility).

In addition, and as a result of a separate stream of work, the International Law Commission has also drafted a separate set of articles regarding harmful effects of "hazardous" acts, even where such acts are not in breach of an international obligation, although such principles only refer to the allocation of loss.[40] This could include making private actors liable under domestic law.[41] In contrast to many of the draft articles on State responsibility, these draft articles do not reflect customary law. Although neither of these rules as such prohibit geoengineering, they could provide a basic framework for managing the risks involved in view of intended global and potentially irreversible consequences.

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[34] *Directive 91/414/EC.*

[35] Beyerlin and Marauhn (2011), p. 40 ff.

[36] Cf. ILC, on draft articles on State responsibility, in UN Doc. A/56/10, para. 77, commentary in Chapter III, para 2; ILC, on draft articles on prevention of transboundary harm from hazardous activities, in UN Doc. A/56/10, para. 98, commentary on Article 3 (para. 8).

[37] Note that the exact relationship between the two dimensions of the no harm concept is still subject to significant lack of clarity. However, all sources seem to agree that the obligation to prevent harm represents an essential aspect of the obligation not to cause significant harm. Cf. Handl (2007), pp. 531 and 539.

[38] ICJ, *Case concerning pulp mills on the river Uruguay (Argentia v. Uruguay)*, judgment of 20 April 2010, para. 101; available at www.icj-cij.org.

[39] Article 25 of the articles on State responsibility.

[40] See for instance the work of the ILC on *Draft articles on prevention of transboundary harm from hazardous activities*, in UN Doc. A/56/10.

[41] Cf. ILC, *Draft principles on the allocation of loss in the case of transboundary harm arising out of hazardous activities, in* UN Doc. A/61/10, para. 66, in particular principle 4.2.

Gaps and limitations include the following:

- The obligation to prevent transboundary harm is retrospective. International law provides only very limited means to obtain advance provisional measures in order to stop activities that could be in breach of international obligations;[42]
- The burden of proof could be addressed and clarified. However, how could the attribution of harm hold up in cases of several concurrent geoengineering activities and given our still incomplete understanding of the complex climate system?
- The standard of care required for due diligence is not clear for geoengineering;
- Whether to address or clarify the potential defence on the basis that cooling the climate outweighs the harm caused.

2.3 DUTY TO UNDERTAKE AN ENVIRONMENTAL IMPACT ASSESSMENT

A further general rule is the duty to carry out an environmental impact assessment. Conceptually, environmental impact assessment (EIA) addresses individual projects, while strategic environmental assessment (SEA) takes into account the environmental consequences of programmes and policies. The duty to conduct an environmental assessment is included in several treaties, for example in Article 14 of the CBD,[43] which is referred to in CBD decision X/33, in article 206 of UNCLOS, and in regional instruments such as the United Nations Economic Commission for Europe (UNECE) Espoo Convention, which also has a Protocol on Strategic Environmental Assessment.

According to Article 14 of the CBD, each Contracting Party shall, as far as possible and as appropriate:

- Introduce appropriate procedures requiring environmental impact assessment of its proposed projects that are likely to have significant adverse effects on biological diversity with a view to avoiding or minimizing such effects and, where appropriate, allow for public participation in such procedures;
- Introduce appropriate arrangements to ensure that the environmental consequences of its programmes and policies that are likely to have significant adverse impacts on biological diversity are duly taken into account;
- Promote, on the basis of reciprocity, notification, exchange of information and consultation on activities under their jurisdiction or control which are likely to significantly affect adversely the biological diversity of other States or areas beyond the limits of national jurisdiction, by encouraging the conclusion of bilateral, regional or multilateral arrangements, as appropriate;
- In the case of imminent or grave danger or damage, originating under its jurisdiction or control, to biological diversity within the area under jurisdiction of other States or in areas beyond the limits of national jurisdiction, notify immediately the potentially affected States of such danger or damage, as well as initiate action to prevent or minimize such danger or damage; and
- Promote national arrangements for emergency responses to activities or events, whether caused naturally or otherwise, which present a grave and imminent danger to biological diversity and

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[42] In recent years the ICJ has only granted two applications for provisional measures, in cases involving the imminent execution of prisoners, *LaGrand* Case (*Germany v. United States of America)*, Provisional Measures, order of 3 March 1999; Avena and Other Mexican Nationals (*Mexico v. United States of America*), order of 5 February 2003. All other applications were rejected, see Armed Activities on the Territory of the Congo (New Application: 2002) (*Democratic Republic of the Congo v. Rwanda*), order of 10 July 2002; Certain Criminal Proceedings in France (*Republic of the Congo v. France*), order of 17 June 2003; Pulp Mills on the River Uruguay (*Argentina v. Uruguay*), orders of 13 July 2006 and 23 January 2007; Questions relating to the Obligation to Prosecute or Extradite (*Belgium v. Senegal*), order of 28 May 2009; Proceedings instituted by the Republic of Costa Rica against the Republic of Nicaragua, press release of 19 November 2010; all available at http://www.icj-cij.org.

[43] See also CBD decisions VII/16, VIII/28 and X/42 in this respect.

> encourage international cooperation to supplement such national efforts and, where appropriate and agreed by the States or regional economic integration organizations concerned, to establish joint contingency plans.

Moreover, an environmental impact assessment is required in many domestic legal orders. The requirement to carry out an environmental impact assessment has become customary international law and applies even in the absence of a treaty obligation to this effect.

The ICJ has recently recognized that the accepted practice among States amounted to "a requirement under general international law to undertake an environmental impact assessment where there is a risk that the proposed industrial activity may have a significant adverse impact in a transboundary context, in particular, on a shared resource".[44] In the particular case before it, the ICJ also held that conducting an EIA was part of exercising due diligence.[45] The judgment refers to particular industrial activities and does not necessarily establish a general requirement for a strategic environmental assessment.

The ICJ left it to the States to determine the specific content of the impact assessment required. However, it also specified some details, including the following:

- The duty involves "having regard to the nature and magnitude of the proposed development and its likely adverse impact on the environment as well as to the need to exercise due diligence in conducting such an assessment";
- The impact assessment has to be carried out prior to the implementation of the activity;
- Continuous monitoring of the activity's effect on the environment is required. As a legal rule in customary international law, it is an important development that might require clarification as to its precise implications.

There are cases in which the EIA process has been applied to geoengineering research with controversial outcomes. For example, the Lohafex ocean fertilization experiment carried out in January 2009 was conducted in spite of concern among non-governmental organizations and the German Federal Ministry of the Environment concerning the adequacy of the environmental risk assessment that was done, on the basis of the CBD decision on ocean fertilization, decision IX/16 C (see also section 3.3 below on the London Convention / London Protocol).[46]

The complexity of the climate system will in some cases make it difficult to assess the environmental impacts of geoengineering activities in advance as well as subsequently (see the complementary CBD study on the impacts of climate-related geoengineering on biological diversity). However, this might be an inherent issue rather than a regulatory gap. It may be worth considering whether and to what extent this could be addressed through different or more specific guidance regarding EIA and SEA.

Some geoengineering techniques, such as artificial trees, would require cumulative deployment of relatively small interventions in order to be effective. An EIA of a single unit might not address such cumulative impacts, while an SEA would only presuppose that the cumulative deployment is part of a plan or programme as defined by the provision in question.

In the context of trade and technologies, the International Assessment of Agricultural Knowledge, Science and Technology suggested considering the option of an intergovernmental framework for the comparative assessment of the environmental impact of new technologies as they evolve from initial scientific discovery through to possible "commercialization".[47]

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[44] ICJ, *Pulp mills on the river Uruguay*, paras. 204–206.

[45] Ibid.

[46] http://www.bmu.de/english/press_releases/archive/16th_legislative_period/pm/42985.php and http://www.etcgroup.org/en/node/712.

[47] McIntyre et al. (2009), p. 467; see ETC Group (2009a) and ETC Group (2011).

2.4 PRECAUTIONARY PRINCIPLE OR APPROACH

There is no uniform formulation or usage for the precautionary principle or approach,[48] and its legal status in customary international law has not yet been clearly established,[49, 50, 51] although it has been invoked several times.[52] Under the Convention on Biological Diversity, the precautionary approach is introduced in the preamble, where it is noted that "where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat". The decisions of the Conference of the Parties to the Convention have frequently been based on and stressed the importance of the precautionary approach,[53] including in decision X/33, which addresses geoengineering (see section 3.1 below on CBD). Under the London Protocol, article 3.1 requires the application of the precautionary approach.

Another legal formulation in the operative part of a treaty text with near universal application is Article 3(3) of the United Nations Framework Convention on Climate Change (UNFCCC).[54] Almost all States have ratified the UNFCCC,[55] including the US.[56] While this renders the question of the precautionary principle/approach's legal status in customary law less relevant, the precise consequences remain unclear.

On the one hand, while all proponents of geoengineering stress that it is no substitute for reducing emissions, they would argue that it would contribute to fighting climate change:[57] extracting carbon dioxide from the atmosphere reduces greenhouse gases, and solar radiation management has the potential to limit temperature increases. On this basis, it might be argued that lack of full scientific certainty should not be used as a reason for postponing geoengineering, provided that there are threats of serious or irreversible damage. Geoengineering proponents would argue that such threats exist, in view of the slow progress in reducing global emissions at source and the short time remaining during which emission trends need to be reversed (peak).

On the other hand, faced with this same scenario, it may be argued that the precautionary approach would imply following the less risky action of implementing emission reductions. In fact, at the time it was drafted, Article 3(3) of UNFCCC was generally viewed as having the intention of postponing mitigation measures by referring to scientific uncertainty about climate change. In this context, an interpretation in support of geoengineering would

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[48] Cf. Principle 15 of the Rio Declaration; Article 3.3 of UNFCCC; Article 3 of the London Protocol; CBD Preamble; Birnie et al. (2009), p. 160.

[49] Cf. Virgoe, J. (2009), p. 111; UK House of Commons Science and Technology Committee (2010), paras. 85–86. Güssow et al. (2009), p. 15, acknowledge a "considerable degree of unclarity (sic) as to its normative content and validity", but apply Principle 15 of the Rio Declaration without further analysis as to legal status.

[50] Cf. Article 11 of the 1982 World Charter for Nature and article 6 of the 2000 Earth Charter.

[51] See generally Birnie et al. (2009), p. 152 ff.; UK House of Commons Science and Technology Committee (2010), para. 86. On the basis of the heading "principles" in Article 3.3 of UNFCCC, the present study uses the term "precautionary principle" without prejudice to this debate.

[52] In its judgment on the *Pulp mills on the river Uruguay* case, the ICJ considered that a precautionary approach may be relevant in the interpretation and application of the provisions the treaty in question, but it rejected Argentina's argument that it operates as a reversal of the burden of proof: cf. Memorial of Argentina of 15 January 2007, paras. 3.194-3.197 and 5.15. and the judgment, para. 164. (All documents available at www.icj-cij.org.) See also dissenting opinions of Judges Weeramantry and Palmer in the ICJ cases *Nuclear Tests II*, paras. 342 and 412; dissenting opinion of Judge Weeramantry in the *Nuclear Weapons* opinion, para. II.10.e; see also WTO Appellate Body, *EC Measures Concerning Meat and Meat Products (Hormones)*, paras. 16 and 120–125; ITLOS Case No.17, "Responsibilities and obligations of States sponsoring persons and entities with respect to activities in the Area (Request for Advisory Opinion submitted to the Seabed Disputes Chamber)", http://www.itlos.org; separate opinion of Judge Wolfrum in the ITLOS Case No. 10, *The MOX Plant Case (Ireland v. United Kingdom),* Provisional Measures (www.itlos.org); see also Marr (2000).

