CBD

UNEP

Convention on
Biological Diversity

Distr.
GENERAL

UNEP/CBD/SBSTTA/18/INF/5
22 May 2014

ORIGINAL: ENGLISH

SUBSIDIARY BODY ON SCIENTIFIC, TECHNICAL AND TECHNOLOGICAL ADVICE
Eighteenth meeting
Montreal, 23-28 June 2014
Item 9.3 of the provisional agenda*

INTERIM UPDATE OF INFORMATION ON THE POTENTIAL IMPACTS OF CLIMATE GEOENGINEERING ON BIODIVERSITY AND THE REGULATORY FRAMEWORK RELEVANT TO THE CONVENTION ON BIOLOGICAL DIVERSITY

I. INTRODUCTION

1. The eleventh meeting of the Conference of the Parties (COP-11) to the Convention on Biological Diversity (CBD) discussed and noted reports on technical and regulatory matters relating to climate geoengineering arising from the sixteenth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA-16). These reports were published in September 2012 as CBD Technical Series No. 66, *Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters* (hereafter CBD, 2012).

2. At COP-11, Parties requested the Executive Secretary, subject to the availability of resources, to prepare for a future meeting of the Subsidiary Body an "update on the potential impacts of geoengineering techniques on biodiversity, and on the regulatory framework of climate-related geoengineering relevant to the Convention on Biological Diversity, drawing upon all relevant scientific reports such as the Fifth Assessment Report of the Intergovernmental Panel on Climate Change and discussions under the Environment Management Group" (decision XI/20, paragraph 16 (a)).

3. That mandate cannot be fully addressed for SBSTTA-18, since (i) the Synthesis of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) is not available until September 2014; and (ii) the detailed contributions of IPCC Working Groups II and III have only been completed in late March and mid-April 2014 respectively. For these reasons, an interim update is provided here, comprising a bibliography of around 300 peer-reviewed scientific papers and other relevant reports published since the preparation of CBD (2012), together with a brief analysis of their key features. In addition, the most relevant excerpts of the Summaries for Policymakers of the reports of Working Groups I and III are contained in annex II.

4. This interim update has been prepared by the CBD Secretariat with the assistance of the lead author[1] of CBD (2012) and other members of the CBD Expert Group on Geoengineering. It has not yet been peer-reviewed. It is anticipated that a more comprehensive update will be prepared for a future meeting of the Subsidiary Body, when there will be the opportunity for detailed consideration to be given to all the IPCC AR5 reports and their geoengineering-relevant aspects. Further attention could then also be given to the publications identified in annex I, together with other emerging scientific and technical evidence on climate change and its impacts on biodiversity; the potential risks and benefits of geoengineering approaches that might be considered as policy responses; associated research gaps; and the suitability of existing and proposed regulatory mechanisms.

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5. For the purposes of this update, the following definition of geo-engineering is used, consistent with CBD (2012), "deliberate intervention in the planetary environment of a nature and scale intended to counteract anthropogenic climate change and/or its impacts". This definition includes techniques intended to increase the Earth's energy loss (primarily by long-term removal of greenhouse gases from the atmosphere) or decrease the Earth's energy gain (primarily by increasing atmospheric or surface reflectivity), but excludes actions taken to reduce anthropogenic emissions.

6. This definition was developed by the Expert Group on the basis of wider usage, clarity, purpose, brevity and etymological consistency.[2] It avoids ambiguities relating to 'carbon sequestration' and focuses on functional aspects; i.e. the purpose of geoengineering, rather than the methods by which it might be achieved or its potential for indirect effects. A relatively wide spectrum of approaches is covered by the above definition; thus additional, second order information, specifying the technique(s) under consideration, is likely to be needed when the term geoengineering is used for most practical purposes – not only for scientific research on effectiveness and impacts, but also for consideration of ethical and justice issues, public engagement, economic assessments, policy development, and the establishment of appropriate regulatory frameworks at national and international levels.

7. Discussions at COP-11 included consideration of four definition options without prejudice to future deliberations on this issue (decision XI/20, paragraphs 5 (a) – (d)), including the definition used in CBD (2012) as option (b). Subsequent to CBD (2012), the term 'climate engineering' has increased in prominence in the scientific literature, as a synonym for "climate-related geoengineering. In due course, SBSTTA may consider a definitive recommendation on the definition of geoengineering, or on alternative terminology. Until such issues have been resolved, there will continue to be undesirable confusion as to what is intended by COP decisions in this area; for example, the request to Parties to report on their geoengineering-related activities.

II. BIBLIOGRAPHY

8. Following the final editing of CBD (2012), the CBD Secretariat and Expert Group members have maintained their awareness of new scientific papers and reports relevant to the continued consideration of geoengineering in the context of the Convention, with focus on peer-reviewed literature that is available online and included in databases such as the Web of Science. The main outcome is given here (annex I) as a bibliography of more than 300 publications from 2012[3] to early 2014. These publications are provided in two main groups, Parts 1 and 2, respectively covering (i) impacts of climate geoengineering on biodiversity and (ii) the regulatory framework for climate geoengineering relevant to the Convention on Biological Diversity. Thus the two groups match the COP-11 request for an update covering those two areas, and also match Part I and Part II of CBD (2012).

9. Within the bibliography for Part 1 in annex I, four sub-groups are distinguished, matching the following four chapters of Part I of CBD (2012):

- *Chapter 3: Overview of climate change and ocean acidification and of their impacts on biodiversity*. Here covered by "Context of climate change and ocean acidification". Publications cited in this sub-group are selective, with focus on reviews and those with greatest applicability to considerations under the CBD. The main topic area for each publication is individually indicated, acknowledging that there may be overlap between topic areas, established here for 'working purposes' (sub-headings in Sections 3 - 6 below); other typologies could be equally valid.
- *Chapter 4: Potential impacts on biodiversity of climate geoengineering achieved by sunlight reflection methods.* Here covered by "Sunlight reflection methods (SRM)". This group of techniques is also known as solar radiation management. The main topic area is identified for each publication, with the same caveats as above.
- *Chapter 5: Potential impacts on biodiversity of carbon dioxide removal geoengineering techniques.* Here covered by "Greenhouse gas removal (GGR) methods", with the change of wording giving

[2] Additional discussion on the definition of geoengineering is given in annex II (p 83-84) of Part I of CBD (2012)

[3] Around 20 publications from 2012 that were fully cited in Technical Series No. 66 are not re-included in the bibliography given in annex I.

greater flexibility in what might be covered by such approaches. An alternative title "Negative emissions techniques" was considered, since that term is now widely used in the scientific literature; e.g. relating to IPCC scenarios. However, negative emissions is a contradiction in terms and its use can cause confusion. The main topic area is identified for each publication, with the same caveats as above. Note that several publications in the GGR category relate to land management, or CO_2 storage primarily developed for pre-emission carbon capture and storage, rather than necessarily being geoengineering-directed.

- *Chapter 6: Social, economic, cultural and ethical considerations of climate-related geoengineering.* Here covered by "Socio-economic, cultural and ethical aspects". Policy and governance-related issues are included, with some overlap with Part 2. The main topic area is identified for each publication, with the same caveats as above.

10. The numbering of the publications is consecutive within each Part of the bibliography. In cases where a publication is considered relevant to more than one of the four sub-groups of Part 1, it is repeated in the list, with the number remaining as allocated on first mention. The statistics given in Table 1 provide an indication of relative research activity in sub-groups and topic areas of geoengineering research during the past two years, acknowledging that there may be uncontrolled factors affecting initial identification of publications (e.g. searching efficiency via keywords) and unintentional bias in allocation to topic areas. There are also differences in publication behaviour between natural and social scientists; e.g. more multi-author publications by the former. A peer-reviewed bibliometric analysis of geoengineering literature (covering > 500 publications in the period 1984-2011) discusses some of these issues (ref 43).

Table 1. Distribution of recent geoengineering-related publications between different topic categories, based on the bibliography given in annex I. Numbers within sub-group 1.1 are bracketed, since very many publications in these topic areas were not included in the list. There may also be biases or incomplete coverage for other groups, as discussed in the text. The overall total for Part 1 publications (332) is less than the sum of the sub-totals (373) due to overlap between sub-groups.

Part 1: Impacts of geoengineering on biodiversity								**Part 2: Regulatory Framework**
1.1 Context of climate change & ocean acidification		1.2. Sunlight reflection methods (SRM)		1.3. Greenhouse gas removal (GGR) methods		1.4 Socio-economic, cultural & ethical aspects		
Climate driver	(5.5)	Space SRM	3	Biochar	34	Ethics & values	51	No sub-groups or topic areas
Climate trend/projection	(4.5)	Stratospheric SRM	46	BECCS	7	Policy & governance	40	
Climate impact: Land (12.5), Ocean (9.5)	(22)	Tropospheric SRM	23	Biomass storage: Land 3, Ocean 2	5	Discourse analysis	11	
		Surface albedo: Land 3, Ocean 1	4			Economics	4	
				Direct air capture	5	Multi-topic	23	
Ocean acidification	(2)	Multi-technique	23	Enhanced weathering: Land 3.5, Ocean 4.5	8	***SUB-TOTAL***	**129**	***TOTAL*** **35**
SUB-TOTAL	**(34)**	***SUB-TOTAL***	**99**					
				CO_2 storage: Land 1, Ocean 6	7			
				Ocean fertilization	9			
				Multi-technique	36			
				SUB-TOTAL	**111**			

III. CONTEXT OF CLIMATE CHANGE AND OCEAN ACIDIFICATION

11. The IPCC AR5 WG I report (ref 16) is the main information source providing the climate context for proposed geoengineering techniques and their potential impacts. As noted above (para 3), AR5 WG II and WG III reports (refs 17, 18) are also highly relevant, but were not available in time for consideration by this interim update, and IPCC's overall synthesis has yet to be published. However, relevant paragraphs from the Summaries for Policy Makers of AR5 WG II and WG III are included in annex II. Key findings from the WG I report, that focuses on climate trends, climate dynamics and model-based projections of future conditions, include the following:

- Warming of the climate system is now unequivocal, driven by anthropogenic greenhouse gas emissions (primarily CO_2). Many aspects of climate change would continue even if emissions could be immediately stopped.

- Climate models have improved since the previous IPCC assessment [AR4, used to provide climate change context for CBD (2012)]. There is therefore greater confidence in their projections, based on radiative forcing scenarios; however, uncertainties still remain.
- Future warming will be greater in the Arctic than the global mean, and greater over land than over the ocean. Warming will continue to exhibit interannual-to-decadal and regional variability.
- Ocean acidification will intensify, with greatest changes in the upper ocean, driven by increases in atmospheric CO_2.
- The threshold for loss of the Greenland ice sheet is likely to be in the range 1-4°C of global warming; if that occurs, global mean sea level would rise by up to 7m over several centuries.

IPCC WG I climate projections for four policy-dependent and emission-related scenarios are summarized in Table 2. The scenarios are defined in terms of Representative Concentration Pathways (RCPs), quantifying the additional radiative forcing (due to greenhouse gases) in year 2100 relative to 1750, as a global mean: 2.6 W m^{-2} for RCP 2.6, 4.5 W m^{-2} for RCP 4.5, 6.0 W m^{-2} for RCP 6.0 and 8.5 W m^{-2} for RCP 8.5.

Table 2. Summary outcomes of IPCC WG 1 multi-model comparisons, based on four scenarios, for likely end of century (2081-2100) atmospheric CO_2, increase in global mean temperature; increase in global mean sea level; and increase in ocean acidity. The increases in temperature and sea level are relative to 1986-2005. Note that: i) there is expected to be considerable regional variability in these changes, ii) atmospheric CO_2 values are currently ~390 ppm, compared to a value of ~280 ppm in 1750; and iii) there has already been a global temperature increase of ~0.7°C, a global sea level increase of ~20 cm, and a global mean pH fall of 0.075 (representing a 26% increase in acidity) since 1850.

Scenario		**Projections for end of 21st century**			
		Atmospheric CO_2	Increase in global mean temperature	Increase in global mean sea level	Increase in ocean acidity (pH fall)
RCP 2.6	Strong mitigation (low emissions), also CO_2 removal from atmosphere; radiative forcing peaks then declines	~420 ppm	0.3 -1.7°C	26-55 cm	-0.065
RCP 4.5	Strong mitigation (low emissions); radiative forcing stabilizes by 2100	~540 ppm	1.1-2.6°C	32-63 cm	-0.150
RCP 6.0	Moderate mitigation (moderate emissions); radiative forcing still increasing in 2100,	~670 ppm	1.4-3.1°C	33-63 cm	-0.225
RCP 8.5	Low mitigation (high emissions; current trend); radiative forcing still increasing in 2100	~940 ppm	2.6-4.8°C	45-82 cm	-0.350

12. The IPCC scenarios RCP 4.5, 6.0 and 8.5 provide the ‘controls’ against which the climatic impacts of different geoengineering techniques, simulated at different scales within models, can be assessed. Whilst the present day (or pre-industrial) climatic conditions can also be used for comparative purposes, it is not valid to ascribe the difference between present day and projected future geoengineered climatic conditions (however achieved) as a ‘geoengineering impact’. Instead that impact is the difference between the non-geoengineered and geo-engineered projected future climate, expected to be climatically beneficial if the geoengineering is effective. There may, however, be regional differences in those effects, also additional, unintended non-climatic impacts due to the geoengineering. As discussed in CBD (2012), the unintended impacts are more likely to be adverse than beneficial.[4]

13. Scenario RCP 2.6 does not provide a non-geoengineered ‘control’, since that pathway is only achievable through active removal of CO_2 (cumulative total in range 100-500 Pg, assumed to be via BECCS) from the atmosphere. Such action is regarded by IPCC AR5 – and here – as geoengineering. The linkage between mitigation and geoengineering is considered further in section 8 below.

14. The IPCC WG I report includes assessments of the climatic consequences of geoengineering through greenhouse gas removal and sunlight reflection methods; key aspects are briefly summarised in Sections 4 and 5 below. Wider impacts of projected climate change on natural systems and society are considered in the WG II report, not discussed here. A selection of other recent publications since CBD

[4] Additional details on RCP 2.6 scenario are contained in IPCC Working Group III.

(2012) on climate change and its impacts are identified in Part 1.1 of the annex I bibliography, from which the following preliminary conclusions can be drawn:

- Species' range shifts, that are already underway, show wide variability between different groups (affecting community structure), and between marine and terrestrial habitats (refs 4, 25).
- The rates of projected climate change are likely to exceed climatic niche evolution by vertebrates (ref 29) and overall biodiversity loss is likely to accelerate as warming intensifies (ref 30). However, temperature increase *per se* may not be the main factor causing extinctions during conditions of rapid climate change (refs 1, 5, 24).
- Experimental studies and models are now being developed to take account of multiple stressors associated with climate change in the marine environment, including ocean acidification effects (refs 3, 8, 20, 25).
- When the criteria for 'dangerous' climate change is adjusted to take account of multiple impacts, allowable carbon emissions are much reduced (ref 28).
- For land plants, experimentally-induced phenological responses to warming may underestimate observed responses (ref 33).

IV. SUNLIGHT REFLECTION METHODS (SRM)

15. There have been around 100 publications on sunlight reflection methods (solar radiation management) in the past two years, with nearly half of these addressing ***stratospheric SRM***, based on increasing the concentration of aerosols in the upper atmosphere. This topic area is covered in Chapter 7 of the IPCC WG I report. Recent advances in understanding, based on both these sources, include:

- Model intercomparisons (GeoMIP) and other studies confirm that stratospheric aerosol injection (e.g. by SO_2) could offset the global temperature increases of RCP 4.5 (refs 90, 119), but major hydrological effects are likely to remain (refs 66, 89, 125). Overall consequences could, in theory, be optimized (refs 85, 98, 99).
- Regional climatic responses to stratospheric SRM would be affected by the latitude, altitude and season of the aerosol injection (refs 68, 129). If aerosols are only added to the northern hemisphere, models show less rainfall in the Sahel but more in Brazil: if only added to the southern hemisphere, the opposite effect occurs. Observations from hemispherically asymmetric volcanic eruptions confirm these results (ref 68).
- The potential for regionally-targeted stratospheric SRM, to limit Arctic sea ice-melt, has been simulated (ref 126); this requires very strong local radiation reduction, and could cause other regional climate changes.
- As indicated by earlier studies, the cessation of stratospheric SRM is near-certain to produce very rapid warming, with potentially severe environmental consequences (refs 42, 79, 101).

16. The scientific literature on ***tropospheric SRM*** (cloud brightening) has greatly increased, from <10 papers in CBD (2012) to >20 in the past two years. Model-based studies generally confirm the theoretical potential of the approach (ref 35, 80), although its effectiveness is likely to be a function of particle size, micro-physical processes, injection amount and diurnal timing (refs 36, 37, 77, 78, 108, 124). Proposals for field-testing have been developed (ref 130); these may need to be on a relatively large-scale for satellite-based detection of albedo changes (ref 120).

17. The limited numbers of additional studies on ***surface albedo changes*** (refs 75, 109, 122, 127), *space SRM* (refs 45, 46, 47) and cirrus cloud manipulation (ref 123) do not indicate that these techniques have high potential for further development.

V. GREENHOUSE GAS REMOVAL (GGR)

18. Chapter 6 of the IPCC WG I report gives detailed attention to carbon dioxide removal (CDR), recognising that there may also be potential for removal of other greenhouse gases (e.g. methane, ref 214) and that the more general term of negative emissions is also used for this category of geoengineering, particularly by climate modellers. Key WG 1 messages relate to the relative slowness

of GGR (decadal to century) in providing climatic benefits, the scale of the effort required, and potential conflicts with food production for biologically-based, terrestrial GGR.

19. The WG I report also emphasises the importance of carbon cycle dynamics when assessing GGR effectiveness. In the same way that anthropogenic emissions of CO_2 do not increase the longterm atmospheric content by the same amount (because of uptake by the ocean and land systems), its removal is partly offset by outgassing from natural sources. Recent papers on this issue include refs 138, 178 and 219.

20. There are many (> 30) publications on ***biochar*** listed in annex I; these cover its use as a soil improver as well as its potential for carbon sequestration. Effects of biochar on soil greenhouse gas emissions (N_2O and CH_4) are generally considered favourable (refs 142, 149, 167, 207, 211, 220, 223, 224) although dependent on treatment conditions (refs 177, 188) and with negative albedo impacts (refs 187, 217).

21. As identified by CBD (2012), the scope for large-scale CO_2 removal by ***BECCS*** (bioenergy with carbon capture and storage) and ***land biomass storage*** is closely linked to land availability (refs 135, 173, 194, 195, 225). Cost-effective carbon capture and storage is also crucial for the former, and remains an issue for direct air capture (refs 163, 190). Recent papers cover leakage risks from both ***land and ocean CO_2 storage*** reservoirs (refs 133, 148, 159, 191): there is much more extensive literature on pre-emission CCS, geological considerations and ocean acidification impacts that is not included here.

22. The feasibility of ***enhanced weathering*** on land and in the ocean has been further investigated (refs 200 and 165, 172, 193, 201 respectively) and reviewed (ref 162). Unresolved issues for geoengineering application relate to the cost and energy requirements of material processing and transport, also the environmental consequences of raising silicate levels and pH in rivers and/or coastal seas. Whilst the latter could counteract ocean acidification, very large alkalinity additions (in a ratio of 2:1 with respect to emitted CO_2) are likely to be needed to achieve this effect on a global scale (ref 165).

23. The topic of ***ocean fertilization*** has attracted recent interest due to an unauthorized iron addition experiment in the Gulf of Alaska (ref 222), primarily justified on the basis of fishery enhancement. Whilst further research in this topic area has been advocated (ref 158), limitations on overall effectiveness and feasibility have also been identified (ref 221).

VI. SOCIO-ECONOMIC, CULTURAL AND ETHICAL ASPECTS

24. Annex I includes around 130 recent publications covering the human dimensions of climate geoengineering, mostly relating to stratospheric SRM. Additional categorization on a technique-specific basis was not considered helpful; instead, the topic areas identified in annex I, and discussed briefly below, relate to the main focus or perspective of the texts. There is, however, a continuum between these topics, and other groupings would be possible.

25. Several of the 51 recent papers in the ***ethics and values*** topic area can be considered 'non-research' (ref 43), in that they provide comment or overviews, rather than novel analyses. Nevertheless, the majority make significant contributions to the debate on two key moral dilemmas: whether it could ever be acceptable to implement geoengineering without the informed consent of all groups affected; and whether research on geoengineering might increase or reduce the likelihood of subsequent implementation. These questions are examined through surveys of public attitudes and perceptions (refs 236, 246, 249, 250, 274, 301, 331) and consideration of psychological (refs 226, 255), gender (ref 242), religious (ref 248) and equity issues (ref 244, 290). There is clear disquiet amongst social scientists that a simplistic cost-benefit or 'public good' approach might be used for policy development in this area (refs 239, 251, 262, 264, 293).

26. The 40 recent contributions to the literature in the area of ***policy and governance*** connect public consent (also considered above) with political legitimacy and specific regulatory mechanisms (also considered below). They also cover issues of 'self regulation' by the research community (refs 232, 307). The relatively undeveloped status of the field is exemplified by five publications including "?" in their titles (refs 238, 256, 257, 270, 328) and one with "!" (ref 326). A multi-topic and multi-group paper on climate engineering categorization (ref 49) is also relevant here, since it distinguishes between territorial/domestic actions, and those with potentially significant trans-territorial impacts,

either on climate at the regional or global scale, or on common resources. There is obvious benefit if those involved in governance issues have a well-developed appreciation of the full range of geoengineering techniques; as discussed in CBD (2012) and above, the impacts and implications of different techniques are very different.

27. The ***discourse analysis*** topic area considers framing and perspective issues, in academic and public discussion (refs 277, 288, 314, 315) and in the media (refs 241, 286, 303, 313). Such considerations provide additional insights into how attitudes and values develop, and, ultimately, how policy decisions are reached at the national and international level. Only four recent publications address the ***economics*** of geoengineering (refs 48, 100, 184, 280).

VII. REGULATORY FRAMEWORK

28. Regarding the international regulatory framework of geoengineering relevant to the CBD, an important recent development relates to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Convention) and its 1996 Protocol (London Protocol). The Meeting of Contracting Parties to the London Protocol adopted, on 18 October 2013, resolution LP.4(8) on the amendment to the London Protocol to regulate the placement of matter for ocean fertilization and other marine geoengineering activities. The amendment is structured to allow other marine geoengineering activities to be considered and listed in a new annex in the future if they fall within the scope of the London Protocol and have the potential to harm the marine environment. The amendment will enter into force 60 days after two thirds of the Contracting Parties to the London Protocol have deposited an instrument of acceptance of the amendment with the International Maritime Organization. As of April 2014, the amendment has not received any ratification (ref 278).

29. This amendment, once entered into force, will strengthen the regulatory framework for ocean fertilization activities and provide a framework for the further regulation of other marine geoengineering activities. However, this recent development, so far, has not changed the validity of the key messages from the earlier report (CBD, 2012, part II), including that "the current regulatory mechanisms that could apply to climate-related geoengineering relevant to the Convention do not constitute a framework for geoengineering as a whole that meets the criteria of being science-based, global, transparent and effective" and that "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."

30. Other recent literature relevant to the international regulatory framework is contained in refs 272, 283, 299, 308, 328, 329, 335, 337, 340 and 343; and for climate change more generally in refs 14 and 19. Relevant issues regarding national legislation are covered in refs 339 and 341.

VIII. SYNTHESIS: INTERDISCIPLINARITY AND INTEGRATION

31. Overall, the key messages identified in the report reviewed at the sixteenth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (UNEP/CBD/SBSTTA/16/10) and published in CBD Technical Series No. 66 remain valid and are consistent with the recent scientific literature and information contained in the Summary for Policy Makers of the three Working Group reports of the IPCC's fifth Assessment.

32. The grouping of the annex I publications to match the main chapters and parts of CBD (2012) has comparative benefits for updating purposes. However, that compartmentalization does risk missing an important development within the past two years: the increased attention that has been given to a more interdisciplinary, integrated approach to address not only the problem of climate change but also potential solutions. Thus there is now greater appreciation of the commonalities and interactions, rather than the boundaries, between the natural sciences, socio-economic systems and legal domains when considering the complexities and uncertainties of climate change responses.

33. That approach has, in part, been stimulated by the IPCC AR5 scenarios. As noted in Section 3, RCP 2.6 – the pathway to avoid 'dangerous' climate change – is only achievable within emission-based climate models if, in addition to emission reductions of ~50% by 2050, there is active removal of greenhouse gases from the atmosphere. IPCC WG I considers such removal of CO_2 (and potentially

other greenhouse gases) to be a geoengineering action, although with overlap to mitigation. The need to consider both inputs and outputs to the atmosphere was recognised by COP-11: "… climate change should primarily be addressed by reducing anthropogenic emissions by sources and by increasing removals by sinks of greenhouse gases …" (Decision XI/20, paragraph 4). Recent publications in annex I that are relevant to the interaction of geoengineering and mitigation include refs 19, 22, 28, 31, 49, 81, 82, 128, 150, 153, 237 and 273.

34. Taken together, annex I publications indicate that there is now greater knowledge of the limitations of a range of geoengineering approaches, both in terms of their acceptability, governance and risks (SRM), and their costs, scalability and unintended impacts (GGR). Such considerations would support the view that most, if not all, forms of geoengineering are an inappropriate potential response to climate change, justifying strong international regulation to limit geoengineering research and/or applications (refs 57, 248, 259, 267). The counterargument is that the past two years have also delivered greater knowledge of the scale and dangers of future climate change, that may become unstoppable (Part 1 ref 14), with reduced abilities for emission reductions to diminish its potentially catastrophic consequences for biodiversity and humanity. Evidence for that position is presented in the IPPC AR5 WG I, WG II and WG III reports and many additional analyses, including those that take account of the combined effects of multiple stressors on species and ecosystems (Part 1 refs 3, 23, 28, 29). On that basis, geoengineering research – to continue to investigate whether or not some techniques might provide an environmentally and politically viable future policy option - may now be a higher priority than it was two years ago.

Annex 1

BIBLIOGRAPHY OF RECENT PUBLICATIONS RELEVANT TO CLIMATE-RELATED GEOENGINEERING

Part 1. Impacts of climate geoengineering on biological diversity

The four sub-groups 1.1 -1.4 below correspond to Chapters 3-6 in CBD Technical Series No. 66 (CBD, 2012), as explained in the main text. However there is not an exact match between the Chapter titles and the headings used below, since some of the latter have been shortened or amended. Publications are limited to those dated 2012, 2013 and 2014 (to 31 March), excluding those cited in CBD (2012).

1.1 Context of climate change and ocean acidification. This listing is highly selective. Publications have been allocated to the following topic areas: climate driver; climate trend/ projection; climate impact (separated into land and ocean); and ocean acidification.