[53] See for instance CBD decisions IV/10 para. 1; V/3 para. 5; VI/7 annex I, paras. 24 and 31; VI/26 annex, para. 1(e); VII/5 annex I, appendix 3, para. 2; VII/11 principle 6, guideline 6.2; VII/14, paras. 54 and 75.

[54] United Nations Framework Convention on Climate Change, of 9 May 1992, 31 ILM 849 (1992), in force 1994.

[55] Currently 194 Parties, http://unfccc.int/parties_and_observers/parties/items/2352.php.

[56] The US is one of the major emitters and potential geoengineering States but is not Party to the Kyoto Protocol.

[57] All proponents of geoengineering acknowledge and stress that it does not reduce anthropogenic CO_2 emissions levels.

be unusual, but not evidently contrary to the wording. However, Article 3(3) of UNFCCC could not be read as actually requiring geoengineering measures.[58]

In any event, Article 4(1)(f) of UNFCCC requires all Parties to employ appropriate methods "with a view to" minimizing adverse effects of their mitigation and adaptation measures on the economy, public health and the quality of the environment.[59] Impact assessments are explicitly mentioned as an example of such methods. However, this provision is not overly specific and would only apply to geoengineering techniques that are regarded as mitigation or adaptation measures.

The legal role of the precautionary principle in Article 3(3) of UNFCCC in the geoengineering debate remains ambiguous. Depending on how we assess the risk posed by geoengineering in relation to a scenario with substantial mitigation and in relation to a scenario of unmitigated climate change, the precautionary principle embodies the core arguments both for and against geoengineering.

2.5 ARTICLE 39 OF THE CHARTER OF THE UNITED NATIONS

Depending on the impacts of the geoengineering concept and activity in question, States might argue that geoengineering activities constitute a threat to or breach of the peace or aggression under Article 39 of the Charter of the United Nations. For instance, they could claim that the activity in question affects their agricultural economy or water supplies by interfering with local microclimates. However, the current state of knowledge concerning geoengineering reveals a great deal of uncertainty. In any event, the Security Council has wide discretion in determining whether the requirements of Article 39 of the Charter are met, and in deciding on its response.

2.6 OTHER CONCEPTS

Common but differentiated responsibilities

The concept of **common but differentiated responsibilities** is listed in Principle 7 of the Rio Declaration. In many treaties, notably the UNFCCC, common but differentiated responsibilities (CBDR) are explicitly mentioned or implicit in differentiated obligations (often together with "and respective capabilities").

The main practice has so far been the basis for differentiating obligations within a treaty, usually between developed and developing countries or sub-groups, frequently combined with support for developing countries.

However, the status as a legal customary principle and its precise content are disputed.[60] CBDR does not mean that international rules and governance *have to* differentiate obligations. In addition, the countries and groups between which obligations are differentiated vary from case to case.[61]

The concept of CBDR does not address whether or not countries are allowed to conduct geoengineering. The main notions that have been underpinned by CBDR in practice are that developed countries should take more stringent obligations than developing countries (or that a time delay should be granted to developing countries), and that developing countries should receive financial and other support in order to be able to fulfil their obligations. Neither of these notions appears to address issues raised by geoengineering. Such issues could arise if certain geoengineering technologies will be available to certain countries only whereas other countries may be the most affected. However, there is no consensus or established practice that CBDR means a right to access to a specific technology or an obligation to pay for impacts of a specific technology.

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[58] On the precautionary approach in this regard, see Birnie et al. (2009), pp. 162 and 164.

[59] Cf. Freestone and Rayfuse (2008), p. 231, and Bodansky (1996), p. 313.

[60] Cf. Stone (2004), p. 276 ff.; Birnie et al. (2009), p. 160.

[61] Michels (1999), p. 54.

Sustainable development

The concept of **sustainable development** is fundamental not just for international environmental law. It is referred to in several treaties, including Article 4 of UNFCCC, and other instruments such as the Rio Declaration, Agenda 21,[62] the 2002 World Summit on Sustainable Development in Johannesburg (the 2002 Earth Summit),[63] and the 2005 UN World Summit Outcome Document.[64] It is also central to the IUCN's 1995/2004 Draft Covenant on Environment and Development (for instance Article 1). Sustainable development was first defined in the 1987 report of the World Commission on Environment and Development, *Our Common Future* (the Brundtland Report), as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".[65] There are at least three "interdependent and mutually reinforcing pillars" of sustainable development: economic development, social development, and environmental protection,[66] and indigenous groups often argue that there is a fourth pillar of sustainable development, namely cultural diversity.[67] Whether and to what extent the concept of sustainable development has a specific normative legal content is still under debate. There is no consensus, for example, as to whether the concept would prohibit certain activities. However, it is of high political relevance and has to be taken into account in considering regulatory frameworks for geoengineering. This includes the concept of intergenerational equity, which is relevant in particular if certain solar radiation management activities would have to be maintained by future generations in order to avoid severe impacts.

Other

There are several concepts addressing international interest in the protection of areas beyond national jurisdiction and cross-cutting issues such as the atmosphere and biodiversity. The term "common goods" may be used as an overarching general term for such concepts of global environmental responsibility. However, the concept of common goods is not as such a separate legal term or concept.[68] In practice, a variety of terms are used. For instance, the conservation of biological diversity as well as change in the earth's climate and its adverse effects are each mentioned as a "common concern of humankind" in the CBD and the UNFCCC respectively.[69] The moon and its natural resources, as well as the seabed and ocean floor and the subsoil thereof beyond the limits of national jurisdiction, as well as its resources, are mentioned as "common heritage of mankind" in the Moon Treaty and UNCLOS.[70] It has been also argued in this context that the atmosphere has become a distinct concern of the international community.[71] The legal status or content of these concepts is mostly unclear and needs to be assessed in each particular case.

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[62] See www.un.org/esa/dsd/agenda21.

[63] See www.un.org/jsummit/html/basic_info/basicinfo.html.

[64] See 2005 World Summit Outcome Document, 15 September 2005, UNGA resolution 60/1 (UN Doc. A/RES/60/1).

[65] *Our Common Future, Report of the World Commission on Environment and Development,* Chapter 2: Towards Sustainable Development, "Conclusion": http://www.un-documents.net/ocf-02.htm.

[66] 2005 World Summit Outcome Document, World Health Organization, 15 September 2005: www.un.org/summit2005/documents.html.

[67] See, for instance, the UNESCO Universal Declaration on Cultural Diversity (2001), available at http://unesdoc.unesco.org/images/0012/001271/127160m.pdf.

[68] See Durner (2001), p. 18 and p. 17 footnote 2, for the variety of terms used in practice.

[69] Preamble to the CBD and UNFCCC; cf. also paragraph 1 of UNGA resolution 43/53 of 6 December 1988: "Recognizes that climate change is a common concern of mankind, since climate is an essential condition which sustains life on earth."

[70] Article 11 of the Moon Treaty; preamble and article 136 of UNCLOS.

[71] Wustlich (2003), p. 319 ff.

2.7 SUMMARY ASSESSMENT OF CUSTOMARY RULES

Customary law provides few rules applicable to all States and all geoengineering concepts. Customary rules reflect other States' legitimate expectations. They provide common legal ground, but their actual content is not specific enough to provide clear guidance as to geoengineering.

The customary rules identified above are subject to and can be derogated from by special rules agreed between States. For instance, customary law prohibits transboundary environmental harm. Producing an ozone-depleting substance could be regarded as being in violation of that rule. However, the ozone regime (Vienna Convention and Montreal Protocol) provides special treaty rules regulating the production and consumption of certain ozone-depleting substances. States that are Party to and comply with the ozone regime would therefore not be in breach of the customary rule on preventing transboundary environmental damage if they produce or emit ozone-depleting substances consistent with that regime. The special rules of the ozone regime define the permitted conduct and transboundary effects in this regard.

The customary rules that apply to all States and all geoengineering concepts provide some guidance on principles that would need to be considered, but they would be an incomplete basis for international governance, mainly because the geographic scope and the risks associated with geoengineering are so large-scale and because of the uncertain legal status and their unclear specific legal content.

CHAPTER 3

SPECIFIC TREATY REGIMES AND INSTITUTIONS

3.1 THE CONVENTION ON BIOLOGICAL DIVERSITY

The Convention on Biological Diversity (CBD) has nearly universal membership and a wide scope of application. The US is not a Party, although as a signatory, it is under an obligation not to defeat its object and purpose (Article 18 of the Vienna Convention on the Law of Treaties, VCLT).

The CBD has referred to and incorporated the work of the London Convention/London Protocol (LC/LP) in its own decisions, thus widening their application beyond the smaller number of Parties to the LC/LP. With respect to ocean fertilization, in decision X/29, the Conference of the Parties to the CBD, at its tenth meeting (COP 10), in October 2010, reaffirmed the precautionary approach and provided guidance to Parties with a view to ensuring that no ocean fertilization takes place unless in accordance with its decision IX/16 of 2008. It also invited Parties to act in accordance with the LC/LP Assessment Framework.[72]

The tenth meeting of the Conference of the Parties also went beyond ocean fertilization and adopted a decision addressing geoengineering in general.[73] This appears to be the only all-encompassing governance measure at this level to date. Paragraph 8 of decision X/33 invites "Parties and other Governments, according to national circumstances and priorities, … to consider the guidance below", which includes the following:

> (w) Ensure, in line and consistent with decision IX/16 C, on ocean fertilization and biodiversity and climate change, in the absence of science based, global, transparent and effective control and regulatory mechanisms for geo-engineering, and in accordance with the precautionary approach and Article 14 of the Convention, that no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting in accordance with Article 3 of the Convention, and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment.

The 2010 CBD decision on geoengineering is not legally binding. However, the decision is important for a global governance framework because of the consensus of the 193 Parties it represents and the political signal it sends. It also addresses geoengineering in general, based on its own definition.[74]

The text of the CBD decision refers specifically to "the precautionary approach and Article 14 of the Convention" when inviting Parties to establish limits on geoengineering.

Paragraph 8 (w) of decision X/33 is intended to be an interim measure subject to further consideration and action, including under the CBD itself and in other fora. It is a transitional measure based on the need to establish whether there are science based, global, transparent and effective control and regulatory mechanisms in place for geoengineering, and whether geoengineering has been scientifically justified.

In order to facilitate further consideration of geoengineering as additional scientific evidence and understanding becomes available, paragraph 8 (w) of decision X/33 allows for exceptions for small-scale, controlled scientific activities, for those activities for which there is an adequate scientific basis and for which appropriate consideration

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[72] CBD decision X/29, para. 13(e) and paras. 57–62.

[73] UNEP/CBD/COP/DEC/X/33, available at www.cbd.int/cop10/doc/.

[74] ETC Group (2010b).

is given to the associated risks for the environment and biodiversity and associated social, economic and cultural impacts and for those activities for which a science-based global, transparent, and effective regulatory mechanism is in place. With regard to implementation, it appears to be subject to the determination of each Party whether an "adequate scientific basis" exists or whether such activities are small scale and controlled, bearing in mind obligations under Article 3 of the Convention, which reiterates the duty to prevent transboundary environmental harm.

The end of paragraph 8 (w) of decision X/33 requires that the studies mentioned above are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment. Again, the determination of whether such criteria are met is subject to the determination of individual Parties subject to the additional obligations mentioned above.