	Authors (date)	Publication title; *journal/book details*	Topic area
1	Bellard C., Bertelsmeier C., Leadley P., Thuiller W. & Courchamp F. (2012)	Impacts of climate change on the future of biodiversity. *Ecol. Lett.*, 15, 365-377; doi: 10.1111/j.1461-0248.2011.01736.x	*Climate impact: land & ocean*
2	Bony S., Bellon G., Klocke D., Sherwood S. *et al* (2013)	Robust direct effect of carbon dioxide on tropical circulation and regional precipitation. *Nature Geoscience*, 6, 447-451 (2013); doi: 10.1038/NGEO1799	*Climate trend/ projection*
3	Bopp L., Resplandy L., Orr J.C., Doney S.C. *et al* (2013)	Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models. *Biogeosciences*, 10, 6225-6245.	*Climate impact: ocean*
4	Burrows M.T., Schoeman D.S., Richardson A.J., Molinos J.G. *et al* (2014)	Geographical limits to species-range shifts are suggested by climate velocity. *Nature* 507, 492-495; doi: 10.1038/nature12976	*Climate impact: land & ocean*
5	Cahill A.E., Aiello-Lammens M.E., Fisher-Reid M.C., Hua X. *et al* (2013)	How does climate change cause extinction? *Proc. Roy. Soc. B*, 280, 20121890.	*Climate impact: land & ocean*
6	Cernusak L.A., Winter K., Dalling J.W., Holtum J.A.M. *et al*. (2013)	Tropical forest responses to increasing atmospheric CO_2: current knowledge and opportunities for future research. *Functional Plant Biol.*, 40, 531-551.	*Climate impact: land*
7	Cleland E.E., Collins S.L., Dickson T.L., Farrer E.C. *et al* (2013)	Sensitivity of grassland plant community composition to spatial vs. temporal variation in precipitation. *Ecology*, 94, 1687-1696.	*Climate impact: land*
8	Cocco V., Joos F., Steinacher M., Frolicher T.L. *et al* (2013)	Oxygen and indicators of stress for marine life in multi-model global warming projections. Biogeosciences, 10, 1849-1868; doi: 10.5194/bg-10-1849-2013	*Climate impact: ocean*
9	Cook B.I., Wolkovich E.M., Davies T.J., Ault T.R. *et al* (2012)	Sensitivity of spring phenology to warming across temporal and spatial climate gradients in two independent databases. *Ecosystems*, 15, 1283-1294.	*Climate impact: land*
10	De Frenne P., Rodríguez-Sánchez F., Coomes D.A., Baeten L. *et al* (2013)	Microclimate moderates plant responses to macroclimate warming. *Proc. Natl. Acad. Sci. USA*, 110, 18561-18565.	*Climate impact: land*
11	de Vries P., Tamis J.E., Foekema E.M. et al (2013)	Towards quantitative ecological risk assessment of elevated carbon dioxide levels in the marine environment. *Mar Poll. Bull.*, 73 (special issue), SI 516-523	*Climate impact: ocean*
12	Doney S.C., Ruckelshaus M., Duffy J.E., Barry J.P. et al (2012)	CLIMATE CHANGE IMPACTS ON MARINE ECOSYSTEMS. *ANN. REV. MAR. SCI.*, 4, 11-37; DOI: 10.1146/ANNUREV-MARINE-041911-111611	*Climate impact: ocean*
13	Donohue R.J., Roderick M.J.M., McVicar T.R. & Farquhar, G.D. (2013)	Impact of CO_2 fertilization on maximum foliage cover across the globe's warm, dry environments. *Geophys. Res. Lett.*, 40, 3031-3035.	*Climate impact: land*
14	Goldblatt C. & Watson A.J. (2012)	The runaway greenhouse: implications for future climate change, geoengineering and planetary atmospheres. *Phil. Trans. Roy. Soc. A*, 370, 4197-4216.	*Climate trend/ projection*
15	Higgins S.I. & Scheiter S. (2012)	Atmospheric CO_2 forces abrupt vegetation shifts locally, but not globally. *Nature*, 488, 209-212.	*Climate impact: land*

16	IPCC (2013)	*Climate Change 2013: The Physical Science Basis.* Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http: www.ipcc.ch	*Climate driver; climate trend/ projection*
17	IPCC (2014a)	*Climate Change 2014: Impacts, Adaptation and Vulnerability*. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http: www.ipcc.ch	*Climate impact: land & ocean*
18	IPCC (2014b)	*Climate Change 2014: Mitigation of Climate Change.* Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http: www.ipcc.ch	*Climate driver*
19	Jones C., Robertson E., Arora V., Friedlingstein P. *et al.* (2013)	Twenty-first-century compatible CO_2 emissions and airborne fraction simulated by CMIP5 Earth System Models under four representative concentration pathways. *J. Climate*, 26, 4398–4413; doi: 10.1175/JCLI-D-12-00554.1	*Climate driver*
20	Kroeker K. J., Kordas R. C., Crim R., Hendriks I.E. *et al* (2013)	Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. *Global Change Biol.*, 19, 1884-1896.	*Ocean acidification*
21	Le Quéré C., Peters G. P., Andres R. J., Andrew R. M., Boden T. *et al* (2013)	Global carbon budget 2013. *Earth System Sci. Data Discuss.* doi: 10.5194/essdd-6-689-2013	*Climate driver*
22	Luderer G., Bertram C., Calvin K., De Cian E. & Kriegler E. (2013)	Implication of weak near-term climate policies on longterm mitigation pathways. *Clim. Change*, doi: 10.1007/s10584-013-0899-9	*Climate driver*
23	Mora C., Wei C.L., Rollo A., Amaro T. *et al* (2013)	Biotic and human vulnerability to projected changes in ocean biogeochemistry over the 21st century. *PLOS Biology*, 11, e1001682; doi: 10.1371/journal.pbio.1001682	*Climate impact: ocean*
24	Moritz C. & Agudo R. (2013)	The future of species under climate change: resilience or decline? *Science*, 341, 504-508; doi: 10.1126/science.1237190	*Climate impact: land*
25	Poloczanska E.S., Brown C.J., Sydeman W.J., Kiessling W. *et al* (2013)	Global change imprint on marine life. *Nature Climate Change* 3, 919-925; doi: 10.1038/nclimate1958	*Climate impact: ocean*
26	Pörtner H.O. (2012)	Integrating climate-related stressor effects on marine organisms: unifying principles linking molecule to ecosystem-level changes. *Mar. Ecol. Prog. Ser.*, 470, 273-290.	*Climate impact: ocean*
27	Seneviratne S.I., Donat M.G., Mueller B. & Alexander L.V. (2014)	No pause in the increase of hot temperature extremes. *Nature Climate Change*, 4, 161-163; doi: 10.1038/nclimate2145	*Climate trend/ projection*
28	Steinacher M., Joos F. & Stocker T.F. (2013)	Allowable carbon emissions lowered by multiple climate targets. *Nature* 499, 197-201	*Climate driver; climate impact: land & ocean*
29	Quintero I. & Wiens J.J. (2013)	Rates of projected climate change dramatically exceed past rates of climatic niche evolution among vertebrate species. *Ecology Letters*, 16, 1095-1103.	*Climate trend/ projection*
30	Warren R., VanDerWal J., Price J., Walbergen J.A. *et al* (2013)	Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss. *Nature Climate Change*, 3, 678-682; doi: 10.1038/nclimate1887.	*Climate driver; climate impact: land & ocean*
31	Wiltshire A.J., Gornall J., Booth B.B.B., Dennis E. *et al*. (2013)	The importance of population, climate change and CO_2 plant physiological forcing in determining future global water stress. *Global Environ. Change*, 23, 1083-1097.	*Climate impact: land*
32	Wiltshire A.J., Kay G., Gornall J.L. & Betts R.A. (2013)	The impact of climate, CO_2 and population on regional food and water resources in the 2050s. *Sustainability*, 5, 2129-2151; doi:10.3390/su5052129	*Climate impact: land*
33	Wittmann A.C. & H.O. Pörtner (2013)	Sensitivities of extant animal taxa to ocean acidification. *Nature Climate Change* 3, 995–1001	*Ocean acidification*
34	Wolkovich E.M., Cook B.I., Allen J.M.. Crimmens T.M. *et al* (2012)	WARMING EXPERIMENTS UNDERPREDICT PLANT PHENOLOGICAL RESPONSES TO CLIMATE CHANGE. *NATURE*, 485, 494-497;doi: 10.1038/nature11014	*Climate impact: land*

1.2 Sunlight reflection methods (SRM). Publications have been allocated to the following topic areas: space SRM; stratospheric SRM; tropospheric SRM; surface albedo (separated into land and ocean); and multi-technique. Publications with reference numbers in brackets have already been listed in Part 1.1.

Authors (date)	Publication title; *journal/book details*

35	Alterskjær K., Kristjánsson J.E. & Seland Ø. (2012)	Sensitivity to deliberate sea salt seeding of marine clouds – observations and model simulations. *Atm. Chem. Phys.*, 12, 2795-2807.	*Tropospheric SRM*
36	Alterskjær K. & Kristjánsson J.E. (2013).	The sign of the radiative forcing from marine cloud brightening depends on both particle size and injection amount. *Geophys. Res. Lett.*, 40, 210-215; doi: 10.1002/grl.50117.	*Tropospheric SRM*
37	Alterskjær K., Kristjánsson J.E., Boucher O., Muri H. *et al* (2013)	Sea-salt injections into the low-latitude marine boundary layer: The transient response in three Earth system models. *J. Geophys. Res. Atmos.*, 118, 12,195–12,206, doi: 10.1002/2013JD020432.	*Tropospheric SRM*
38	Andrejczuk M., Gadian A. & Blyth A. (2014)	Numerical simulations of stratocumulus cloud response to aerosol perturbation. *Atmos. Res.*, doi: 10.1016/ j.atmosres.2014.01.006	*Tropospheric SRM*
39	Andrews T., Gregory J.M., Webb M.J., Gregory J.M. & Forster P.M. (2012)	Cloud adjustment and its role in CO_2 radiative forcing and climate sensitivity: a review. *Surveys in Geophysics*, 33, 619-635.	*Tropospheric SRM*
40	Aquila V., Garfinkel C.I., Newman P.A., Oman L.D. & Waugh D.W. (2014)	Modifications of the quasi-biennial oscillation by a geoengineering perturbation of the stratospheric aerosol layer. *Geophys. Res. Lett.*, doi: 10.1002/2013GL058818	*Stratospheric SRM*
41	Baughman E., Gnanadesikan A., Degaetano A. & Adcroft A. (2012)	Investigation of the surface and circulation impacts of cloud-brightening geoengineering. *J. Climate* 25, 7527-7543; doi: 10.1175/JCLI-D-11-00282.1	*Tropospheric SRM*
42	Baum S.D., Maher T.M. & Haqq-Misra J. (2013)	Double catastrophe: intermittent stratospheric geoengineering induced by societal collapse. *Environ. Sys. Decisions*, 33, 168-180.	*Stratospheric SRM*
43	Belter C.W. & Seidel, D.J. (2013)	A bibliometric analysis of climate engineering research, *WIREs Clim. Change*, 4, 417-427; doi: 10.1002/wcc.229.	*Multi-technique*
44	Berdahl M., Robock A., Ji D., Moore J.C., Jones A.., Kravitz B & Watanabe S. (2014)	Arctic cryosphere response in the Geoengineering Model Intercomparison Project G3 and G4 scenarios. *J. Geophys. Res. Atmos.*, 119, 1308-1321; doi: 10.1002/2013JD020627	*Stratospheric SRM*
45	Bewick R., Lücking C., Colombo C., Sanchez J.P. & McInnes C.R. (2012)	Heliotropic dust rings for Earth climate engineering. *Advances in Space Research*, 51, 1132-1144	*Space SRM*
46	Bewick R., Sanchez J.P. & McInnes C.R. (2012)	Gravitationally bound geoengineering dust shade at the inner Lagrange point. *Advances in Space Research*, 50, 1405-1410	*Space SRM*
47	Bewick R., Sanchez J.P. & McInnes C.R. (2012)	The feasibility of using an L 1 positioned dust cloud as a method of space-based geoengineering. *Advances in Space Research*, 49, 1212-1228.	*Space SRM*
48	Bickel J. E. & Agrawal S. (2013).	Re-examining the economics of aerosol geoengineering. *Climatic Change* 119.3-4: 993-1006.	*Stratospheric SRM*
49	Boucher O., Forster P.M., Gruber N., Ha-Duaong M. *et al* (2014)	Rethinking climate engineering categorization in the context of climate change mitigation and adaptation. *WIREs Clim. Change*, 5, 23-35; doi: 10.1002/wcc.261	*Multi-technique*
50	Braesicke P., Morgenstern O. & Pyle J. (2012)	Might dimming the sun change atmospheric ENSO teleconnections as we know them? *Atmos. Sci. Lett.*, 12, 184-188.	*Stratospheric SRM*
51	Caldeira K., Govindasamy B. & Cao L. (2013)	The science of geoengineering. *Ann. Rev. Earth Planetary Sci.*, 41, 231-256.	*Multi-technique*
52	Canty T., Mascioli N. R., Smarte, M. D. & Salawitch R. J. (2013)	An empirical model of global climate - Part 1: A critical evaluation of volcanic cooling. *Atmos. Chem. Physics*, 13, 3997–4031.	*Stratospheric SRM*
53	Cirisan A., Spichtinger P., Luo B.P., Weisenstein D. K., Wernli H., Lohmann U. & Peter T. (2013)	Microphysical and radiative changes in cirrus clouds by geoengineering the stratosphere. *J. Geophys. Res. Atmos.*, 118, 4533-4548; doi: 10.1002/jgrd.50388.	*Stratospheric SRM*
54	Cooper G., Johnston D., Foster J., Galbraith L. *et al* (2013)	A review of some experimental spray methods for marine cloud brightening. *Int. J. Geosciences,*. 4, 78-97. doi: 10.4236/ijg.2013.41009	*Tropospheric SRM*
55	Couce E., Irvine P.J., Gregorie L.J., Ridgwell A. & Hendy E.J. (2013)	Tropical coral reef habitat in a geoengineered, high-CO_2 world. *Geophys. Res. Lett.*, 40, 1-6, doi: 10.1002/grl.50340.	*Stratospheric SRM*
56	Davidson P., Burgoyne C., Hunt H. & Causier M. (2012)	Lifting options for stratospheric aerosol geoengineering: advantages of tethered balloon systems, *Phil. Trans. R. Soc. A*, 370, 4263–4300; doi:10.1098/rsta.2011.0639	*Stratospheric SRM*
57	Driscoll S., Bozzo A., Gray L. J., Robock A. & Stenchikov G. (2012)	Coupled Model Intercomparison Project 5 (CMIP5) simulations of climate following volcanic eruptions. *J. Geophys. Res.* 117, article D17105	*Stratospheric SRM*

58	English J.T., Toon O.B. & Mills M.J. (2012	Microphysical simulations of sulfur burdens from stratospheric sulphur geoengineering. *Atmos. Phys. Chem.*, 12, 4775-4793	*Stratospheric SRM*
59	ETC Group – Mooney P., Wetter K.J. & Bronson D. (2012)	Darken the sky and whiten the earth – The dangers of geoengineering. *Development Dialogue No 61 (Sept 2012); What Next Volume IIII: Climate Development & Equity;* 210-237	*Multi-technique*
60	ETC Group (2013)	The artificial intelligence of geoengineering. *ETC Communique 109* (8pp)	*Multi-technique*
61	Ferraro A.J., Highwood E.J. & Charlton-Perez A.J. (2014)	Weakened tropical circulation and reduced precipitation in response to geoengineering. *Environ. Res. Lett.* 9, 014001; doi:10.1088/1748-9326/9/1/014001	*Stratospheric SRM*
62	Ferraro A. J., Charlton-Perez A.J. & Highwood E.J. (2014)	A risk-based framework for assessing the effectiveness of stratospheric aerosol geoengineering. *PloS ONE* 9, e88849.	*Stratospheric SRM*
63	Foley A. M., Willeit M., Brovkin V., Feulner G. & Friend A. D. (2014)	Quantifying the global carbon cycle response to volcanic stratospheric aerosol radiative forcing using Earth System Models. *J. Geophys. Res. Atmos*., 119, 101-111; doi: 10.1002/2013jd019724	*Stratospheric SRM*
64	Foster J., Cooper G. & Galbraith L. (2013)	Patent application PCT/US2013/020589: Salt water spray systems for cloud brightening droplets and nano-particle generation. USA.	*Tropospheric SRM*
65	Fyfe J. C., von Salzen K., Cole J. N. S., Gillett N. P. & Vernier J.P. (2013)	Surface response to stratospheric aerosol changes in a coupled atmosphere-ocean model. *Geophys. Res. Lett*., 40, 584-588; doi: 10.1002/grl.50156.	*Stratospheric SRM*
66	Fyfe J. C., Cole J.N.S., Arora V.K. & Scinocca J.F. (2013)	Biogeochemical carbon coupling influences global precipitation in geoengineering experiments. *Geophys. Res. Lett.* 40, 651-655; doi: 10.1002/grl.50166.	*Stratospheric SRM*
67	Hardman-Mountford N.J., Polimene L., Hirata T., Brewin R.J. & Aiken J. (2013)	Impacts of light shading and nutrient enrichment geoengineering approaches on the productivity of a stratified, oligotrophic ocean ecosystem. *J. Roy. Soc. Interface*, 10, 20130701.	*Multi-technique*
68	Haywood J.M., Jones A., Bellouin N. & Stephenson D.B. (2013)	Asymmetric forcing from stratospheric aerosols impacts Sahelian rainfall. *Nature Climate Change,* 3, 660-665; doi: 10.1038/nclimate1857.	*Stratospheric SRM*
69	Hill S. & Ming Y. (2012)	Nonlinear climate response to regional brightening of tropical marine stratocumulus. *Geophys. Res. Lett*., 39, Article 15707	*Tropospheric SRM*
70	Hommel R. & Graf H.-F. (2012)	Modelling the size distribution of geoengineered stratospheric aerosols. *Atmos. Sci. Lett.,* 12, 168-175.	*Stratospheric SRM*
71	Honeggar M., Michaelowa A. & Butzengeiger-Geyer S. (2012)	*Climate Engineering: Avoiding Pandora's Box through Research and Governance*. FIN Climate Policy Perspectives 5 (8pp)	*Multi-technique*
72	Hulme M. (2012)	Climate change: climate engineering through stratopheric aerosol injection. *Prog. Phys. Geog*. 36, 694-705	*Stratospheric SRM*
(16)	IPCC (2013)	*Climate Change 2013: The Physical Science Basis.* Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http: www.ipcc.ch.	*Multi-technique*
(17)	IPCC (2014a)	*Climate Change 2014: Impacts, Adaptation and Vulnerability.* Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http: www.ipcc.ch.	*Multi-technique*
(18)	IPCC (2014b)	*Climate Change 2014: Mitigation of Climate Change.* Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http: www.ipcc.ch.	*Multi-technique*
73	Irvine P.J., Sriver R.L. & Keller K. (2012)	Tension between reducing sea-level rise and global warming through solar-radiation management. *Nature Climate Change*, 2, 97-100.	*Stratospheric SRM*
74	Izrael Y. A., Volodin E.M., Kostrykin S.V., Revokatova A.P. & Ryaboshapko A.G. (2013)	Possibility of geoengineering stabilization of global temperatures in the 21st century using the stratospheric aerosol and estimation of potential negative effects. *Russian Meteorol. & Hydrol.*, 38, 371-381.	*Stratospheric SRM*
75	Jacobson M.Z. & Ten Hoeve J.E. (2012)	EFFECTS OF URBAN SURFACES AND WHITE ROOFS ON GLOBAL AND REGIONAL CLIMATE. *J. CLIM*., 25, 1028-1044	*Surface albedo: land*
76	Jarvis A. & Leedal D. (2012)	The Geoengineering Model Intercomparison Project (GeoMIP): A control perspective. *Atmos. Sci. Lett*. 13, 157-163.	*Multi-technique*
77	Jenkins A.K.L. & Forster P.M. (2013)	The inclusion of water with the injected aerosol reduces the simulated effectiveness of marine cloud brightening. *Atmos. Sci. Lett.,* 14, 164-9	*Tropospheric SRM*
78	Jenkins A.K.L., Forster P.M. & Jackson L.S. (2012)	The effects of timing and rate of marine cloud brightening aerosol injection on albedo changes during the diurnal cycle of marine stratocumulus clouds. *Atmos. Chem. Phys.*, 13, 1659-1673	*Tropospheric SRM*

79	Jones A., Haywood J.M., Alterskjaer K., Boucher O. *et al* (2013)	The impact of abrupt suspension of solar radiation management (termination effect) in experiment G2 of the Geoengineering Model Intercomparison Project (GeoMIP). *J. Geophys. Res. Atmos.*, 118, 9743-9752	*Stratospheric SRM*
80	Jones A. & Haywood J. M. (2012)	Sea-spray geoengineering in the HadGEM2-ES Earth-system model: radiative impact and climate response, *Atmos. Chem. Phys*., 12, 10887-10898, doi: 10.5194/acp-12-10887-2012.	*Tropospheric SRM*
81	Jones C., Williamson P., Haywood J., Lowe J. *et al* (2013)	*LWEC Geoengineering Report. A forward look for UK research on climate impacts of geoengineering*. Living With Environmental Change (LWEC), UK; 36 pp. http://www.lwec.org.uk/publications/lwec-geoengineering-report-forward-look-uk-research-climate-impacts-geoengineering	*Multi-technique*
82	Keith D. (2013)	*A Case for Climate Engineering*. MIT Press, Cambridge MA. 112 pp	*Multi-technique*
83	Keith D.W. & Parker A. (2013)	The fate of an engineered planet. *Scientific American*, 308, 34-36	*Multi-technique*
84	Keller D.P., Feng E.Y. & Oschlies A. (2014)	Potential climate engineering effectiveness and side effects during a high carbon dioxide-emission scenario. *Nature Communications*, 5, 1-11; doi: 10.1038/ncomms4304	*Multi-technique*
85	Kosugi T. (2013)	Fail-safe solar radiation management geoengineering. *Mitig. Adapt. Strateg. Glob. Change*, 18, 1141-1166	*Stratospheric SRM*
86	Kravitz B. (2013)	Stratospheric aerosols for solar radiation management. In: *Geoengineering Responses to Climate Change* (ed: T. M. Lenton & N. E. Vaughan) p. 21-38. Springer, New York.	*Stratospheric SRM*
87	Kravitz B., Caldeira K., Boucher O., Robock A. *et al* (2013)	Climate model response from the Geoengineering Model Inter-comparison Project (GeoMIP). *J. Geophys. Res. Atmos.*, 118, 8320-32.	*Stratospheric SRM*
88	Kravitz B.,Forster P.M., Jones A., Robock A. *et al* (2013)	Sea spray geoengineering experiments in the Geoengineering Model Intercomparison Project (GeoMIP): Experimental design and preliminary results. *J. Geophys. Res. Atmos.*, 118, 11175-11186; doi: 10.1002/jgrd.50856	*Tropospheric SRM*
89	Kravitz B., Rasch P. J., Forster P. M., Andrews T. *et al* (2013)	An energetic perspective on hydrological cycle changes in the Geoengineering Model Intercomparison Project. *J. Geophys. Res. Atmos.*, 118, 13087-13102; doi: 10.1002/2013jd020502	*Stratospheric SRM*
90	Kravitz B., Robock A. & Irvine P. (2013)	Robust results from climate model simulations of geoengineering. *Eos Trans. Am. Geophys. Union*, 94, 292.	*Stratospheric SRM*
91	Kravitz B., Robock A, Shindell D.T. & Miller M.A. (2012)	Sensitivity of stratospheric geoengineering with black carbon to aerosol size and altitude of injection. *J. Geophys. Res*., 117, Article D09203, doi:10.1029/2011JD017341.	*Stratospheric SRM*
92	Kuebbeler M., Lohmann U. & Feichter J. (2012)	Effects of stratospheric sulfate aerosol geo-engineering on cirrus clouds. *Geophys. Res. Lett.*, 39, Article L23803	*Stratospheric SRM*
93	Laakso A., Partanen A.-I., Kokkola H., Laaksonen A. *et al* (2012)	Stratospheric passenger flights are likely an inefficient geoengineering strategy. *Environ. Res. Lett.*, 7, 034021; doi:10.1088/1748-9326/7/3/034021	*Stratospheric SRM*
94	Latham J., Bower K., Choularton T., Coe H. *et al* (2012)	Marine cloud brightening. *Phil. Trans. R. Soc. A* , 370, 4217-4262; doi:10.1098/rsta.2012.0086	*Tropospheric SRM*
95	Latham J., Kleypas J., Hauser R., Parkes B. & Gadian A. (2013)	Can marine cloud brightening reduce coral bleaching? *Atmos. Sci. Lett*. 24, 214-219; doi: 10.1002/asl2.442	*Tropospheric SRM*
96	Latham J., Parkes B., Gadian A. & Salter S. (2012)	Weakening of hurricanes via marine cloud brightening (MCB). *Atmos. Sci. Lett.*, 13, 231-237 ; doi: 10.1002/asl.402	*Tropospheric SRM*
97	Lunt D. J. (2013)	Sunshades for solar radiation management. In: *Geoengineering Responses to Climate Change* (ed: T.M. Lenton & N E. Vaughan), p 9-20. Springer, New York.	*Stratospheric SRM*
98	MacMartin D.G., Keith D.W., Kravitz B. & Caldeira K. (2013)	Management of trade-offs in geoengineering through optimal choice of non-uniform radiative forcing. *Nature Climate Change* 3, 365-368; doi: 10.1038/nclimate1722	*Stratospheric SRM*
99	MacMartin D.G., Kravitz B., Keith D. W. & Jarvis A. (2013)	Dynamics of the coupled human-climate system resulting from closed-loop control of solar geoengineering. *Climate Dynamics,* doi: 10.1007/s00382-013-1822-9	*Stratospheric SRM*
100	McClellan J., Keith D. & Apt J. (2012)	Cost analysis of stratospheric albedo modification delivery systems. *Environ. Res. Lett.*, 7, 034019; doi: 10.1088/1748-9326/7/3/034019	*Stratospheric SRM*
101	McCusker K.E., Armour K.C., Bitz C.M. & Battisti (2014)	Rapid and extensive warming following cessation of solar radiation management. *Environ. Res. Lett.,* 9, 024005 (9 pp); doi: 10.1088/1748-9326/9/2/024005	*Stratospheric SRM*