In addition to the CBD, there are other biodiversity-related conventions, such as the Ramsar Convention on Wetlands, the Convention on Migratory Species (CMS) and the World Heritage Convention. Geoengineering techniques such as enhanced weathering in the form of spreading base minerals, afforestation, reforestation, soil carbon enhancement, land-based albedo enhancement, biomass and charcoal production and storage have land-use change impacts.

While no general regulation of land use or land-use change appears to exist under international law, specific international regimes might potentially apply to certain areas, which could be affected by large-scale land-use changes. In particular, rules on nature and habitat protection could restrict land-use changes that would be part of certain geoengineering techniques. Such regimes include, for instance, the Convention on Migratory Species regarding the habitat of migratory species and the World Heritage Convention regarding specific areas defined as cultural or natural heritage. However, the consideration of such potentially affected specific provisions would fall beyond the scope of this study.

3.2 UNCLOS—UNITED NATIONS CONVENTION ON THE LAW OF THE SEA

The 1982 United Nations Convention on the Law of the Sea (UNCLOS), which has been very widely ratified, sets out the legal framework within which all activities in the oceans and seas must be carried out, thus including geoengineering activities, such as ocean fertilization, maritime cloud albedo enhancement, altering ocean chemistry through enhanced weathering, as well as projects such as ocean mixing (enhanced upwelling and downwelling through technological means). UNCLOS provides for a number of maritime zones within which States have specific rights and obligations. These rights and obligations differ within each zone.

UNCLOS contains specific obligations relating to the protection and preservation of the marine environment (Part XII). These obligations apply to areas within and beyond national jurisdiction. UNCLOS also provides for a number of obligations related to marine scientific research (Part XIII), which are relevant in the context of geoengineering experiments.

States have the general obligations to protect and preserve the marine environment (article 192) and to take all measures necessary to prevent, reduce and control pollution of the marine environment from any source, including pollution by dumping (articles 1, 194 and 210). In addition, States are required to take all measures necessary to ensure that activities under their jurisdiction or control do not cause damage by pollution to other States and their environment (article 194). In taking measures to prevent, reduce and control pollution of the marine environment, States shall act so as not to transfer, directly or indirectly, damage or hazards from one area to another or transform one type of pollution into another (article 195).[75] UNCLOS also provides that dumping within the territorial sea and the exclusive economic zone or onto the continental shelf shall not be carried out without the express prior approval of the coastal State (article 210).

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[75] It has been suggested that some geoengineering technologies may involve a transfer of one form of pollution (excessive greenhouse gas concentrations in the atmosphere) into another (excessive greenhouse gases in the oceans). See Verlaan (2009) for elaboration of this argument.

With regard to pollution of the marine environment resulting from the use of technologies under their jurisdiction or control, States are required to "take all measures necessary to prevent, reduce and control" such pollution (article 196). Furthermore, when States have reasonable grounds for believing that planned activities under their jurisdiction or control may cause substantial pollution of or significant and harmful changes to the marine environment, they shall, as far as practicable, assess the potential effects of such activities on the marine environment and shall communicate reports of the results of such assessments (article 206).

It has been argued that an activity is permitted in principle by the freedom of the high seas unless it is specifically excluded by a rule of international law.[76] As the freedoms described in article 87(1) are indicative only, these activities must be exercised in accordance with the provisions of UNCLOS, as described, and with due regard for the interests of other States.

States are also responsible under UNCLOS for the fulfilment of their international obligations concerning the protection and preservation of the marine environment and they shall be liable in accordance with international law (article 235).

Ocean fertilization could arguably be seen as "placement of matter for a purpose other than the mere disposal thereof" and therefore excluded from the definition of dumping under article 1 paragraph 5(b)(ii) of UNCLOS. However, such placement must not be contrary to the aims of UNCLOS.

The legal framework established by UNCLOS in 1982 to prevent, reduce and control pollution by dumping reflects the approach adopted in the London Convention in 1972, and was developed further by the London Protocol in 1996 consistent with UNCLOS article 210(4). The definitions provided in UNCLOS are very similar to those that have been incorporated into the London Convention and the London Protocol, and, as noted elsewhere, the Contracting Parties to these instruments have concluded that the scope of the London Convention and the London Protocol includes ocean fertilization activities. In addition, the reference to "global rules and standards" in article 210(6) of UNCLOS is generally understood to include the London Convention, which thus serves as minimum standard with regard to Part XII of UNCLOS.[77]

Ocean-based geoengineering approaches such as ocean fertilization, maritime cloud albedo enhancement, ocean based weathering, and ocean mixing have not been explicitly addressed in UNCLOS, but such activities may, where applicable, be subject to general provisions dealing with, for example, the rights, jurisdiction and duties of States, the protection and preservation of the marine environment and marine scientific research and other applicable rules.

3.3 LONDON CONVENTION AND LONDON PROTOCOL

The London Convention (LC) and London Protocol (LP)[78,79] address marine pollution from dumping of wastes and other matter at sea. They apply to all marine areas and cover a significant part of global shipping.[80] Article 7 of the LP also addresses internal waters by requiring Parties to either apply the LP or adopt other effective permitting and regulatory measures to control dumping. Article 3(1) of the LP provides that Parties shall apply a precautionary

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[76] Scott (2010a), p. 7, citing Churchill and Lowe (1999), p. 206.

[77] Cf. IMO Doc LEG/MISC/3/Rev.1 of 6 January 2003, Implications of the Entry into Force of the United Nations Convention on the Law of the Sea for the International Maritime Organization, p. 48: "At their Seventeenth Consultative Meeting held in 1994, the Contracting Parties expressed their opinion that States Parties to UNCLOS would be legally bound to adopt laws and regulations and take other measures to prevent, reduce and control pollution by dumping. In accordance with article 210(6) of UNCLOS, these laws and regulations must be no less effective than the global rules and standards contained in the London Convention"; Report of the Secretary-General on the Law of the Sea, 1995, UN Doc. A/50/713, paras. 107 and 108.

[78] The later London Protocol entered into force in 2006 and eventually replaces for its Parties the earlier London Convention. The two instruments will continue to apply in parallel for the time being.

[79] Full names of these and other treaties mentioned are provided in annex II below.

[80] There were 87 Parties to the London Convention and 41 Parties to the London Protocol as of 28 February 2012 (www.londonprotocol.imo.org). The Parties represent about two thirds and one third, respectively, of global merchant shipping tonnage (IMO press briefing 50/2010, 20 October 2010).

approach to environmental protection from dumping of wastes or other matter. The LC/LP have done significant work regarding a regulatory framework for ocean fertilization.

In 2008 the treaty bodies agreed that the scope of the LC/LP includes ocean fertilization activities.[81] From a legal perspective, this can be seen as being in accordance with Article 31(3) of VCLT, which provides for Parties to collectively interpret the meaning of a treaty. To the extent that ocean fertilization activities thus involve "dumping" within the meaning of the LC/LP, they are subject to the binding permitting regime required of Parties to the LC or LP. In 2010, the Parties adopted resolution LC-LP.2(2010) on the "Assessment Framework for Scientific Research Involving Ocean Fertilization", which had been developed since May 2007, as required under resolution LC-LP.1(2008). This assessment framework guides Parties as to how proposals they receive for ocean fertilization research should be assessed; it provides criteria for an initial assessment of such proposals and detailed steps for completion of an environmental assessment, including risk management and monitoring.[82]

The LC/LP Assessment Framework is not legally binding in form or in wording. In addition, participation in the London Convention and London Protocol is not comparable to the CBD or the UNFCCC, for instance, in terms of number of Parties. However, the LC/LP Assessment Framework was incorporated by reference in CBD decision X/29 on ocean fertilization (see section 3.1 above).

In 2009, the Parties to the London Convention and London Protocol considered whether the scope for regulation should be widened to cover emerging "marine geoengineering" proposals, or to focus solely on ocean fertilization activities, which are a subset of marine geoengineering. It was stated in the report that the focus should remain on the latter, while some delegations were of the view that an exploration of marine geoengineering and its possible impacts on the marine environment was desirable and should be planned in the future. Following this meeting, the terms of reference for the Intersessional Working Group on Ocean Fertilization were adopted, including reference to "flexibility and adaptability to address emerging issues that fall within the scope of the LC/LP and have the potential to cause harm to the marine environment."[83]

Subsequently, in 2010, the LC/LP agreed to continue its work towards providing "a global, transparent and effective control and regulatory mechanism for ocean fertilization activities and other activities that fall within the scope of the London Convention and London Protocol and have the potential to cause harm to the marine environment".[84]

There has also been a considerable amount of regulatory work done under the LC/LP on carbon capture and storage (CCS) in sub-seabed geological formations. While carbon capture and storage is not included in the CBD's working definition of geoengineering, the guidance concerning the risk assessment framework for storage in subsurface geological formations may be relevant to CO_2 storage in general. However, it is not clear whether the rules for carbon capture and storage under the LC/LP would apply to CO_2 captured after release into the atmosphere.

3.4 UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCCC) AND THE KYOTO PROTOCOL

The UNFCCC / Kyoto Protocol is a multilateral legal regime, with universal participation in the UNFCCC and almost universal participation in the Kyoto Protocol (the US is not a Party to the Kyoto Protocol; however, participation in the second commitment period of Kyoto is very likely to be reduced[85]). The regime has a strong institutional

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[81] Resolution LC-LP.1 (2008), para. 1. For views on the legal implications of the LC/LP statements and decisions as well as the Lohafex experiment carrying out ocean fertilization in 2009, see Freestone and Rayfuse (2008), Verlaan (2009), and Ginzky (2010).

[82] Resolution LC-LP.2 (2010) on the assessment framework for scientific research involving ocean fertilization, adopted on 14 October 2010. For the assessment framework see the draft elaborated by the Scientific Group of the London Protocol and the Scientific Group of the London Protocol, LC/SG/32/15, Annex 2.

[83] Annex 7 of LC 32/15

[84] Resolution LC-LP.2(2010), para. 5; IMO (2010).

[85] Canada's formal withdrawal from the Kyoto Protocol on 15 December 2011 will become effective on 15 December 2012; Russia and Japan have announced that they would not participate in a second commitment period.

structure and a scientific underpinning with formally established links to the work of the Intergovernmental Panel on Climate Change (IPCC). There have been suggestions outside the climate negotiations to revise the UNFCCC or adopt a new protocol to it on geoengineering governance.[86]

However, the UNFCCC and Kyoto Protocol have not addressed geoengineering concepts or governance.[87] Nevertheless, in view of the slow progress on the climate negotiations for a post-2012 regime, the Executive Secretary of the UNFCCC has recently warned that carbon dioxide removal techniques might have to be developed.[88]

The objective of the climate regime, according to Article 2 of UNFCCC, is to stabilize greenhouse gas concentrations in the atmosphere. Article 2 also states that a level that would prevent dangerous anthropogenic interference with the climate system "should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner". However, the "ultimate" aim of stabilizing greenhouse gas concentrations does not necessarily mean that the UNFCCC or the Kyoto Protocol prohibit other measures intended to prevent global warming. Neither the UNFCCC nor the Kyoto Protocol prohibit geoengineering as such. The UNFCCC "principles" (Article 3) and obligations such as Article 3(1) are quite general.

The objective of both instruments, as stated in Article 2 of UNFCCC, is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Carbon dioxide removal techniques would reduce greenhouse gas concentrations and would as such not be contrary to this objective. Solar radiation management techniques would not change greenhouse gas concentrations. However, both sets of technologies may have effects that, in themselves, could be considered as "(dangerous) anthropogenic interference in the climate system".