102	McCusker, K. E., Battisti, D. S., & Bitz, C. M. (2012).	The climate response to stratospheric sulfate injections and implications for addressing climate emergencies. *J. Clim.*, 25, 3096-116.	*Stratospheric SRM*
103	Moreno-Cruz J.B. & Keith D.W. (2013)	Climate policy under uncertainty: a case for solar geoengineering. *Climatic Change* 121, 431-444	*Stratospheric SRM*
104	Neukermans A., Cooper G., Foster J., Galbraith L. *et al* (2013)	Sub-micrometer salt aerosol production intended for marine cloud brightening. *Atmos. Res*., doi: 10.1016/j.atmosres.2013.10.025	*Tropospheric SRM*
105	Niemeier U., Schmidt H., Alterskjaer K. & Kristjánsson J.E. (2013)	Solar radiance reduction via climate engineering: impact of different techniques on the energy balance and the hydrological cycle. *J. Geophys. Res. Atmos.,* 118, 11905-11917	*Multi-technique*
106	Oeste F.D. (2012)	*The ISA Procedure for Climate Cooling*. http://www.gm-ingenieurbuero.com/publications/ISA_booklet_20130816.pdf (37pp).	*Multi-technique*
107	Parkes B., Gadian A. & Latham J. (2012)	The effects of marine cloud brightening on seasonal polar temperatures and the meridional heat flux. *ISRN Geophysics*, 2012, Article 142872; doi: 10.5402/2012/142872	*Tropospheric SRM*
108	Partanen A. I., Kokkola H., Romakkaniemi S., Kerminen V. M. *et al* (2012)	Direct and indirect effects of sea spray geoengineering and the role of injected particle size. *J. Geophys. Res. Atmos.*, 117, D02203; doi: 10.1029/2011JD016428	*Tropospheric SRM*
109	Piskozub J. & Neumann T. (2012)	Dim waters: side effects of geoengineering using ocean albedo modification. EGU2012-7007-2. *EGU General Assembly 2012*, Vienna.	*Surface albedo: ocean*
110	Pitari G., Aquila V., Kravitz B., Robock A. *et al* (2014)	Stratospheric ozone response to sulfate geoengineering: Results from the Geoengineering Model Intercomparison Project (GeoMIP). *J. Geophys. Res. Atmos.,*119, doi: 10.1002/2013JD020566	*Stratospheric SRM*
111	Pope F. D., Braesicke P., Grainger R. G., Kalberer M. *et al* (2012)	Stratospheric aerosol particles and solar-radiation management. *Nature Climate Change*, 2, 713-719; doi: 10.1038/nclimate1528	*Stratospheric SRM*
112	Pringle, K. J., Carslaw, K. S., Fan, T., Mann, G. W. et al. (2012)	A multi-model assessment of the impact of sea spray geoengineering on cloud droplet number. *Atmos. Chem. Phys*., 12, 11647-11663.	*Tropospheric SRM*
113	Ricke K.L., Rowlands D.J., Ingram W.J., Keith D.W. & Morgan M.G. (2012)	Effectiveness of stratospheric solar-radiation management as a function of climate sensitivity, *Nature Climate Change*, 2, 92–96, doi:10.1038/nclimate1328	*Stratospheric SRM*
114	Ridgwell A., Freeman C. & Lampitt R. (2012)	Geoengineering – taking control of our planet's climate? *Phil Trans Roy Soc A,* 370, 4163 -4165	*Multi-technique*
115	Robock A., MacMartin D.G., Duren R. & Christensen M.W. (2013)	Studying geoengineering with natural and anthropogenic analogs. *Climatic Change* 121, 445-458.	*Stratospheric SRM*
116	Salter S.H. (2013)	Solar radiation management, cloud albedo enhancement. In: *Geoengineering Responses to Climate Change*, (ed: T. M. Lenton & N. E. Vaughan) p. 39-51. Springer, New York.	*Tropospheric SRM*
117	Sandler R.L. (2012)	Solar radiation management and non-human species. Chapter 6, p 95-110. In: *Engineering the Climate: The Ethics of Solar Radiation Management* (Ed C.J. Preston). Lexington/Rowman & Littlefield, MD	*Multi-technique*
118	Schäfer S., Irvine P. J., Hubert A.-M., Reichwei D. et al (2013)	Field tests of solar climate engineering. *Nature Climate Change*, 3, 766; doi:10.1038/nclimate1987	*Multi-technique*
119	Schmidt H., Alterskær K., Bou Karam D., Boucher O. *et al* (2012)	Solar irradiance reduction to counteract radiative forcing from a quadrupling of CO_2: climate responses simulated by four earth system models. *Earth Syst. Dynam.,* 3, 63-78, doi: 10.5194/esd-3-63-2012	*Stratospheric SRM*
120	Seidel D. J., Feingold G., Jacobson A. R. & Loeb N. (2014)	Detection limits of albedo changes induced by climate engineering. *Nature Climate Change*, 4, 93-98; doi: 10.1038/nclimate2076	*Multi-technique*
121	Shepherd J.G. (2012)	Geoengineering the climate: an overview and update. *Phil. Trans. R. Soc. A,* 370, 4166-4175; doi: 10.1098/rsta.2012.0186	*Multi-technique*
122	Singarayer J. & Davies-Barnard T. (2012)	Regional climate change mitigation with crops: context and assessment. *Phil. Trans. Roy. Soc A,* 370, 4301- 4316.	*Surface albedo: land*
123	Storelvmo T., Kristjansson J.E., Muri H. *et al.* (2013)	Cirrus cloud seeding has potential to cool climate. *Geophys. Res. Lett,*, 40, 178-182	*"Stratospheric SRM" not exactly*
124	Stuart G.S., Stevens R.G., Partanen A.-I. *et al* (2013)	Reduced efficacy of marine cloud brightening geoengineering due to in-plume aerosol coagulation: parameterization and global implications. *Atmos. Chem. Phys*., 13, 10385-10396	*Tropospheric SRM*
125	Tilmes S., Fasullo J., Lamarque J.-F., Marsh D.R. et al (2013)	The hydrological impact of geoengineering in the Geoengineering Model Intercomparison Project (GeoMIP). *J. Geophys. Res. Atmos.*, 118, 11,036-11,058.	*Stratospheric SRM*

126	Tilmes S., Jahn A., Kay J. E., Holland M. & Lamarque J.-F. (2014)	Can regional climate engineering save the summer Arctic Sea-Ice? *Geophys. Res. Lett.*, 41, 880-885; doi: 10.1002/2013gl058731	*Stratospheric SRM*
127	VanCuren R. (2012).	The radiative forcing benefits of "cool roof" construction in California: Quantifying the climate impacts of building albedo modification. *Clim. Change*, 112, 1071-1083	*Surface albedo: land*
128	Vaughan N.E. & Lenton T.M. (2012)	Interactions between reducing CO_2 emissions, CO_2 removal and solar radiation management. *Phil. Trans. R. Soc. A*, 370, 4343-4364; doi:10.1098/rsta.2012.0188	*Multi-technique*
129	Volodin, E. M., Kostrykin, S. V., & Ryaboshapko, A. G. (2012).	Climate response to aerosol injection at different stratospheric locations. *Atmos. Sci. Lett.*, 12, 381-385.	*Stratospheric SRM*
130	Wood R. & Ackerman T.P. (2013)	Defining success and limits of field experiments to test geoengineering by marine cloud brightening. *Clim. Change*, 121, 459-472	*Tropospheric SRM*
131	Wood R., Gardiner S. & Hartzell-Nichols L. (2013).	Climatic Change special issue: geoengineering research and its limitations. *Clim. Change*, 121, 427-430.	*Multi-technique*

1.3 Greenhouse gas removal (GGR) methods. Publications have been allocated to the following topic areas: biochar; BECCS (bioenergy with carbon capture and storage); biomass storage (separated into land and ocean); direct air capture; enhanced weathering (separated into land and ocean, the latter including ocean alkalinization); CO_2 storage (separated into land and ocean); ocean fertilization; and multi-technique. Publications with reference numbers in brackets have already been listed above.

	Authors (date)	Publication title; *journal*	Topic area
132	Achterberg E.P., Moore C.M, Henson S. A., Steigenberger S. *et al* (2013)	Natural iron fertilization by the Eyjafjallajökull volcanic eruption. *Geophys. Res. Lett.*, 40, 921-926; doi: 10.1002/grl.5022	*Ocean fertilization*
133	Al-Traboulsi M., Sjoegersten S., Colls J. et al. (2013)	Potential impact of CO_2 leakage from Carbon Capture and Storage (CCS) systems on growth and yield in maize. *Plant & Soil*, 365, 267-281	*CO_2 storage: land*
134	Ameloot N., Graber E.R., Verheijen F.G.A. et al. (2013)	Interactions between biochar stability and soil organisms: review and research needs. *Europ. J. Soil Sci*., 64, 379-390	*Biochar*
135	Azar C., Johansson D.J.A. & Mattsson N. (2013)	Meeting global temperature targets—the role of bioenergy with carbon capture and storage. *Environ. Res. Lett.*, 8, 034004; doi:10.1088/1748-9326/8/3/034004	*BECCS*
(43)	Belter C.W. & Seidel, D.J. (2013)	A bibliometric analysis of climate engineering research, *WIREs Clim. Change*, 4, 417-427; doi: 10.1002/wcc.229.	*Multi-technique*
136	Biederman L.A. & Harpole W.S. (2013)	Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. *Glob. Change Biol. Bioenergy*, 5, 202-214	*Biochar*
137	Boucher J. F., Tremblay P., Gaboury S. & Villeneuve C. (2013)	Can boreal afforestation help offset incompressible GHG emissions from Canadian industries? *Process Safety and Environmental Protection*, 90, 459-466.	*Biomass storage: land*
(49)	Boucher O., Forster P.M., Gruber N., Ha-Duaong M. *et al* (2014)	Rethinking climate engineering categorization in the context of climate change mitigation and adaptation. *WIREs Clim. Change*, 5, 23-35; doi: 10.1002/wcc.261	*Multi-technique*
138	Boucher O., Halloran P., Burke E., Doutriaux-Boucher M. et al (2012)	Reversibility in an Earth System model in response to CO_2 concentration changes. *Environ. Res. Lett*. 7, 024013 (9pp). doi: 10.1088/1748-9326/7/2/024013	*Multi-technique*
139	Boyd P.W. (2013)	Ocean fertilization for sequestration of carbon dioxide from the atmosphere. p 53-72. In *Geoengineering Responses to Climate Change* (Eds: T. M. Lenton & N. E. Vaughan). Springer, New York.	*Ocean fertilization*
140	Boyd P.W., Bakker D. C. E. & Chandler C. (2012)	A new database to explore the findings from large-scale ocean iron enrichment experiments. *Oceanography*, 25, 64-71.	*Ocean fertilization*
(51)	Caldeira K., Govindasamy B. & Cao L. (2013)	The science of geoengineering. *Ann. Rev. Earth Planetary Sci.*, 41, 231-256.	*Multi-technique*
141	Case S. D. C., McNamara N. P., Reay D.S. et al. (2014)	Can biochar reduce soil greenhouse gas emissions from a *Miscanthus* bioenergy crop? *Glob. Change Biol. Bioenergy* 6, 76-89	*Biochar*