Article 3(3) of UNFCCC incorporates the precautionary principle into the UNFCCC. However, the wording is ambiguous regarding geoengineering (see above under precautionary principle or approach).

The obligations on all Parties in Article 4(1) of UNFCCC aim at mitigation and adaptation measures in a general way. They do not explicitly or by implication prohibit or permit measures such as geoengineering.

The obligations in Article 4(2)(a) of UNFCCC require developed countries to take measures on mitigation by limiting their anthropogenic emissions of greenhouse gases and protecting and enhancing their greenhouse gas sinks and reservoirs. These obligations do not by implication prohibit geoengineering measures.

The Kyoto Protocol's provisions do not address or prohibit geoengineering. Geoengineering techniques such as enhanced weathering in the form of spreading base minerals, afforestation, reforestation, soil carbon enhancement, land-based albedo enhancement, biomass and charcoal production and storage have land-use change impacts. The Kyoto Protocol addresses land-use change only to the extent that the removal or emission of greenhouse gases are concerned. Specifically, the Kyoto Protocol regulates the way in which Parties account for the removal of greenhouse gases from the atmosphere and emissions reduced or generated by land-use changes. Only for this purpose do decisions under the Kyoto Protocol define certain forms of land use.

However, the potential relevance of geoengineering for the flexible mechanisms under the Kyoto Protocol, for instance as carbon offsets, has attracted attention.[89] So far, only carbon capture and storage in geological formations has been considered for inclusion in the Kyoto Protocol's Clean Development Mechanism (CDM).[90] The inclusion of

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[86] Barrett (2010), pp. 10–11; Scott (2010a), p. 11.

[87] Cf. the report by the UNFCCC technical subsidiary body SBSTA on future financing options for technology transfer, FCCC/SB/2009/2, p. 79. The IMO mentioned ocean fertilization as an example of its efforts to address climate change in its report to the UNFCCC; cf. IMO (2008).

[88] Harvey (2011).

[89] Virgoe 2009; Bertram 2009.

[90] Decision 7/CMP.6, paras. 1–3; decision 2/CMP.5, para. 29 identifying specific issues. See also decision 10/CMP.7, Modalities and procedures for carbon dioxide capture and storage in geological formations as clean development mechanism project activities.

geoengineering concepts in the flexible mechanisms can be addressed by the Kyoto Protocol even if geoengineering is otherwise addressed elsewhere by a different instrument or institution.

3.5 VIENNA CONVENTION FOR THE PROTECTION OF THE OZONE LAYER AND THE MONTREAL PROTOCOL

It is not clear at this stage to what extent particular geoengineering concepts, e.g., aerosol injection, would modify or be likely to modify the ozone layer. This has to be established by science.[91] Although the impacts of proposed geoengineering approaches on ozone are uncertain, with mixed result from models, some proposed approaches may have impacts on the ozone layer, at least seasonally and regionally. Therefore, geoengineering activities could fall within the scope of the Vienna Convention for the Protection of the Ozone Layer (Vienna Convention) and the Montreal Protocol, both of which are instruments with near universal ratification.[92] However, the Vienna Convention is mainly a basic framework with few specific obligations.[93] Apart from general provisions on research, cooperation and exchange of information, the only substantive obligations that could govern geoengineering activities are general obligations under article 2 (1) and 2 (2)(b) of the Convention.

The general obligations under the Vienna Convention require its Parties to take "appropriate measures" to protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone layer.

The general obligation is further specified in article 2 (2)(b) to include policies "to control, limit, reduce or prevent human activities" if they are at least likely to have adverse effects resulting from modification or likely modification of the ozone layer.

Annex I to the Vienna Convention lists substances which "are thought to" have the potential to modify the chemical and physical properties of the ozone layer, but it does not impose specific obligations regarding these substances. The list includes water vapor in relation to the stratospheric effects of hydrogen substances.[94] It does not mean that geoengineering concepts for creating clouds or artificial vapour trails in lower atmospheric areas would be covered. Annex I does not cover other substances such as sulphur or its compounds. However, annex I is non-exhaustive, and the effect of materials and processes used in particular geoengineering concepts on the ozone layer would have to be assessed.

Geoengineering approaches that modify or are likely to modify the ozone layer would not, on this basis alone, be contrary to the Vienna Convention. They would also have to result or be likely to result in "adverse effects", which are defined in article 1 (2) as "changes in the physical environment or biota, including changes in climate, which have significant deleterious effects on human health or on the composition, resilience and productivity of natural and managed ecosystems, or on materials useful to mankind".[95]

The term "significant deleterious effects" would suggest that a considerable intensity of the effects is required—as opposed to just any deleterious effects. Article 2 (2)(b) refers to effects that are "likely to" result, which does not require that these effects are proven. It is important to note that this provision requires a double link: the geoengineering activity has to result in a (at least likely) modification of the ozone layer, and this modification has or is likely to have adverse effects as defined by the Vienna Convention.

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[91] The potential ozone-depleting effect of sulphur aerosols would be expected to be primarily in the polar regions and occur only for a period each year in the polar spring (see the complementary CBD study on the impacts of climate-related geoengineering on biological diversity, in Part I of the present Technical Series Document).

[92] The Vienna Convention for the Protection of the Ozone Layer and the original 1987 Montreal Protocol have 197 Parties. Subsequent amendments to the Montreal Protocol have slightly fewer parties; cf. http://ozone.unep.org/new_site/en/treaty_ratification_status.php.

[93] Birnie et al. (2009), p. 350.

[94] Para. 4(e) of annex I to the Vienna Convention.

[95] Article 1 (2) of the Vienna Convention.

The essence of the obligation on Parties is to "take appropriate measures … ", further specified in article 2 (2)(b) as "appropriate legislative or administrative measures and co-operate in harmonizing appropriate policies to control, limit, reduce or prevent human activities under their jurisdiction or control ... ". This implies wide discretion regarding which measures are considered to be "appropriate". For instance, a Party could argue that it fulfils its obligation by "controlling" geoengineering activities that affect the ozone layer, rather than preventing them.

Although article 2 of the Vienna Convention contains a legal obligation, its content is general and it appears not to sufficiently impose specific for obligations regarding the regulation of geoengineering activities. On this basis, it can be argued that the Vienna Convention does not ban geoengineering activities or clearly impose specific restrictions on them. However, it provides a framework under which geoengineering could be further regulated. It would appear to be within the mandate of the Conference of the Parties to establish further knowledge and provide guidance in this regard under article 6(4). However, it may be unusual for it to do so given the limited role the Vienna Convention has so far played regarding specific activities. The Montreal Protocol is the instrument in which States have agreed on specific obligations.

The Montreal Protocol is widely acknowledged as one of the most successful multilateral environmental agreements. It imposes specific obligations, especially to phase down certain substances that deplete the ozone layer with respect to certain activities, i.e., the import, export, production and consumption of a number of ozone-depleting substances. Geoengineering activities such as aerosol injection could raise issues if they involve a substance whose consumption (production and import) is covered by the Montreal Protocol.

3.6 ENMOD CONVENTION

The ENMOD Convention is a treaty that addresses severe environmental harm as a military or any other hostile use. It was a reaction to deliberate attempts at weather modification by the US during the Vietnam War,[96] and was intended to restrict such means of warfare.[97] Consideration of the ENMOD Convention has to take into account the fact that participation is limited[98] and the rules have not been invoked in practice.[99] The ENMOD Convention provides rules and procedures that could apply to geoengineering when used for hostile or military purposes, as well as definitions, such as on environmental modification, which may be useful to consider as precedents for other processes.

The main substantial obligation under ENMOD is that the Parties, in article I of ENMOD, "undertake not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to any other State Party". Article II of ENMOD provides a broad definition of environmental modification techniques comprising "any technique for changing—through the deliberate manipulation of natural processes—the dynamics, composition or structure of the earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space". An interpretative understanding[100] provides definitions on (a) "widespread": encompassing an area on the scale of several hundred square kilometres; (b) "long-lasting": lasting for a period of months, or approximately a season; (c) "severe": involving serious or significant disruption or harm to human life, natural and economic resources or other assets. The definitions would apply to at least some geoengineering concepts, in particular as an interpretative understanding to article II of ENMOD explicitly listing changes in climate patterns.

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[96] Weather Modification: Hearings before the Subcommittee on Oceans and International Environment of the Committee on Foreign Relations, United States Senate, 1974, *Vietnam Center and Archive,* www.virtualarchive.vietnam.ttu.edu/.

[97] ENMOD preamble, first sentence: "Guided by the interest of ... saving mankind from the danger of using new means of warfare".

[98] It has 74 Parties, of which only few have acceded in recent years: http://treaties.un.org, accessed on 31 October 2010.

[99] For instance, the ENMOD Convention was not applicable to actions in the 1991 Gulf War such as the burning of oil fields by Iraq, because Iraq had not ratified the Convention; United States Department of Defense (1992), p. 616.

[100] The understanding is not part of the treaty but is part of the negotiating record and was included in the report of the negotiating Committee to the United Nations General Assembly. It can guide interpretation in accordance with Article 31 (2) and 31 (4) of the Vienna Convention on the Law of Treaties.

However, the ENMOD Convention is part of the international law of armed conflict and only applies to military or any other hostile use of environmental modification techniques. It clearly distinguishes between hostile and peaceful purposes. The text and the interpretative notes explicitly clarify that the Convention is without prejudice to the use for peaceful purposes.[101] The distinction between the law applying in peacetime and the law of military or any other hostile use is crucial, although it can be difficult to draw. Whether each case is considered hostile would have to be determined in accordance with the principles and criteria used in the law of armed conflict. Consideration of the ENMOD Convention should not erode this distinction.

Although the ENMOD Convention is not directly applicable in non-military and non-hostile cases and was not designed to govern contemporary geoengineering technologies, it contains ideas and concepts which will likely need to be considered by other processes addressing geoengineering. For instance, article V provides for a rudimentary procedure for addressing potential problems which may arise in relation to the objectives of, or in the application of the provisions of, the Convention, through a Consultative Committee of Experts. It also envisages dispute resolution through a complaint procedure to the UN Security Council.[102]

3.7 SPACE LAW

The main framework and rules of space law were developed at a time where exploration of outer space was at its beginning and not all activities and their impacts were foreseen.[103] Space law essentially comprises the international rules on outer space that have been designed and adopted as of the 1960s. The international legal regime regulating environmental aspects of outer space includes mainly five treaties:

- The Outer Space Treaty;
- The Space Registration Convention;
- The Moon Treaty;
- The Liability Convention;
- The Rescue Agreement, which is of marginal relevance to geoengineering governance.

In addition, there are a number of UN General Assembly resolutions. These are not per se legally binding, but they can have legal relevance for interpreting binding rules, and they can reflect or evolve into binding customary law.[104] The Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space was adopted in 1963 and contains most of the principles elaborated later in the four main treaties on outer space.[105] Subsequent resolutions elaborate further principles and deal with issues such as direct broadcasting by satellites, remote sensing and the use of nuclear power sources in outer space. In addition, there are other institutions dealing with space activities under their particular mandate, such as the International Telecommunication Union (ITU), the Inter-Agency Space Debris Coordination Committee (IADC), and the Committee on Earth Observation Satellites (CEOS).

A number of geoengineering technologies are intended to be carried out in the atmosphere or in space. These include the release of sulphur aerosols into the stratosphere to reflect the sun's radiation, the seeding of clouds with seawater particles to increase their reflectivity, and the deployment of mirrors or shields of various sizes to block solar radiation. Space law does not necessarily apply to all of these geoengineering concepts. Under international law, airspace and outer space are different areas subject to different rules. The main difference is that, under

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[101] Preamble, article III, and Understanding relating to article III of ENMOD; Bodansky (1996), p. 311.