142	Cayuela L.M., Sanchez-Monedero M.A, Roig A. et al. (2013)	Biochar and denitrification in soils: when, how much and why does biochar reduce N_2O emissions? *Scientific Reports*, 3, Article 1732; doi: 10.1038/srep01732.	*Biochar*
143	Chadwick R., Wu P., Good P. & Andrews T. (2013)	Asymmetries in tropical rainfall and circulation patterns in idealised CO_2 removal experiments. *Clim. Dynamics*, 40, 295-316.	*Multi-technique*
144	Chen C. & Tavoni M. (2013)	Direct air capture of CO_2 and climate stabilization: a model based assessment. *Clim. Change* 118, 59-72; doi: 10.1007/s10584-013-0714-7	*Direct air capture*
145	Cockerill T. (2012)	Carbon capture and storage technologies. In: *Environment and Energy Law* (ed: K. Makuch & R. Pereira); Chapter 12, p 257-269; Wiley -Blackwell	*CO_2 storage: land & ocean*
146	Crane-Droesch, A., Abiven S., Jeffery S. et al. (2013)	Heterogeneous global crop yield response to biochar: a meta-regression analysis. *Env. Res. Lett.*, 8, 044049	*Biochar*
147	Cross A. & Sohi S.P. (2013)	A method for screening the relative long-term stability of biochar. *Glob. Change Biol. Bioenergy* 5, 215-220 76-89	*Biochar*
148	de Orte M.R., Sarmiento A.M., Basallote M.D. et al. (2014)	Effects on the mobility of metals from acidification caused by possible CO_2 leakage from sub-seabed geological formations. *Sci. Total Env.*, 470, 356-363	*CO_2 storage: ocean*
(11)	de Vries P., Tamis J.E., Foekema E.M. et al (2013)	Towards quantitative ecological risk assessment of elevated carbon dioxide levels in the marine environment. *Mar Poll. Bull*., 73 (special issue), SI 516-523	*CO_2 storage: ocean*
149	Dong D.. Yang M., Wang C. et al. (2013)	Responses of methane emissions and rice yield to applications of biochar and straw in a paddy field. *J. Soils Sediments*, 13, 1450-1460	*Biochar*
150	Edmonds J., Lucklow P., Calvin K., Wise M. *et al* (2012)	Can radiative forcing be limited to 2.6 W/m^2 without negative emissions from bioenergy AND CO_2 capture and storage? *Clim. Change*, 118, 29-43; doi: 10.1007/s10584-012-0678-z	*BECCS*
(59)	ETC Group – Mooney P., Wetter K.J. & Bronson D. (2012)	Darken the sky and whiten the earth – The dangers of geoengineering. *Development Dialogue No 61 (Sept 2012); What Next Volume IIII: Climate Development & Equity;* 210-237	*Multi-technique*
(60)	ETC Group (2013)	The artificial intelligence of geoengineering. *ETC Communique 109* (8pp)	*Multi-technique*
151	Fang Y., Singh B., Singh B. P. et al. (2014)	Biochar carbon stability in four contrasting soils. *Europ. J. Soil Sci*., 65, 60-71	*Biochar*
152	Freeman C., Fenner N. & Shirsat A.H. (2012)	Peatland geoengineering: an alternative approach to terrestrial carbon sequestration. *Phil. Trans. Roy. Soc A,* 370, 4404-4421.	*Biomass storage: land*
153	Fuss S., Reuter W.H., Szolgayová J. & Obersteiner M. (2013)	Negative emission technology and the impact of carbon sink uncertainty on mitigation strategies. *Clim. Change*, 118, 73-87; doi: 10.1007/s10584-012-0676-1	*Multi-technique*
154	Glaser B. & Birk J.J. (2012)	State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de Indio). *Geochim. Cosmochim. Acta*, 82, 39-51	*Biochar*
155	Goeppert A., Czaun M., Prakash G.K.S. & Olah G.A. (2012)	*Air as the renewable carbon source of the future: an overview of CO_2 capture from the atmosphere. Energy Environ. Sci.*, 5, 7833-7853; doi: 10.1039/C2EE21586A	*Direct air capture*
156	Gomez J. D., Denef K., Stewart C. E. et al. (2014)	Biochar addition rate influences soil microbial abundance and activity in temperate soils. *Europ. J. Soil Sci*., 65, 28-39	*Biochar*
157	Gurwick N. P., Moore L. A., Kelly C. et al. (2013)	A systematic review of biochar research, with a focus on its stability in situ and its promise as a climate mitigation strategy. *PloS ONE*, 8, e75932	*Biochar*
158	Güssow K., Oschlies A., Proelss A., Rehdanz K. & Rickels W. (2013)	Ocean iron fertilization: time to lift the research taboo. In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed W.G. Burns & A.L. Strauss), Chapter 11, p 242-262. CUP, Cambridge UK	*Ocean fertilization*
159	Halsband C. & Kurihara H. (2013)	Potential acidification impacts on zooplankton in CCS leakage scenarios. *Mar. Poll. Bull*., 73 (Special Issue) SI 495-503	*CO_2 storage: ocean*
160	Hammer K. M. & Pedersen S.A. (2013)	Deep-water prawn *Pandalus borealis* displays a relatively high pH regulatory capacity in response to CO_2-induced acidosis. *Mar. Ecol. Prog. Ser.*, 492, 139-151	*CO_2 storage: ocean*
161	Hammond J., Shackley S., Prendergast-Miller M. et al. (2013)	Biochar field testing in the UK: outcomes and implications for use. *Carbon Management*, 4, 159-170	*Biochar*
(67)	Hardman-Mountford N.J., Polimene L., Hirata T., Brewin R.J. & Aiken J. (2013)	Impacts of light shading and nutrient enrichment geoengineering approaches on the productivity of a stratified, oligotrophic ocean ecosystem. *J. Roy. Soc. Interface*, 10, 20130701.	*Multi-technique*

162	Hartmann J., West A.J., Renforth P., Kohler P. et al (2013)	Enhanced chemical weathering as a geoengineering strategy to reduce atmospheric carbon dioxide, supply nutrients, and mitigate ocean acidification. *Rev. Geophys.*, 51, 113-149.	*Enhanced weathering: land & ocean*
163	Holmes G. & Keith D.W. (2012	An air-liquid contactor for large-scale capture of CO_2 from air. *Phil. Trans. Roy. Soc. A*, 370, 4380-4403	*Direct air capture*
(71)	Honeggar M., Michaelowa A. & Butzengeiger-Geyer S. (2012)	*Climate Engineering: Avoiding Pandora's Box through Research and Governance*. FIN Climate Policy Perspectives 5 (8pp)	*Multi-technique*
164	Ianson D., Völker C., Denman K., Kunze E. & Steiner N. (2012)	The effect of vertical and horizontal dilution on fertilized patch experiments. *Global Biogeochem. Cycles* 26, GB3002	*Ocean fertilization*
165	Ilyina, T., Wolf-Gladrow D., Munhoven G., & Heinze C. (2013)	Assessing the potential of calcium-based artificial ocean alkalinization to mitigate rising atmospheric CO_2 and ocean acidification. *Geophys. Res. Lett*., 40, 5909-5914; doi: 10.1002/2013gl057981	*Enhanced weathering: ocean*
166	IMO (2013)	Marine geoengineering including ocean fertilization to be regulated under amendments to international treaty. International Maritime Organization. http://www.imo.org/MediaCentre/PressBriefings/Pages/45-marine-geoengieneering.aspx	*Ocean fertilization*
(16)	IPCC (2013)	*Climate Change 2013: The Physical Science Basis.* Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http: www.ipcc.ch.	*Multi-technique*
(17)	IPCC (2014a)	*Climate Change 2014: Impacts, Adaptation and Vulnerability*. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http: www.ipcc.ch	*Multi-technique*
(18)	IPCC (2014b)	*Climate Change 2014: Mitigation of Climate Change.* Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http: www.ipcc.ch.	*Multi-technique*
167	Ippolito J. A., Laird D. A. & Busscher W. J. (2012)	Environmental benefits of biochar. *J. Env. Qual.*, 41, 967-972	*Biochar*
168	Ishida H., Golmen L.G., West J. *et al.* (2013)	Effects of CO_2 on benthic biota: An *in situ* benthic chamber experiment in Storfjorden (Norway). *Mar. Poll. Bull*., 73, (Special Issue) SI 443-451	*CO_2 storage: ocean*
(81)	Jones C., Williamson P., Haywood J., Lowe J. *et al* (2013)	*LWEC Geoengineering Report. A forward look for UK research on climate impacts of geoengineering*. Living With Environmental Change (LWEC), UK; 36 pp. http://www.lwec.org.uk/publications/lwec-geoengineering-report-forward-look-uk-research-climate-impacts-geoengineering	*Multi-technique*
169	Jaffé R., Ding Y., Niggemann J., Vähätalo A. V. et al. (2013)	Global charcoal mobilization from soils via dissolution and riverine transport to the oceans. *Science*, 340, 345-347.	*Biochar*
170	Karer J., Wimmer B., Zehetner F. *et al*. (2013)	Biochar application to temperate soils: effects on nutrient uptake and crop yield under field conditions. *Agric. Food Sci.*, 22, 390-403	*Biochar*
(82)	Keith D. (2013)	*A Case for Climate Engineering*. MIT Press, Cambridge MA. 112 pp	*Multi-technique*
(83)	Keith D.W. & Parker A. (2013)	The fate of an engineered planet. *Scientific American*, 308, 34-36	*Multi-technique*
(84)	Keller D.P., Feng E.Y. & Oschlies A. (2014)	Potential climate engineering effectiveness and side effects during a high carbon dioxide-emission scenario. *Nature Communications*, 5, 1-11; doi: 10.1038/ncomms4304	*Multi-technique*
171	Klein D., Luderer G., Kriegler E., Strefler J. *et al* (2014)	The value of bioenergy in low stabilization scenarios: an assessment using REMIND-MAgPIE. *Clim. Change*, 123, 705-718; doi: 10.1007/s10584-013-0940-z	*BECCS*
172	Köhler P., Abrams J.F., Völker C., Hauck J. & Wolf-Gladrow D.A. (2013)	Geoengineering impact of open ocean dissolution of olivine on atmospheric CO_2, surface ocean pH and marine biology. *Environ. Res. Lett.* 8, Article 014009; doi: 10.1088/1748-9326/8/1/014009	*Enhanced weathering: ocean*
173	Kraxner F, Aoki K., Ledus S., Kindermann G. *et al* (2014)	BECCS in South Korea – Analysing the negative emission potential of bioenergy as a mitigation tool. *Renewable Energy*, 61, 102-108; doi: 10.1016/j.renene.2012.09.064	*BECCS*
174	Kriegler E., Edenhofer O., Reuster L., Luderer G. & Klein D. (2013)	Is atmospheric carbon dioxide removal a game changer for climate change mitigation? *Clim. Change*, 118, 45-57; doi: 10.1007/s10584-012-0681-4	*Multi-technique*
175	Lackner S.K., Breman S., Matter J.M., Park A.H.A. et al. (2012)	The urgency of the development of CO_2 capture from ambient air. *Proc. Natl. Acad. Sci. U.S.A.*, 109, 13156-13162	*Direct air capture*

176	Lal, R. (2014)	Managing terrestrial carbon in a changing climate. In: *Soil Security for Ecosystem Management* (Ed: S. Kapur & S. Erşahin), p. 1-18. Springer International.	*Multi-technique*
177	Liu X., Zhang A., Ji C. *et al*. (2013)	Biochar's effect on crop productivity and the dependence on experimental conditions-a meta-analysis of literature data. *Plant & Soil*, 373, 583-594	*Biochar*
178	MacDougall A. H. (2013)	Reversing climate warming by artificial atmospheric carbon–dioxide removal: Can a Holocene-like climate be restored? *Geophys. Res. Lett.*, 40, 5480-5485	*Multi-technique*
179	Manning D. A. C. & Renforth P. (2013)	Passive sequestration of atmospheric CO_2 through coupled plant-mineral reactions in urban soils. *Environ. Sci. Technol*., 47, 135-141; doi: 10.1021/es301250j.	*Enhanced weathering: land*
180	Marks E. A. N., Mattana S., Alcaniz J.M. et al. (2014)	Biochars provoke diverse soil mesofauna reproductive responses in laboratory bioassays. *Europ. J. Soil Biol*., 60, 104-111	*Biochar*
181	Martin P., van der Loeff M.R., Cassar N., Vandromme P. *et al* (2013)	Iron fertilization enhanced net community production but not downward particle flux during the Southern Ocean iron fertilization experiment LOHAFEX. *Global Biogeochem. Cycles* 27, 871-881; doi: 10.1002/gbc.20077	*Ocean fertilization*
182	Mattila T., Grönroos J., Judl J. & Korhonen M.-R. (2012)	Is biochar or straw-bale construction a better carbon storage from a life-cycle perspective? *Process Safety Environ. Protection*, 90, 452-458.	*Biochar*
183	McCormack S. A., Ostle N., Bardgett R.D., Hopkins D.W. & Vanbergen A.J. (2013).	Biochar in bioenergy cropping systems: impacts on soil faunal communities and linked ecosystem processes." *GCB Bioenergy,* 5, 81-95; doi: 10.1111/gcbb.12046.	*Biochar*
184	McGlashan N., Shah N., Caldecott B. & Workman M. (2012)	High-level techno-economic assessment of negative emissions technologies. *Process Safety Environ. Protection*, 90, 501-510.	*Multi-technique*
185	McLaren D. (2012)	A comparative global assessment of potential negative emissions technologies. *Process Safety Environ. Protection*, 90, 489-500.	*Multi-technique*
186	Meadowcroft J. (2013)	Exploring negative territory carbon dioxide removal and climate policy initiatives. *Clim. Change*, 118, 137-149; doi: 10.1007/s10584-012-0684-1.	*Multi-technique*
187	Meyer S., Bright R.M., Fischer D. et al. (2012)	Albedo impact on the suitability of biochar systems to mitigate global warming. *Env. Sci. Technol*., 46, 12726-12734	*Biochar*
188	Mohd A., Ghani W. A. W. A. K., Resitanim N.Z. et al. (2013)	A review: carbon dioxide capture: biomass-derived-biochar and its applications. *J. Dispersion Sci. Technol*., 34, 974-984	*Biochar*
189	Morris P. J. & Charette M.A. (2013)	A synthesis of upper ocean carbon and dissolved iron budgets for Southern Ocean natural iron fertilisation studies. *Deep Sea Res. Part II: Topical Stud. Oceanogr.*, 90, 147-157; doi: 10.1016/j.dsr2.2013.02.001.	*Ocean fertilization*
190	Nemet G.F. & Brandt A.R. (2012)	WILLINGNESS TO PAY FOR A CLIMATE BACKSTOP: LIQUID FUEL PRODUCERS AND DIRECT CO_2 AIR CAPTURE. *ENERGY J.*, 33, 59-81.	*Direct air capture*
191	Noble R. R. P., Stalker L., Wakelin S. A. et al. (2012)	Biological monitoring for carbon capture and storage – A review and potential future developments. *Int. J. Greenhouse Gas Control*, 10, 520-535	*CO_2 storage: ocean*
192	N'Yeurt A. d. R., Chynoweth D.P, Capron M.E., Stewart J.R. & Hasan M.A. (2012)	Negative carbon via ocean afforestation. *Process Safety Environ. Protection*, 90, 467-474.	*Biomass storage: ocean*
(106)	Oeste F.D. (2012)	*The ISA Procedure for Climate Cooling*. http://www.gm-ingenieurbuero.com/publications/ISA_booklet_20130816.pdf (37pp).	*Multi-technique*
193	Paquay, F.S. & Zeebe, R.E. (2013)	Assessing possible consequences of ocean liming on ocean pH, atmospheric CO_2 concentration and associated costs. *Int. J. Greenhouse Gas Control* 17, 183-188.	*Enhanced weathering: ocean*
194	Popp A., Rose S.K., Calvin K., van Vuuren D.P. *et al* (2013)	Land-use transition for bioenergy and climate stabilization: model comparison of drivers, impacts and interactions with other land use based mitigation options. *Clim. Change*. 123, 495-509; doi: 10.1007/s10584-013-0926-x	*BECCS*
195	Powell T.W.R. & Lenton T.M. (2012)	Future carbon dioxide removal via biomass energy constrained by agricultural efficiency and dietary trends. *Energy Environ. Sci*, 5, 8116-8133; doi: 10.1039/c2ee21592f	*BECCS*
196	Prommer J., Wanek W., Hofhansl F. *et al*. (2014)	Biochar decelerates soil organic nitrogen cycling but stimulates soil nitrification in a temperate arable field trial. *PloS ONE*, 9, e86388	*Biochar*
197	Qanbari F., Pooladi-Darvish	CO_2 disposal as hydrate in ocean sediments. *J. Natural Gas Sci. Engin*., 8	*CO_2 storage:*