[102] Article V(3)-(6) of ENMOD.

[103] Lafferranderie (2005), p. 6.

[104] Hobe (2010), page 27.

[105] UNGA resolution 1962 (XVIII) of 13 December 1963.

international law, States generally enjoy sovereignty in the airspace above their territories, whereas outer space is not subject to the sovereign jurisdiction of any one State. Whether space law generally applies to a geoengineering concept depends on the scope of application of space law.

Space law does not provide any precise definition of its scope of application or its key concepts, "outer space" and "space objects". The question of the legal "delimitation" of outer space from airspace has been discussed for decades without a clear agreed outcome. It has been on the agenda of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), the main institution in this area, since the 1960s.[106] There are a number of conceptual approaches to defining the application of space law, including the view that many years of practice have shown that there is no need for a clear definition. The area beyond 110 km above sea level is generally regarded as being part of outer space,[107] but the status of the zone between 80 and 110 km is controversial.[108] However, this lack of clarity regarding the boundary is not material here. Solar radiation management would be carried out either below 80 km, i.e., in the mesosphere or lower, or clearly above 110 km. Only the latter would be subject to space law. This would only include the deployment of shields or mirrors of various sizes in outer space to reflect or block solar radiation before it is able to reach lower atmosphere levels.

The main basis for international space law is the Outer Space Treaty. Its 100 Parties include the main space nations.[109] In literature, the legal status of outer space and the celestial bodies, as provided for in the treaty, are generally considered to be customary international law (see below).[110] However, the treaty has weaknesses such as the lack of important definitions on outer space, objects and damage, and the lack of a dispute settlement mechanism.[111]

Article III of the Outer Space Treaty clarifies that general international law applies in outer space. This includes at least all customary international law.[112] Therefore, the general duty to prevent transboundary environmental harm and the customary rules on State responsibility apply to activities in outer space, except to the extent that space law takes priority by virtue of being more specific (*lex specialis).*

Article I of the Treaty lays down the rights to access, usage and exploration of outer space. Generally, exploration and use of outer space is free for all States. Article I links these freedoms with the notion of the "province of all mankind". Thus, outer space is a common space in which States do not enjoy sovereign rights. The exploration and use of outer space "shall be carried out for the benefit and in the interests of all countries". The concept "province of all mankind" thus limits the freedoms of outer space in the sense that neither exploration nor use of outer space shall be undertaken for the sole advantage of one country, but shall be done only for the benefit of the international community.[113] The precise contours of this concept and of its restricting effect, however, remain unclear. The use of military observation satellites, for instance, does not seem to be contrary to the Outer Space Treaty, although such satellites arguably serve only the country they belong to.

Deployment of space mirrors or shields would qualify as "use" of outer space. The question of whether such geoengineering would be in the interest of all countries goes to the heart of the debate around geoengineering. Opponents would point to the known and unintended side effects and the need to address the cause of global warming; proponents would argue that global cooling effects are in the global interest and they would outweigh the side effects at least in the short term. However, it is not resolved who would determine, and from which perspective and on what basis, whether an activity was for the benefit of all countries. Although it has been argued

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[106] Committee on the Peaceful Uses of Outer Space (2002).

[107] Some authors argue that this line has become accepted as customary international law; cf. Vitt (1991), p. 46; Hobe (2009), p. 32, suggests the following definition: "*Outer space encompasses the terrestrial and the interplanetary space of the universe, whereby the delimitation of the Earth space around the Earth to outer space starts at least 110 km above sea level.*"

[108] Hobe (2009), p. 31.

[109] cf. http://treaties.un.org/pages/UNTSOnline.aspx?id=1.

[110] Durner (2000), p. 146.

[111] Lafferranderie (2005), p. 10.

[112] Hobe (2009), p. 67.

[113] Hobe (2009), p. 32.

that article I of the Outer Space Treaty could justify the side effects of geoengineering as long as it is globally beneficial,[114] it is suggested that it is unclear whether article I legally operates in terms of such a cost-benefit analysis. As with other obligations of a general nature, the uncertainty about their legal operation and effect in a concrete case is a gap in the current regulatory framework.

Article IX of the Outer Space Treaty could also apply to geoengineering in space, as it addresses environment, contamination and interference in the activities of other States. It imposes obligations regarding cooperation, mutual assistance, non-harmful interference, non-contamination as well as consultation. However, the obligation to respect the interests of other Parties in the first sentence merely refers to the space activities of other Parties to the Outer Space Treaty. Whether the geoengineering concept in space would interfere with other States' space activities—e.g., communication channels—would depend on the specific case. In any event, the last sentence of article IX merely envisages appropriate international consultations in the event of potential interference. The environmental obligations in the second sentence refer to the contamination of space or celestial bodies as well as to adverse changes to the earth's environment resulting from introduction of extraterrestrial matter. Geoengineering concepts in space do not introduce extraterrestrial matter. However, an argument could be made that reflecting material used for geoengineering ought to be considered as space debris and thus as "contamination of space" if it did not function properly and if such reflective material poses a concrete danger for other objects which have lawfully been introduced into outer space.[115] So far there have been no cases on the basis of article IX that could provide guidance.[116]

Articles VI and VII of the Outer Space Treaty provide rules on State responsibility and liability for damage. Article VI clarifies that States are responsible for their national activities in outer space and have to authorize and continuously supervise any non-governmental activities. Article VII provides for liability for damage caused "by" space objects to another Party. The classic environmental problems in outer space include orbital space debris, environmental damage caused on or to other planets and environmental damage caused on earth as a result of space objects falling from space.[117] Geoengineering is different in that the mirrors etc. deployed in space are unlikely to cause direct damage themselves—unless they would physically impact with other objects. The potential damage would be the result of the mirrors reducing incoming solar radiation and, for instance, causing weather modifications. It is not entirely clear whether this would be damage "by" the space object. Article VII does not appear to restrict any particular form of damage—material or immaterial, loss suffered as well as gain or loss of profit.[118] In the absence of express wording, arguably article VII requires an adequate level of causation between the placing of mirrors in space and the reduction of solar radiation as well as between the reduced sunlight and the damage.[119] This can be difficult to prove. In addition, article VII is silent on whether any fault or negligence is required.

In order to address these shortcomings, the general principle of liability imposed by article VII on a launching State was further developed by the Liability Convention. For those States which are Parties to the Liability Convention, as well as to the Outer Space Treaty, it provides special rules that take priority over article VII of the Outer Space Treaty.[120] It provides for absolute liability for damage caused by space objects, irrespective of any fault or negligence. However, the problem of proving causation remains[121] and there is virtually no practice to draw from.[122]

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[114] Zedalis (2010), p. 24

[115] However, it could be argued that geoengineering is neither carrying out studies nor exploration and would thus not be covered by the second sentence; cf. Zedalis (2010) p. 25.

[116] Kerrest and Smith (2009), p. 144.

[117] Sands (2003), p. 382.

[118] Kerrest and Smith (2009), p. 141.

[119] Ibid.

[120] As of 1 April 2008, there were 86 ratifications and 3 acceptances of obligations of the Liability Convention; see http://www.oosa.unvienna.org/oosa/en/SpaceLaw/Treaties.html.

[121] Malanczuk (1991), p. 792.

[122] Kerrest and Smith (2009), p. 143.

Even the Cosmos 954 incident, in which a Soviet satellite went out of control and crashed on Canadian territory, is inconclusive. Canada's claim for damages was based on the Liability Convention and general principles of international law, but it is debated whether the final settlement and payment was an acknowledgment of an international obligation.[123]

The other space treaties are relevant only to the extent that they provide for procedural obligations such as registration of space objects.[124]

As indicated above, a great number of General Assembly resolutions have been adopted concerning outer space. Although not binding as such, they can have political impact and can be of legal relevance as interpretative guidance or by evolving into customary law. However, the resolutions adopted so far do not seem to add to the findings based on the space treaties. The "Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries",[125] overlaps with articles I and IX of the Outer Space Treaty and could thus be relevant for States that are not Party to that treaty.

Space law is relevant only for the geoengineering concept of positioning reflecting objects in space in order to block solar radiation.

States that are Party to the Liability Convention may be liable for damage caused by the reflecting objects placed in space. If the damage occurs to the surface of the earth or to aircraft flight, State Parties are liable irrespective of any fault or negligence; however, if the damage is to another space-based object, fault must be proven. The problem of proving causation remains and there is virtually no practice to draw from. However, obtaining insurance for such space activity could be difficult and could *de facto* restrict such activities.

So far, geoengineering does not seem to be on the agenda of the relevant institutions addressing international space law. Climate change is one of the topics addressed by the UN Office for Outer Space Affairs and the Committee on the Peaceful Uses of Outer Space. However, the focus has been on using space applications such as monitoring to facilitate climate modelling and disaster mitigation.[126]

3.8 ANTARCTIC TREATY SYSTEM

The Antarctic is subject to a regime of several treaties, with the Antarctic Treaty and recommendations adopted under its auspices at its core.[127] The Antarctic regime, including the Protocol on Environmental Protection to the Antarctic Treaty (1991), regulates the Antarctic as an area beyond national jurisdiction, albeit without prejudice to sovereign claims maintained by seven States. The regime is only relevant to geoengineering activities and associated scientific research that take place in the Antarctic (cf. Article 3 of the 1991 Antarctic Environmental Protocol).

3.9 OSPAR CONVENTION

The OSPAR Convention of 1992 is a regional convention, with 16 Parties, including the EU, to protect the marine environment of the North-East Atlantic.

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[123] See references in Malanczuk (1991), p. 775.

[124] The register is operated by the United Nations Office for Outer Space Affairs (UNOOSA), http://www.oosa.unvienna.org/oosa/en/SORegister/index.html.

[125] UNGA resolution 51/122, Annex.

[126] http://www.oosa.unvienna.org/oosa/en/climatechange/index.html.

[127] See www.ats.aq.

Amendments to the OSPAR Convention were adopted in 2007 to allow storage of carbon dioxide in geological formations under the seabed.[128] Annexes II and III of the OSPAR Convention were amended to permit carbon dioxide injection.[129] In 2007, OSPAR also adopted decisions to ensure environmentally safe storage of carbon dioxide streams in geological formations and to prohibit carbon dioxide storage in the water column and on the seabed. [130] The OSPAR Guidelines for Risk Assessment and Management were adopted, also in 2007, to assist in management of carbon dioxide storage by assessing injection sites, identifying measures for hazard reduction, examining remediation and mitigation, characterizing risks to the marine environment, and monitoring.[131] The amendments must be ratified by at least seven Parties before entering force and as of May 2011, only six Parties had done so.[132]

Furthermore, OSPAR has also adopted the OSPAR Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area.[133] This code of conduct considers, *inter alia,* impacts on species, habitats, and marine protected areas and may apply to certain marine geoengineering research activities.

3.10 LRTAP—CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION

The LRTAP Convention addresses air pollution, and is mainly relevant for geoengineering concepts such as aerosol injection, which introduce sulphur or other substances into the atmosphere. It is a regional convention, with 51 Parties covering almost all UNECE States.[134] In addition to the general obligations of the LRTAP Convention, its eight protocols provide concrete obligations addressing specific pollutants or issues. The implementing protocols to the LRTAP Convention are separate international treaties, and not all Parties to the Convention became Parties to all protocols. The following text first addresses the LRTAP Convention and then describes the relevant content of individual protocols.