	M., Tabatabaie S. H. *et al*. (2012)	(Special Issue) SI 139-149	*ocean*
198	Quilliam R.S, Marsden K.A., Gertler C. *et al*. (2012)	Nutrient dynamics, microbial growth and weed emergence in biochar amended soil are influenced by time since application and reapplication rate. *Agric. Ecosystems Environ.* , 158, 192-199	*Biochar*
199	Reilly J., Melillo J., Cai Y., Kicklighter D. *et al* (2012),	Using land to mitigate climate change: hitting the target, recognizing the trade-offs. *Environ Sci. Technol.*, 46, 5672–5679	*Multi-technique*
200	Renforth, P. (2012)	The potential of enhanced weathering in the UK. *Int. J. Greenhouse Gas Control*, 10, 229-243.	*Enhanced weathering: land*
201	Renforth P. & Kruger T. (2013)	Coupling mineral carbonation and ocean liming. *Energy & Fuels*, 27, 4199-4207; doi: 10.1021/ef302030w.	*Enhanced weathering: ocean*
202	Reverchon F., Flicker R.C., Yang H. *et al*. (2014)	Changes in delta N-15 in a soil-plant system under different biochar feedstocks and application rates. *Biol. Fertility Soils*, 50, 275-283	*Biochar*
(114)	Ridgwell A., Freeman C. & Lampitt R. (2012)	Geoengineering – taking control of our planet's climate? *Phil Trans. Roy. Soc. A, 370, 4163 -4421*.	*Multi-technique*
203	Rose S.K., Kriegler E, Bibas R., Calvin K. *et al* (2014)	Bioenergy in energy transformation and climate management. *Clim. Change*, 123, 477-493	*BECCS*
204	Rose S.K., Ahammad H., Eickhout B., Fisher B. *et al* (2012)	Land-based mitigation in climate stabilization. *Energy Econ*. 34, 365–380	*Multi-technique*
205	Russell B. D., Connell S.D. Uthicke S. *et al*. (2013)	Future seagrass beds: Can increased productivity lead to increased carbon storage? *Mar. Poll. Bull*., 73 (Special Issue); SI 463-469	*Biomass storage: ocean*
206	Rutigliano F. A., Romano M., Marzaioli R. *et al* (2014)	Effect of biochar addition on soil microbial community in a wheat crop. *Europ. J. Soil. B*iol. 60, 9-15	*Biochar*
207	Saarnio S., Heimonen K. & Kettunen R. (2013)	Biochar addition indirectly affects N_2O emissions via soil moisture and plant N uptake. *Soil Biol. Biochem*. 58, 99-106	*Biochar*
208	Schuiling R. D. (2013)	Carbon dioxide sequestration, weathering approaches to. In: *Geoengineering Responses to Climate Change* (ed: T. M. Lenton & N. E. Vaughan), p 141-167. Springer, New York.	*Enhanced weathering: land*
209	Schulz H., Dunst G. & Glaser B. (2013)	Positive effects of composted biochar on plant growth and soil fertility. *Agronomy Sustainable Development*, 33, 817-827	*Biochar*
210	Shackley S., Sohi S., Ibarrola R., Hammond J. *et al* (2013)	Biochar, tool for climate change mitigation and soil management. In: *Geoengineering Responses to Climate Change* (ed: T. M. Lenton & N. E. Vaughan), p. 73-140. Springer, New York.	*Biochar*
(121)	Shepherd J.G. (2012)	Geoengineering the climate: an overview and update. *Phil. Trans. R. Soc. A,* 370, 4166-4175; doi: 10.1098/rsta.2012.0186	*Multi-technique*
211	Singla A. & Inubushi K. (2014)	Effect of biochar on CH_4 and N_2O emission from soils vegetated with paddy. *Paddy Water Environ.*, 12, 239-243	*Biochar*
212	Smith L.J. & Torn M.S. (2013)	Ecological limits to terrestrial biological carbon dioxide removal, *Clim. Change*, 118, 89-103; doi: 10.1007/s10584-012-0682-3	*Multi-technique*
213	Stavi I. & Lal R. (2013)	Agroforestry and biochar to offset climate change: a review. *Agronomy for Sustainable Development*, 33, 81-96	*Multi-technique*
214	Stolaroff J.K., Bhattacharyya S., Smith C.A., Bourcier W.L. *et al*. (2012)	Review of methane mitigation technologies with application to rapid release of methane from the Arctic. *Environ. Sci. Technol.*, 46, 6455-6469.	*Multi-technique*
215	Tavoni M. & Socolow R. (2013)	Modeling meets science and technology: an introduction to a special issue on negative emissions, *Clim. Change*, 118, 1-14; doi: 10.1007/s10584-013-0757-9	*Multi-technique*
216	van Vuuren D.P., Deetman S., van Vleit J., van den Berg M. *et al* (2013)	*The role of negative CO_2 emissions for reaching 2° C: insights from integrated assessment modelling. Clim. Change, 118, 59-72; doi: 10.1007/s10584-013-0714-7*	*Multi-technique*
(128)	Vaughan N.E. & Lenton T.M. (2012)	Interactions between reducing CO_2 emissions, CO_2 removal and solar radiation management. *Phil. Trans. R. Soc. A*, 370, 4343-4364; doi:10.1098/rsta.2012.0188	*Multi-technique*
217	Verheijen F.G.A., Jeffery S., van der Velde M. et al. (2013)	Reductions in soil surface albedo as a function of biochar application rate: implications for global radiative forcing. *Environ. Res. Lett*., 8, Article 044008	*Biochar*

218	Verheijen, F. G. A., Montanarella, L., & Bastos, A. C. (2012).	Sustainability, certification, and regulation of biochar. *Pesquisa Agropecuaria Brasileira*, 47, 649-653.	*Biochar*
219	Vichi M., Navarra A. & Fogli P. G. (2013).	Adjustment of the natural ocean carbon cycle to negative emission rates. *Clim. Change*, 118, 105-118; doi: 10.1007/s10584-012-0677-0	*Multi-technique*
220	Wang J., Pan X., Liu Y., Zhang X. & Xiong Z. (2012)	Effects of biochar amendment in two soils on greenhouse gas emissions and crop production. *Plant & Soil*, 360, 287-298.	*Biochar*
221	Williamson P., Wallace D.W.R., Law C.S., Boyd P.W. *et al* (2012)	Ocean fertilization for geoengineering: a review of effectiveness, environmental impacts and emerging governance. *Process Safety Environ. Protection*, 90, 475-488.	*Ocean fertilization*
(131)	Wood R., Gardiner S. & Hartzell-Nichols L. (2013).	Climatic Change special issue: geoengineering research and its limitations. *Climatic Change*, 121, 427-430.	*Multi-technique*
222	Xiu P., Thomas A.C. & Chai F. (2014)	Satellite bio-optical and altimeter comparisons of phytoplankton blooms induced by natural and artificial iron addition in the Gulf of Alaska. *Remote Sensing of Environment*, 145, 38-46	*Ocean fertilization*
223	Xu G., Lv Y., Sun J. et al. (2012)	Recent advances in biochar applications in agricultural soils: benefits and environmental implications. *Clean Soil Air Water*, 40, 1093-1098	*Biochar*
224	Yu L., Tang J., Zhang R. et al. (2013)	Effects of biochar application on soil methane emission at different soil moisture levels. *Biology & Fertility of Soils*, 49, 119-128.	*Biochar*
225	Zeng N., King A.W., Zaitchik B., Wullschleger S.D. et al (2013)	Carbon sequestration via wood harvest and storage: An assessment of its harvest potential. *Climatic Change*, 118, 245-257; doi: 10.1007/s10584-012-0624-0.	*Biomass storage: land*

1.4 Socio-economic, cultural and ethical aspects. Publications have been allocated to the following topic areas: ethics and values; policy and governance; discourse analysis; economics; and multi-topic. Publications with reference numbers in brackets have already been listed above.

	Authors (date)	Publication title; *journal*	Topic area
226	Amelung D. & Funke J. (2013)	Dealing with the uncertainties of climate engineering: Warnings from a psychological complex problem solving perspective. *Technology in Society*, 35, 32-40. doi: 10.1016/j.techsoc.2013.03.001.	*Ethics & values*
(42)	Baum,S. D., Maher T. M. & Haqq-Misra J. (2013)	Double catastrophe: intermittent stratospheric geoengineering induced by societal collapse. *Environ. Sys. Decis.*, 33, 168-180.	*Ethics & values*
227	Bellamy R., Chilvers J., Vaughan N.E. & Lenton T.M (2012)	A review of climate geoengineering appraisals. *WIRes Clim. Change,* 3, 597-615	*Ethics & values*
228	Bellamy R., Chilvers J., Vaughan N.E. & Lenton T.M. (2013)	'Opening up' geoengineering appraisal: Multi-criteria mapping of options for tackling climate change. *Global Environ. Change*, 23, (Special Issue) SI 926-937; doi: 10.1016/j.gloenvcha.2013.07.011.	*Ethics & values*
(43)	Belter C.W. & Seidel, D.J. (2013)	A bibliometric analysis of climate engineering research, *WIRes Clim. Change*, 4, 417-427; doi: 10.1002/wcc.229.	*Multi-topic*
229	Betz G. (2012)	The case for climate engineering research: An analysis of the "arm the future" argument. *Clim. Change* 111, 473-485.	*Ethics & values*
230	Betz G. & Cacean S. (2012)	*Ethical Aspects of Climate Engineering*. KIT Scientific Publishing, Karlsruhe. http://digbib.ubka.uni-karlsruhe.de/volltexte/1000028245	*Ethics & values*
231	Bickel J. E. (2013)	Climate engineering and climate tipping-point scenarios. *Environ. Sys. Decis.* 33, 152-167; doi: 10.1007/s10669-013-9435-8	*Ethics & values*
(48)	Bickel J. E. & Agrawal S. (2013).	Re-examining the economics of aerosol geoengineering. *Climatic Change* 119, 993-1006.	*Economics*
232	Blackstock, J. (2012)	Researchers can't regulate climate engineering alone. *Nature*, 486, 159.	*Policy & governance*
233	Bodansky D. (2013)	The who, what, and wherefore of geoengineering governance. *Climatic Change*, 121, 539-551	*Policy & governance*
234	Bodle R. (2013)	Climate law and geoengineering. In: *Climate Change and the Law*, E. J. Hollo, K. Kulovesi & M. Mehling (eds); 447-471. Dordrecht: Springer.	*Policy & governance*
235	Borgmann A. (2012)	The setting of the scene: technological fixes and the design of the good life. In: *Engineering the Climate: The Ethics of Solar Radiation Maagement* (Ed	*Ethics & values*