The material scope of the LRTAP Convention covers air pollution, defined in article 1 as "the introduction by man, directly or indirectly, of substances or energy into the air resulting in deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems and material property and impair or interfere with amenities and other legitimate uses of the environment".[135]

Some geoengineering concepts, such as the use of aerosols to block incoming sun rays, fulfill the first and second elements of this definition. The nature and intensity of effects which such activities may have is difficult to predict at present. However, the term "deleterious effects" has a broad scope that includes effects on ecosystems and, as such, some geoengineering techniques could have such effects. Furthermore, it is important to note that LRTAP is only applicable if and to the extent to which it is established that the substances or energy introduced into the air result in deleterious effects. In contrast to other instruments, it therefore does not cover situations in which the introduction of a certain substance may have or is likely to have any negative impact on the environment. While LRTAP is in that sense not based on the precautionary approach, some of its protocols explicitly are.[136]

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[128] Amendments of Annex II and Annex III to the Convention in relation to the Storage of Carbon Dioxide Streams in Geological Formations, Annex 4 (Ref. §2.10a), Ostend, 25–29 June 2007.

[129] Annex II, Article 3; Annex III, Article 3.

[130] OSPAR Decision 2007/2 on the Storage of Carbon Dioxide Streams in Geological Formations; OSPAR Decision 2007/1 to Prohibit the Storage of Carbon Dioxide Streams in the Water Column or on the Sea-bed.

[131] OSPAR Guidelines for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formations *(Reference Number: 2007-12),* Ostend, 25–29 June 2007.

[132] International Energy Agency (2011), p. 16.

[133] OSPAR 08/24/1, Annex 6 on the Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area.

[134] As of May 2011; see LRTAP "status of ratification", http://www.unece.org/env/lrtap/status/Status%20of%20the%20Convention.pdf.

[135] LRTAP Convention, article 1 (a).

[136] Cf. the preambles of the 1994 Oslo Protocol on Further Reduction of Sulphur Emissions; the 1998 Aarhus Protocol on Heavy Metals; the 1998 Aarhus Protocol on Persistent Organic Pollutants (POPs); and the 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone.

In the context of geoengineering and the rationale behind it, it could be asked whether LRTAP is open to the possibility of determining "deleterious effects" as "net" effects, i.e., negative impacts of the activity weighed against future negative impacts of climate change avoided by that activity.[137] The text of the LRTAP Convention does not provide for such a consideration of the overall "net" effects on the broader environment in comparison to harm avoided. LRTAP refers to specific effects resulting from the introduction of substances or energy into the air.

The LRTAP Convention covers air pollution whose "physical origin is situated wholly or in part within the area under the national jurisdiction of one State and which has adverse effects in the area under the jurisdiction of another State at such a distance that it is not generally possible to distinguish the contribution of individual emission sources or groups of sources."[138] The Convention can therefore apply to air pollution to which geoengineering concepts at least contributed, even if the pollution cannot be clearly attributed to certain geoengineering activities.

The LRTAP Convention does not require any minimum scale of effect. However, the broad definition does not mean that the LRTAP Convention prohibits any introduction of polluting substances into the air. Under the LRTAP Convention, Parties are only required to "endeavour to limit and, as far as possible, gradually reduce and prevent air pollution including long-range transboundary air pollution".[139] Although this is a legally-binding obligation, the terms "as far as possible" and "gradually" soften its content considerably. The same goes for the obligation on Parties to develop, "by means of exchanges of information, consultation, research and monitoring, … without undue delay policies and strategies which shall serve as a means of combating the discharge of air pollutants".[140] This general obligation does not require specific legal measures to prevent air pollution or to restrict aerosol injection.

In article 6 of the LRTAP Convention, Parties are obliged "to develop the best policies and strategies including air quality management systems and, as part of them, control measures compatible with balanced development, in particular by using the best available technology which is economically feasible …" While the development of "control measures" could imply a substantive, concrete obligation, it is softened significantly by the addition "compatible with balanced development" and economical feasibility.[141]

The LRTAP Convention also requires its Parties, in article 8 (a), to exchange information on "Data on emissions … of agreed air pollutants, starting with sulphur dioxide, … or on the fluxes of agreed air pollutants, starting with sulphur dioxide, across national borders, … ". This could be relevant for geoengineering involving sulphur dioxide in terms of providing transparency. The information exchange is complemented by the procedural obligation, in article 5, that requires consultations between polluting States and States that are actually affected by pollution or exposed to a significant risk.

The 1985 Helsinki Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent (First Sulphur Protocol)[142] imposed specific obligations to reduce sulphur emissions or transboundary fluxes.[143] However, the reduction obligation refers to 1993 and is outdated. The Protocol also established obligations to report on sulphur emissions,[144] which would include emissions in the context of geoengineering activities.

The 1994 Oslo Protocol on Further Reduction of Sulphur Emissions (Second Sulphur Protocol), requires from its 29 Parties[145] that they not exceed the individual sulphur emission ceilings listed in its annex II,[146] and requires

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[137] On the weighing or netting of risks, see also section 2.4 above on the precautionary principle.

[138] LRTAP Convention, article 1 (b).

[139] Ibid., article 2.

[140] Ibid., article 3.

[141] See also Birnie et al. (2009), p. 345.

[142] The 1985 Helsinki Protocol has 25 Parties, which do not include some EU member States and the United States; see http://www.unece.org/env/lrtap/status/85s_st.htm.

[143] Article 2 of the 1985 Helsinki Protocol.

[144] Ibid., articles 4 and 5.

[145] See "Status of Ratification". http://www.unece.org/env/lrtap/status/94s_st.htm.

[146] Article 2(2) of the 1994 Oslo Protocol.

that "depositions of oxidized sulphur compounds in the long term do not exceed critical loads for sulphur, given in annex I, as critical sulphur depositions, in accordance with present scientific knowledge".[147] To achieve this objective, Parties are, as a first step, required not to exceed annually the individual sulphur emission ceilings listed in annex II of the Protocol.[148] Reduced ceilings are established for the years 2000, 2005 and 2010.[149] Geoengineering activities of Parties to this protocol which involve the emission of sulphur dioxide would have to be in accordance with this provision. Article 5 requires Parties to periodically report information on the levels of sulphur emissions, with temporal and spatial resolution as specified. An Implementation Committee under article 7 has the mandate to address implementation and cases of potential non-compliance.

The 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone was ratified by 26 Parties, including most EU member States and the US.[150] The protocol sets emission ceilings for 2010 for four pollutants, including sulphur. In contrast to the Helsinki and Oslo Protocols, which aim directly at the reduction of sulphur emissions, the Gothenburg Protocol addresses three effects through controlling the pollutants causing them.[151] At the moment, negotiations on emission ceilings for 2020 are ongoing under the Gothenburg Protocol.

In sum, the LRTAP Convention as such arguably does not prohibit geoengineering or constitute significant restrictions on it. However, it contains procedural obligations regarding information exchange and consultation among Parties, which could generally apply to certain geoengineering activities. Regarding sulphur, Parties are subject to reporting obligations under the protocols relating to sulphur. The 1994 Oslo Protocol (Second Sulphur Protocol), to some extent, limits the depositions of oxidized sulphur compounds; Parties to the Protocol would have to comply with this when conducting geoengineering activities. Geoengineering covered by article 1 of the LRTAP Convention could generally be further regulated under the LRTAP Convention.

3.11 HUMAN RIGHTS LAW

Human rights law would be relevant if a particular geoengineering activity violates specific human rights. There is no rule in the body of international human rights law that prohibits geoengineering concepts per se.

However, geoengineering activities could involve human rights law, including because of their impacts and consequences. They could also involve human rights law if carried out in a way that violates obligations regarding, for example, non-discrimination or participation and prior informed consent (where legally established).

For example, geoengineering techniques such as enhanced weathering in the form of spreading base minerals, afforestation, reforestation, soil carbon enhancement, land-based albedo enhancement, and biomass and charcoal production and storage have land-use change impacts. As many of these techniques need to be applied on a large scale in order to be effective, they could entail significant, large-scale land-use changes. Potentially, such land-use changes could create conflicts with other forms of land use, such as food production and therefore potentially with the right to food, as recognized in the International Covenant on Social, Economic and Cultural Rights (article 11). Any violation of social, economic and cultural rights related to food, housing and water would have to be assessed considering specific cases and circumstances.

Some have argued that there is, or should be, a human right to a healthy environment. However, no such right is currently recognized in any human rights treaty. Although there have been regional developments in this direction, to date there is no global common ground on a binding and individually enforceable right to this effect.[152]

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[147] Ibid., article 2(1). However, the obligation is softened by qualifications referring to "critical sulphur depositions", and "as far as possible, without entailing excessive costs".

[148] Ibid., article 2(2). See also the definitions in article 1(11) and 1(12). See also Beyerlin and Marauhn (2011), p. 152.

[149] In addition, some Parties have a ceiling only for some of these years.

[150] See http://www.unece.org/env/lrtap/status/99multi_st.html.

[151] See United Nations Economic Commission for Europe (2007), p. 36.

[152] Cf. the comprehensive review by Boyle (2010).

In recent years, human rights bodies have addressed environmental issues in terms of their impacts on certain human rights that are widely recognized, for instance through the rights to life, property and private and family life. The European Court of Human Rights, for instance, held that severe environmental pollution could violate the right to private and family life even where their health is not seriously endangered.[153]

Which human rights could be implicated would depend on how a particular geoengineering activity would be carried out and which effects it might actually have. In addition, impacts on human rights might be justified in a particular case. Although human rights are agreed to be universal as per the Vienna World Conference on Human Rights, in practice it may be necessary to weigh geoengineering impacts on human rights against each other (for instance, geoengineering might protect the livelihoods of one group of people threatened by climate change while endangering another). Such an analysis would require further understanding of the impacts of the activity. Furthermore, certain human rights protections allow for the possibility of restrictions.

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[153] Cf. for instance European Court of Human Rights (ECHR), *Lopez Ostra v Spain*, judgment of 23 November 1994; *Guerra v Italy*, judgment of 19 February 1998; *Hatton and others v. United Kingdom*, judgment of 2 October 2001; *Hatton and others v. United Kingdom* (Grand Chamber), judgment of 8 July 2003, *Kyrtatos v. Greece*, judgment of 22 May.2003, http://www.echr.coe.int/.

CHAPTER 4

INSTITUTIONS

Rules and institutions do not necessarily go hand in hand. In theory, governance could be conceived of in terms of only rules or only institutions. A simple form of geoengineering governance could consist of merely one rule with an outright prohibition, without any special institution dealing with it. In contrast, governance could also consist of an institution with a mandate, for instance, to collect and disseminate information on geoengineering, without material obligations on States. However, there already are institutions with a mandate that would allow them to address at least some geoengineering concepts, and there already are rules.

Governance of geoengineering in all likelihood requires institutions: a forum for exchanging views or agreeing on permissions or restrictions on geoengineering, for monitoring implementation and compliance with expectations and rules, and for exchanging and pooling scientific information, etc.

This section looks at institutions that were created independent of material treaty obligations.

4.1 UNITED NATIONS SECURITY COUNCIL

The Security Council has so far not addressed geoengineering, although it has taken up related issues such as peace and security. An initial special session on the security implications of climate change provided no outcome and some countries expressed doubt as to whether the Security Council was the appropriate forum.[154] Following another debate, in July 2011, the Security Council could not agree on a resolution but instead issued a Presidential Statement that in weak wording acknowledged possible security implications of climate change, without recommending particular steps for addressing that potential threat.[155]

4.2 UNITED NATIONS GENERAL ASSEMBLY

The United Nations General Assembly has directly addressed ocean fertilization in the context of its annual resolution on oceans and the law of the sea by noting the work undertaken by the London Convention / London Protocol and the Convention on Biological Diversity,[156] and in resolution 62/215 of 22 December 2007, the General Assembly also encouraged States to support the further study and enhance understanding of ocean iron fertilization.[157] The General Assembly has also considered the importance of the application of the precautionary approach.[158]

With regard to the development of environmental impact assessment processes, in resolution 65/37 A of 7 December 2010, the General Assembly encouraged States, directly or through competent international organizations, to consider the further development of environmental impact assessment processes covering planned activities under their jurisdiction or control that may cause substantial pollution of, or significant and harmful changes to, the marine environment.[159]

Issues relating to ocean fertilization, the precautionary approach and environmental impact assessment processes have also been discussed by the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea (the “Informal Consultative Process”), which was established by the General Assembly to facilitate

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[154] United Nations Security Council, open debate on energy, security and climate, on 17 April 2007, 5663rd meeting.

[155] Security Council press release SC/10332 of 20 July 2011, http://www.un.org/News/Press/docs/2011/sc10332.doc.htm.

[156] Resolution 65/37 A, paras. 149–152. Cf. UNGA resolutions in UN documents A/RES/62/215; A/RES/63/111, paras 115–116; A/RES/64/71, paras. 132–133; A/RES/65/37, paras. 149–152 (draft doc. A/65/L.20 adopted); A/RES/66/231, paras. 154–156.

[157] Resolution 62/215, para. 98.

[158] See, for example, resolution 65/37 A, paras. 132 and 173.

[159] Resolution 65/37 A, para. 132.

its annual review of developments in ocean affairs.[160] During discussions at the twelfth meeting of the Informal Consultative Process, geoengineering was noted as a significant emerging issue and concerns were expressed over the possible impact on the marine environment of ocean fertilization.[161]

Issues relating to environmental impact assessments have also been a focus of the meetings of an Ad Hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction, which was established by the General Assembly pursuant to resolution 59/24.[162] At its second meeting in 2008, the Ad Hoc Open-ended Informal Working Group recognized the importance of environmentally sound climate change mitigation strategies, but particular concerns were raised over large-scale ocean iron fertilization activities. The view was expressed that the scientific understanding of the role of oceans in regulating climate, as well as of the impacts of both climate change on the marine environment and the technologies used for climate mitigation purposes, should be improved.[163]

4.3 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

Geoengineering was mentioned in the IPCC's second,[164] third and fourth assessment reports, but mainly in a descriptive way.[165]

Geoengineering and its potential effects will also be part of the IPCC's fifth assessment report, including the possible role, options, risks and status of geoengineering as a response option.[166] In June 2011 the IPCC convened a Joint IPCC Expert Meeting of Working Group I, Working Group II, and Working Group III on geoengineering.[167]

4.4 UNITED NATIONS ENVIRONMENT PROGRAMME

The United Nations Environment Programme (UNEP) coordinates environmental activities for the United Nations and works with countries and agencies to create solutions and implement environmental policies and practices. UNEP's broad mission is to "provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations".[168] With such a broad mandate, UNEP's scope covers geoengineering activities, and UNEP has addressed it in major reports.[169] However, apparently UNEP has not taken specific steps to directly address it with a regulatory objective. In 1980, UNEP issued a set of non-binding guidelines for cooperation between States on weather modification, covering information exchange, impact assessment and prior notification.[170] This was long before geoengineering became an issue, but might provide a starting point.

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[160] See reports of the meetings of the Informal Consultation Process at: http://www.un.org/Depts/los/consultative_process/consultative_process.htm.

[161] A/66/186, paras. 23 and 63.

[162] See A/61/65, A/63/79, A/65/68, A/66/119.

[163] A/63/79, para. 14.

[164] IPPC (1995) Working Group II, Chapter 25 on Mitigation: Cross-Sectoral and Other Issues, Section 4.

[165] IPCC AR4 had mentioned geoengineering in WGII 19.4.3 and WGIII 11.2.2.

[166] Scope, Content and Process for the Preparation of the Synthesis Report (SYR) of the IPCC Fifth Assessment Report (AR5), p. 3.

[167] http://www.ipcc-wg3.de/meetings/expert-meetings-and-workshops/em-geoengineering.

[168] http://www.unep.org/.

[169] UNEP (2009), p. 51 ff.

[170] UNEP, *Provisions for Co-operation Between States in Weather Modification*, Decision 8/7/A of the Governing Council of UNEP (1980), available at http://hqweb.unep.org/Law/PDF/UNEPEnv-LawGuide&PrincN03.pdf.

4.5 WORLD METEOROLOGICAL ORGANIZATION

The World Meteorological Organization (WMO) is a specialized agency of the United Nations covering meteorology, the atmosphere, and hydrology.[171] The WMO's agenda easily covers solar radiation management techniques such as, for instance, stratospheric sulphur aerosols or cloud whitening. Thus far, the WMO has only addressed the related area of weather modification and issued non-binding guidelines.[172]

4.6 INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

UNESCO's Intergovernmental Oceanographic Commission (IOC) has been involved in research on ocean fertilization and "blue carbon" and has produced a report on ocean fertilization.[173]

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[171] See http://www.wmo.int/pages/about/index_en.html.

[172] World Meteorological Organization (2007)—weather modification statement and guidelines of 24–26 September 2007, WMO Doc. CAS-MG2/Doc 4.4.1 Appendix C, available at http://www.wmo.int/.

[173] http://ioc-unesco.org/index.php?option=com_content&view=article&id=290:new-ocean-fertilization-publication.

CHAPTER 5

RULES GOVERNING RESEARCH

5.1 THE REGULATORY FRAMEWORK FOR RESEARCH

It has been suggested that governance for research should be addressed separately from governance for deployment.[174] However, once the modelling and laboratory stage is left behind, the distinction between research and deployment could become increasingly difficult to draw for regulatory purposes. At some stage and for some geoengineering approaches there can be no clear borderline between field testing as part of research and actual deployment if scale alone is considered.[175] The risks and physical impacts would be the same. If different rules were to apply, the distinction would require clear criteria for determining the difference. It should be noted, however, that if research occurs at a scale that does not impact the global climate, then it actually falls outside the proposed definition of geoengineering.

While CBD decision X/33 invites Parties and others to ensure (until certain conditions are met) that no geoengineering activities take place, it excludes from this limitation small-scale scientific research studies that are conducted in a controlled setting, scientifically justified and subject to prior environmental impact assessments (decision X/33 paragraph 8 (w)). The LC/LP assessment framework on ocean fertilization provides guidance that is applicable to research studies. A major gap concerns solar radiation management technologies.

The Royal Society, together with the Environmental Defense Fund and the Third World Academy of Sciences, is currently facilitating discussions among a select group on governance of research on solar radiation management.[176] As a working framework, the initiative is exploring a framework with five categories, including four categories of research—(1) non hazardous studies, including modelling; (2) laboratory studies; (3) small field trials; (4) medium and large-scale field trials—and (5) deployment.

5.2 SCIENTIFIC RESEARCH IN INTERNATIONAL TREATY LAW

Research, as distinct from the application of technology with known impacts or risks,[177] is generally not restricted under international law (apart from special rules in certain areas). In the marine environment, it is governed under UNCLOS by general principles to be followed in the conduct of marine scientific research (article 240), including that it shall be conducted exclusively for peaceful purposes, that it shall not unjustifiably interfere with other legitimate uses of the sea compatible with UNCLOS, and that it shall be conducted in compliance with all relevant regulations adopted in conformity with UNCLOS, including those for the protection and preservation of the marine environment. In the territorial sea, marine scientific research shall be conducted only with the express consent of and under the conditions set forth by the coastal State (article 245). In the exclusive economic zones and on the continental shelf, marine scientific research shall be conducted with the consent of the coastal State, which has the right to regulate, authorize and conduct marine scientific research (article 246). Freedom of scientific research is a high seas freedom (article 87). States and competent international organizations are responsible and liable pursuant to article 235 of UNCLOS for damage caused by pollution of the marine environment arising out of marine scientific research undertaken by them or on their behalf (article 263). The deployment of marine scientific installations or equipment shall also not constitute an obstacle to established international shipping routes (article 261).

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[174] United States Government Accountability Office (2010), p. 36.

[175] Robock et al. (2010), p. 531; Bunzl (2009), pp. 2–3. See also Bunzl (2010).

[176] Solar Radiation Management Governance Initiative (SRMGI) (2011).

[177] As governed, for instance, by the Cartagena Protocol on Biosafety to the Convention on Biological Diversity.

There are a number of media-specific international treaties that cover research on certain technologies. Field research is fully prohibited only in exceptional cases. In most cases, the treaty recalls and addresses freedom of research by different means. Many treaties directly call for carrying out scientific research on their subject matter. Other treaties stimulate scientific knowledge by facilitating access of scientific exploration and research teams to areas that are not subject to the jurisdiction of States.[178] In a few cases, certain types of research might be prohibited, for instance if it would encourage nuclear weapons test explosions prohibited by the Partial Test Ban Treaty (PTBT) or the Comprehensive Nuclear-Test-Ban Treaty (CTBT) or the development of biological weapons.[179]

In contrast, the ENMOD Convention, while prohibiting environmental modification techniques in armed conflict, is explicitly without prejudice to research for peaceful purposes. The Outer Space Treaty provides that experiments that "would cause potentially harmful interference with activities of other States" are subject to prior appropriate international consultation (ENMOD article IX).

The Antarctic Treaty provides for freedom of scientific investigation in Antarctica and that scientific observations and results from Antarctica shall be exchanged and made freely available "to the greatest extent feasible and practicable".[180] The Antarctic Environmental Protocol explicitly mentions the value of the Antarctic as an area for the conduct of scientific research as a fundamental consideration in the planning and conduct of all activities in the Antarctic Treaty area.[181] At the same time, it subjects research to the principles of Article 3 of the Antarctic Environmental Protocol.[182]

Moreover, scientific research is frequently institutionally incorporated in treaty regimes by integrated scientific advisory bodies such as under the Subsidiary Body for Scientific and Technological Advice under Article 9 of UNFCCC. These scientific bodies have been established as more or less integral parts of the decision-making systems of their respective regimes.[183]

Apart from these explicit references in binding law, international science is essentially self-organizing through institutions and non-binding rules.[184]

In conclusion, there are generally no general restrictions on research, including *in situ* experimentation, in international law outside the marine environment. The existing rules are mostly specific to certain media or a territory.

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[178] Livingston (1968).

[179] Article I of the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction (1972).

[180] Articles II, III of the Antarctic Treaty.

[181] Article 3 of the Antarctic Environmental Protocol .

[182] Ibid., Article 3 (4).

[183] Andresen and Skjærseth (2007), p. 190.

[184] Cf. the UNESCO Declaration on Science and the Use of Scientific Knowledge, http://www.unesco.org/science/wcs/eng/overview.htm.

CHAPTER 6

CONCLUSIONS

As an overarching concept including several distinct concepts and technologies, geoengineering is currently not as such prohibited by international law. Specific geoengineering activites and potential impacts of specific geoengineering concepts might violate particular rules, however. Additional information on geoengineering impacts would assist in the evaluation of such applicability and support the identification of gaps.

It has been argued that at present, no international treaties or institutions exist with a sufficient mandate to regulate the full spectrum of possible geoengineering activities.[185] However, there are existing rules that would apply to some geoengineering activities, and institutions with at least a partial mandate to address it. A summary of the applicability of the various treaties examined in this report to several geoengineering techniques is provided in annex III below.

Most treaties, but not all, potentially provide for mechanisms, procedures or institutions that could determine whether the treaty in question applies to a specific geoengineering activity and could address such activities. In particular, most relevant treaties have in place a Conference of the Parties (COP) or other institution that can determine to what extent geoengineering can be addressed by the treaty in question and its bodies.

Space law does not have the features of more modern environmental treaty regimes. It remains to be seen whether the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) would be suitable for elaborating specific guidance.

Some rules analysed in this study could apply to particular geoengineering concepts and could restrict them depending on specific impacts. Whether such impacts would actually occur is difficult to assess or predict at this stage. Some rules do not require actual impacts but let potential or likely impacts suffice.

Some general rules, such as for the prevention of transboundary environmental harm, may be intended to cover subsequent developments. In contrast, other rules may not be applicable, or may not provide a clear permission or prohibition of geoengineering.

This study follows a cautious approach in applying or drawing conclusions from existing legal rules.[186] In accordance with established methods of legal interpretation,[187] it considers that rules that were adopted without considering geoengineering, and whose normative content is general or vague, are open to interpretation, and do not on the face of it speak in favour of or against geoengineering as such.

One gap in international environmental governance is the lack of mechanism or treaty to deal with the assessment of technologies before they are commercialized. This gap was pointed out, for example, by the International Assessment of Agricultural Knowledge, Science and Technology.[188] It has also been referred to repeatedly by civil society organizations concerned about the social and environmental impacts of new technologies in the context of UNFCCC.[189]

Before the tenth meeting of the Conference of the Parties to the Convention on Biological Diversity, ocean fertilization (and carbon capture and storage) were the only geoengineering concepts addressed as such at an international regulatory level, namely by the CBD and the London Convention/London Protocol (LC/LP).

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[185] Lattanzio and Barbour (2010), p. 3; Barrett (2008), p. 9.

[186] As suggested by Bodansky as early as 1996; see Bodansky (1996), p. 316.

[187] Cf. Article 31 and 32 of the Vienna Convention on the Law of Treaties.

[188] McIntyre et al. (2009), p. 467; see ETC Group (2009a) and ETC Group (2011).

[189] TWN Info Service on Climate Change (Sept11/02), 6 September 2011, Third World Network, http://www.twnside.org.sg/title2/climate/info.service/2011/climate20110902.htm.

Ocean fertilization is addressed by the LC/LP and CBD. The Assessment Framework established by the LC/LP provides an elaborate and comprehensive governance effort for scientific research projects.

In legal terms, the mandate of several major treaties or institutions is sufficiently broad to address some or all geoengineering concepts. This could lead to potentially overlapping or inconsistent rules or guidance.[190] It is worth noting that IMO information on recent LC/LP activities states that the LC/LP Parties "*have declared themselves the competent international bodies* to regulate legitimate scientific research into ocean fertilization and to prohibit commercial activities in this field" [emphasis added].[191] From a global perspective, the potential scale and scope of activities covered varies from one mechanism to the next, depending, for instance, on their respective levels of participation and the relevance of the instrument.[192]

A distinction has been made in some processes between research and deployment. However, the distinction could be difficult to make from a regulatory point of view.

Virtually all treaties examined impose procedural obligations on geoengineering activities falling within their scope of application. These treaties have general provisions on exchange of information, cooperation and consultation. As a minimum it is suggested by multiple frameworks that States have a duty to inform other States prior to conducting geoengineering activities, including field experiments.

Few rules provide for public participation beyond the representation of the public by delegates, except for the usual rules on observer participation in treaty regimes and institutions.

The treaties examined provide few specific rules on responsibility and liability. The International Law Commission's articles on State responsibility are for the most part customary law that generally applies to breaches of international obligations.

In the context of geoengineering and the rationale behind it, the question could be raised whether relevant treaties are open to the possibility of determining negative impacts as "net" effects, i.e., negative impacts of the activity weighed against future negative impacts of climate change avoided by that activity.[193] The text of most treaties does not appear to provide for such a consideration of the overall "net" effects on the broader environment in comparison to harm avoided, and there are no corresponding decisions on who would evaluate such impacts and over what scale. Rather most treaties refer to specific effects resulting from the introduction of substances or energy into the air. A positive list of concepts or technologies that are considered to be geoengineering might be a useful regulatory approach. The list could be drawn up as a supplement to a general definition. It would need to allow for timely updating in order to provide the flexibility required for scientific and political developments.

Key questions for designing a future governance framework include the following:

- Is it preferable to have a centralized or decentralized governance structure for all or individual geoengineering concepts?
- How can regime conflicts be avoided ?
- What is the most appropriate legal form?
- How should the forum be structured: mandate, flexibility?
- What aspects should be regulated?
- What is the most appropriate political and scientific level?

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[190] Cf. on marine issues Scott (2010a), p. 10; in general, see Scott (2010b).

[191] IMO (2010), p. 1.

[192] For instance, the US is a Party to the London Convention, but not to the London Protocol, and is not a Party to the CBD. However, the US did vote in favour of the UNGA resolutions which welcomed and took note of the LC/LP and CBD activities.

[193] On the weighing or netting of risks, see also section 2.4 above on the precautionary principle.

- How can research and deployment be distinguished? (rationale and criteria)
- What are the most appropriate instruments and tools?
- How can participation and transparency be ensured?
- Do the rules and institutions allow for and incorporate scientific input in decision-making?
- Are scientific functions and political decision-making functions separated?
- How can meaningful research results be achieved? Depending on the particular geoengineering concept, potential research activities might have to be coordinated at the international level in order to ensure that data can be correctly attributed to particular experiments and to ensure validity of results.
- How can potential regime conflicts (overlapping mandates) be avoided?
- How to ensure that the precautionary principle is respected and that populations and ecosystems are not placed at undue risk without their prior knowledge or consent?
- How can proper intergovernmental oversight of relevant private initiatives be implemented?

ANNEX I

ABBREVIATIONS AND ACRONYMS

ABNJ	Area(s) beyond national jurisdiction
CBDR	Common but differentiated responsibilities
CBD	Convention on Biological Diversity
CCS	Carbon capture and storage
CBDR	Common but differentiated responsibilities
CDR	Carbon dioxide removal
COP	Conference of the Parties
COPUOS	United Nations Committee on the Peaceful Uses of Outer Space
EC	European Community
EIA	Environmental impact assessment
ENMOD	Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques
EU	European Union
IPCC	Intergovernmental Panel on Climate Change
ICJ	International Court of Justice
ILC	International Law Commission
ILM	International Legal Materials
IMO	International Maritime Organization
IOC	Intergovernmental Oceanographic Commission of UNESCO
ITLOS	International Tribunal for the Law of the Sea
LC/LP	London Convention/London Protocol
LRTAP	Convention on Long-range Transboundary Air Pollution
SEA	Strategic environmental assessment
SRM	Solar radiation management (also known as sunlight reflection methods)
UK	United Kingdom
UNEP	United Nations Environment Programme
UNCLOS	United Nations Convention on the Law of the Sea
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	General Assembly of the United Nations
US	United States / United States of America
VCLT	Vienna Convention on the Law of Treaties
WMO	World Meteorological Organization
WTO	World Trade Organization

ANNEX II

TREATIES AND INSTRUMENTS CITED

Short form(s) used	Full title and reference
Antarctic Treaty	Antarctic Treaty of 1 December 1959, in force 23 June 1961
Antarctic Environmental Protocol	Protocol to the Antarctic Treaty on Environmental Protection, 3 November 1991, in force 1998
CBD	Convention on Biological Diversity
ENMOD Convention / ENMOD	Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques
Espoo Convention	Convention on Environmental Impact Assessment in a Transboundary Context
Protocol on Strategic Environmental Assessment	Protocol on Strategic Environmental Assessment to the Convention on Environmental Impact Assessment in a Transboundary Context, 2003
	International Covenant on Social, Economic and Cultural Rights
Kyoto Protocol	*see under United Nations Framework Convention on Climate Change*
LC/LP:	
London Convention (LC)	Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972, 1046 UNTS 120, in force 1975
London Protocol (LP)	Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 7 November 1996, 36 ILM 1 (1997), in force 2006
Liability Convention	Convention on the International Liability for Damage Caused by Space Objects, 29 March 1972, 961 UNTS 187, in force 2 September 1972
LRTAP Convention (and its Protocols)	Convention on Long-range Transboundary Air Pollution
Montreal Protocol	*see under Vienna Convention for the Protection of the Ozone Layer*
Moon Treaty	Agreement Governing the Activities of States on the Moon and other Celestial Bodies, 5 December 1979, 1363 UNTS 3, in force 11 July 1984
OSPAR Convention / OSPAR	Convention for the Protection for the Marine Environment of the North-East Atlantic
Outer Space Treaty	Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, 27 January 1967, 610 UNTS 205, in force 10 October 1967
Protocol on Strategic Environmental Assessment	*see under Espoo Convention*
Space Registration Convention	Convention on Registration of Objects Launched into Outer Space, adopted by UNGA Resolution 3235, (12 November 1974), opened for signature on 14 January 1975, entered into force on 15 September 1976, 1023 UNTS 15
UNCLOS	United Nations Convention on the Law of the Sea, 10 December 1982, 21 ILM 1261 (1982) 1833 UNTS 3, in force 1994; Agreement relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982, 28 July 1994, 1836 UNTS 3, in force 1996
UNFCCC	United Nations Framework Convention on Climate Change
Kyoto Protocol	Kyoto Protocol to the United Nations Framework Convention on Climate Change
VCLT	Vienna Convention on the Law of Treaties, 1969
Vienna Convention	Vienna Convention for the Protection of the Ozone Layer
Montreal Protocol	Montreal Protocol on Substances that Deplete the Ozone Layer (as amended)

ANNEX III

TECHNOLOGIES AND THEIR POTENTIAL REGULATION

	Technology / Technique	**Potential significant transboundary harm**	**Potentially deployed in or affects areas beyond national jurisdiction (ABNJ)**	**Customary law principles apply**	**Relevant treaties and potential gaps**
Solar radiation management / Sunlight reflection methods (SRM)	Space-based reflectors	✓	✓	Yes	Space law (Outer Space Treaty), but no rules or guidance developed and governing body —*Potential gap*
	Stratospheric aerosols	✓	✓	Yes	Montreal Protocol could apply depending on gravity of actual impacts; otherwise no global treaty applies specifically to this technique —*Major gap* Procedural obligations under LRTAP
	Cloud reflectivity	✓	✓	Yes	No global treaty applies specifically to this technique —*Major gap*
	Surface albedo (large scale)	✓	✓	Yes	No global treaty applies specifically to this technique —*Major gap*

Carbon dioxide removal (CDR) methods	Ocean fertilization	?	✓	Yes	UNCLOS applies; LC/LP working towards putting in place a regulatory mechanism for ocean fertilization, as well as for other marine geoengineering techniques.
	Enhanced weathering (ocean)	?	✓	Yes	UNCLOS and LC/LP apply
	Ocean CO_2 storage	?	✓	Yes	UNCLOS applies; prohibited under OSPAR in the North-East Atlantic.
	Ocean biomass storage	?	✓	Yes	UNCLOS and LC/LP have already developed guidance for dumping of "organic materials of natural origin"
	Subsurface CO_2 storage	?	✓	Yes	Rules and guidance developed under LC/LP and under OSPAR (OSPAR amendments not yet in force)

ANNEX IV

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