		C.J. Preston), Chapter 11, p 189-200.. Lexington Books/Rowman & Littlefield, Lanham MD	
236	Borick C. & Rabe B.G. (2012)	Americans cool on geoengineering approaches to addressing climate change. *Issues in Governance Studies* 47, 1-6	*Ethics & values*
(49)	Boucher O., Forster P.M., Gruber N., Ha-Duaong M. *et al.* (2014)	Rethinking climate engineering categorization in the context of climate change mitigation and adaptation. *WIREs Clim. Change,* 5, 23-35; doi: 10.1002/wcc.261	*Multi-topic*
237	Brasseur G. P. & Granier C. (2013)	Mitigation, adaptation or climate engineering? *Theoretical Inquiries in Law,* 14, 1-20; doi:10.1515/til-2013-003	*Multi-topic*
238	Brent K. & McGee J. (2012)	The regulation of geoengineering: A gathering storm for international climate change policy? *Air Qual. Clim. Change* 46, 22-27.	*Policy & governance*
239	Buck H.J. (2012)	Climate remediation to address social development challenges: going beyond cost-benefit and risk approaches to assessing solar radiation management. In: *Engineering the Climate: The Ethics of Solar Radiation Management* (Ed C.J. Preston), Chapter 8, p 133-148. Lexington Books/Rowman & Littlefield, Lanham MD	*Ethics & values*
240	Buck H.J. (2012)	Geoengineering: re-making climate for profit or humanitarian intervention? *Development & Change* 43, 253-270.	*Ethics & values*
241	Buck H.J. (2013)	Climate engineering: spectacle, tragedy or solution? A content analysis of news media framing. In: *Interpretive Approaches to Global Climate Governance. Deconstructing the Greenhouse* (Eds: C. Methmann, D. Rothe & B. Stephan), p 166-181. Routledge, New York),	*Discourse analysis*
242	Buck H. J., Gammon A. R. & Preston C. J. (2013)	Gender and geoengineering. *Hypatia,* doi: 10.1111/hypa.12083	*Ethics & values*
243	Burns W. C.G. (2012)	Geoengineering the climate: an overview of solar radiation management options. *Tulsa Law Review* 46, 283-304.	*Multi-topic*
244	Burns W.C.G. (2013)	Climate geoengineering: solar radiation management and its implications for intergenerational equity. In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed W.G. Burns & A.L. Strauss), Chapter 9, p 200-220. CUP, Cambridge UK	*Ethics & values*
245	Carr W.C., Preston C.J., Yung L., Szerszynski, Keith D.W. & Mercer A.M. (2013)	Public engagement on solar radiation management and why it needs to happen now. *Climatic Change* 121, 567-577; doi: 10.1007/s10584-013-0763-y	*Ethics & values*
246	Carr W.C., Mercer A. & Palmer C. (2012)	Public concerns about the ethics of solar radiation management. In: *Engineering the Climate: The Ethics of Solar Radiation Management* (Ed C.J. Preston), Chapter 10, p 169-186. Lexington Books/Rowman & Littlefield, Lanham MD	*Ethics & values*
247	Chen Y. & Liu Z. (2013)	Geoengineering: ethical considerations and global governance. *Chinese J. Urban & Environ. Studies* 1, 1350006.	*Multi-topic*
248	Clingermann F. (2012)	Between Babel and Pelagius: religion, theology and geoengineering. In: *Engineering the Climate: The Ethics of Solar Radiation Management* (Ed C.J. Preston), Chapter 12, p 201-220. Lexington Books/Rowman & Littlefield, Lanham MD	*Ethics & values*
249	Corner A., Parkhill K. Pidgeon N. & Vaughan N.E. (2013)	Messing with nature? Exploring public perceptions of geoengineering in the UK. *Global Environ. Change* 23, 938-947; doi: 10.1016/ j.gloenvcha.2013.06.002.	*Ethics & values*
250	Corner A., Pidgeon N. & Parkill K. (2012)	Perceptions of geoengineering: public attitudes, stakeholder perspectives, and the challenge of 'upstream' engagement. *WIREs Clim. Change*, 3, 451-466; doi: 10.1002/wcc.176	*Ethics & values*
251	Curvelo, P. (2013)	Questioning the geoengineering scientific worldview. *Int. J. Interdisciplinary Environ. Stud.*, 7, 35-53.	*Ethics & values*
252	Curvelo, P. (2013)	Towards an analytical framework for evaluating the ethical dimensions of geoengineering proposals. *Int. J. Climate Change, Impacts & Responses*, 4, 191-208	*Ethics & values*
253	Curvelo, P. (2013)	'Imag[in]ing geoengineering – the plausible and the implausible', *Int. J. Foresight & Innovation Policy,* 9, 162–187.	*Ethics & values*
254	Curvelo, P. & Pereira A.G. (2013)	Geoengineering: reflections on current debates. *Int. J. Sci. Soc.,* 4, 1-21.	*Multi-topic*
255	Davies G. (2013)	The psychological costs of geoengineering: why it may be hard to accept even if it works. In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed W.G. Burns	*Ethics & values*

		& A.L. Strauss), Chapter 3, p 59-79. CUP, Cambridge UK	
256	Dilling L. & Hauser R. (2013)	Governing geoengineering research: why, when and how? *Clim. Change*, 121, 553-565; doi: 10/1007/s10584-013-0835-z	*Policy & governance*
(59)	ETC Group – Mooney P., Wetter K.J. & Bronson D. (2012)	Darken the sky and whiten the earth – The dangers of geoengineering. *Development Dialogue No 61; What Next Volume IIII: Climate Development & Equity;* 210-237	*Multi-topic*
(60)	ETC Group (2013)	The artificial intelligence of geoengineering. *ETC Communique 109* (8pp)	*Multi-topic*
257	Fleming, J. R. (2012)	Will geoengineering bring security and peace? What does history tell us? *S+F Sicherheit und Frieden*. Special issue Geoengineering: An Issue for Peace and Security? no. 4	*Policy & governance*
(153)	Fuss S., Reuter W.H., Szolgayová J. & Obersteiner M. (2013)	Optimal mitigation strategies with negative emission technologies and carbon sinks under uncertainty. *Clim. Change*, 118, 73-87; doi: 10.1007/s10584-012-0676-1	*Multi-topic*
258	Galaz V. (2012)	Geo-engineering, governance, and social-ecological systems: critical issues and joint research needs. *Ecology & Society*, 17, 24 (10 pp); doi: 19.5751/ES-04677-170124 Soc.	*Policy & governance*
259	Galarraga M. & Szerszynski B. (2012)	Making climates: solar radiation management and the ethics of fabrication. In: *Engineering the Climate: The Ethics of Solar Radiation Management* (Ed C.J. Preston), Chapter 13, p 221-236. Lexington Books/Rowman & Littlefield, Lanham MD	*Ethics & values*
260	Gardiner S. (2012)	Are we the scum of the Earth? Climate change, geoengineering, and humanity's challenge. In *Ethical Adaptation to Climate Change: Human Virtues of the Future* (Ed: A. Thompson & J. Bendik-Keyme, eds) p 241-260. MIT Press, Cambridge, MA.	*Ethics & values*
261	Gardiner S.M. (2013)	Ethics, geoengineering and moral schizophrenia: what's the question? In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed W.G. Burns & A.L. Strauss), Chapter 1, p 11-38. CUP, Cambridge UK	*Ethics & values*
262	Gardiner S.M. (2013)	Why geoengineering is not a 'global public good', and why it is ethically misleading to frame it as one. *Climatic Change*, 121, 513-525	*Ethics & values*
263	Gardiner S.M. (2013)	The desperation argument for geoengineering. *PS: Political Science and Politics*, 46, 28-33.	*Ethics & values*
264	Gardiner S.M. (2014)	Why 'global public good' is a treacherous term, especially for geoengineering. *Climatic Change* 121 (Special Issue), SI 513-525; doi: 10.1007/s10584-014-1079-2.	*Ethics & values*
265	Gordijn B. & ten Have H. (2012)	Ethics of mitigation, adaptation and geoengineering. *Medicine, Health Care & Philosophy*, 15, 1-2.	*Ethics & values*
(160)	Güssow K., Oschlies A., Proelss A., Rehdanz K. & Rickels W. (2013)	Ocean iron fertilization: time to lift the research taboo. In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed W.G. Burns & A.L. Strauss), Chapter 11, p 242-262. CUP, Cambridge UK	*Policy & governance*
266	Hale B. (2012)	The world that would have been: moral hazard arguments against geoengineering. In: *Engineering the Climate: The Ethics of Solar Radiation Management* (Ed C.J. Preston), Chapter 7, p 113-131. Lexington Books/Rowman & Littlefield, Lanham MD	*Ethics & values*
267	Hale B. (2013)	An act-description approach to approving and funding geoengineering research. In: *Designer Biology: The Ethics of Intensively Engineering Biological and Ecological Systems (ed.* J. Basl & R. L. Sandler. Lexington Books, Lanham.	*Policy & governance*
268	Hamilton C. (2013)	The ethical foundations of climate engineering. In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed W.G. Burns & A.L. Strauss), Chapter 2, p 39-58. CUP, Cambridge UK	*Ethics & values*
269	Hamilton C. (2013)	No, we should not just 'at least do the research'. *Nature*, 496, 139	*Ethics & values*
270	Harnisch, S. (2012)	Minding the gap? CE, CO_2 abatement, adaptation and the governance of the global climate. *S+F Sicherheit und Frieden*. Special issue Geoengineering: An Issue for Peace and Security? no. 4 .	*Policy & governance*
271	Hauser R. (2013)	Using twentieth-century U.S. weather modification policy to gain insight into global climate remediation governance issues. *Weather, Climate, & Society*, 5, 180-193.	*Policy & governance*
272	Hester T. (2013)	Remaking the world to save it: applying U.S. environmental laws to climate engineering projects. In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed W.G. Burns	*Policy & governance*

		& A.L. Strauss), Chapter 12, p 263-314. CUP, Cambridge UK	
273	Heyward C. (2013)	Situating and abandoning geoengineering: a typology of five responses to dangerous climate change. *Political Science & Politics*, Jan 2013, 23-27; doi: 10.1017/ S1049096512001436	*Discourse analysis*
274	Hiller S. & Renn O. (2012)	Public perception of geoengineering. *S+F Sicherheit und Frieden*. Special issue: Geoengineering: An Issue for Peace and Security? no. 4	*Ethics & values*
(67)	Honeggar M., Michaelowa A. & Butzengeiger-Geyer S. (2012)	*Climate Engineering: Avoiding Pandora's Box through Research and Governance*. FIN Climate Policy Perspectives 5 (8pp)	*Multi-topic*
275	Horton J.B. (2013)	Geoengineering and the myth of unilateralism: pressures and prospects for international cooperation. In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed: W.G. Burns & A.L. Strauss), Chapter 7, p 168-181. CUP, Cambridge UK	*Policy & governance*
276	Houdequin M. (2012)	Geoengineering, solidarity and moral risk. In: *Engineering the Climate: The Ethics of Solar Radiation Management* (Ed C.J. Preston), Chapter 1, p 15-32. Lexington Books/Rowman & Littlefield, Lanham MD	*Ethics & values*
277	Huttunen S & Hilden M. (2014)	Framing the controversial: geoengineering in academic literature. *Science Communication*, 36, 3-29	*Discourse analysis*
278	IMO (2013)	Marine geoengineering including ocean fertilization to be regulated under amendments to international treaty. International Maritime Organization. http://www.imo.org/MediaCentre/PressBriefings/Pages/45-marine-geoengieneering.aspx	*Policy & governance*
(18)	IPCC (2014b)	*Climate Change 2014: Mitigation of Climate Change.* Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http: www.ipcc.ch.	*Multi-topic*
279	Jamieson D. (2013)	Some whats, whys and worries of geoengineering. *Climatic Change*, 121, 527-537	*Multi-topic*
(81)	Jones C., Williamson P., Haywood J., Lowe J. *et al* (2013)	*LWEC Geoengineering Report. A forward look for UK research on climate impacts of geoengineering*. Living With Environmental Change (LWEC), UK; 36 pp. http://www.lwec.org.uk/publications/lwec-geoengineering-report-forward-look-uk-research-climate-impacts-geoengineering	*Multi-topic*
(82)	Keith D. (2013)	*A Case for Climate Engineering.* MIT Press, Cambridge MA. 112 pp	*Multi-topic*
(83)	Keith D.W. & Parker A. (2013)	The fate of an engineered planet. *Scientific American*, 308, 34-36	*Multi-topic*
280	Klepper G. (2012)	What are the costs and benefits of climate engineering? And can we assess them? S+F Sicherheit und Frieden. Special issue *Geoengineering: An Issue for Peace and Security?* no. 4	*Economics*
281	Lane L. (2013)	Climate engineering and the Anthropocene era. In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed W.G. Burns & A.L. Strauss), Chapter 5, p 115-145. CUP, Cambridge UK	*Multi-topic*
282	Lemoine D.M., Fuss S., Szolgayová J., Obersteiner M., & Kammen D.M. (2012)	The influence of negative emission technologies and technology policies on the optimal climate mitigation portfolio. *Clim. Change,* 113, 141–162	*Policy & Governance*
283	Lin A.C. (2013)	International legal regimes and principles relevant to geoengineering. In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed W.G. Burns & A.L. Strauss, Chapter 8, p 182-199. CUP, Cambridge UK	*Policy & Governance*
284	Link P. M., Brzoska M., Maas A., Neuneck G. & Scheffran J. (2013)	Possible implications of climate engineering for peace and security. *Bull. Am. Meteorol. Soc.,* 94, ES13-ES16. doi: 10.1175/bams-d-12-00022.1	*Policy & governance*
285	Low S., Moore N., Chen Z., McManamen K. & Blackstock J.J. (2013)	Geoengineering policy and governance issues. In: *Geoengineering Responses to Climate Change* (ed: T. M. Lenton & N. E. Vaughan) p., 169-191. Springer, New York.	*Policy & governance*
(22)	Luderer G., Bertram C., Calvin K., De Cian E. & Kriegler E. (2013)	Implication of weak near-term climate policies on longterm mitigation pathways. *Clim. Change*, doi: 10.1007/s10584-013-0899-9	*Policy & governance*
286	Luokkanen M., Huttunen S. & Hildén M. (2013)	Geoengineering, news media and metaphors: Framing the controversial. *Public Understanding of Science*. doi: 10.1177/0963662513475966.	*Discourse analysis*
287	Maas A. & Jürgen Scheffran J. (2012)	Climate conflicts 2.0? Climate engineering as a challenge for international peace and security. S+F Sicherheit und Frieden. Special issue	*Policy & governance*

		"*Geoengineering: An Issue for Peace and Security*?" no. 4.	
(99)	MacMartin D.G., Kravitz B., Keith D. W. & Jarvis A. (2013)	Dynamics of the coupled human-climate system resulting from closed-loop control of solar geoengineering. *Climate Dynamics*, doi: 10.1007/s00382-013-1822-9	*Policy & governance*
288	Macnaghten P. & Szerszynski B. (2013).	Living the global social experiment: An analysis of public discourse on solar radiation management and its implications for governance, *Global Environ. Change*, 23, 465-474; doi: 10.1016/j.gloenvcha.2012.12.008.	*Discourse analysis*
289	Markusson N., Ginn F., Ghaleigh N.S. & Scott, V. (2013)	'In case of emergency press here': framing geoengineering as a response to dangerous climate change. *WIREs Climate Change*, 5, 281-290; doi: 10.1002/wcc.263	*Discourse analysis*
(100)	McClellan J., Keith D. & Apt J. (2012)	Cost analysis of stratospheric albedo modification delivery systems. *Environ. Res. Lett.*, 7, 034019; doi: 10.1088/1748-9326/7/3/034019	*Economics*
(184)	McGlashan N., Shah N., Caldecott B. & Workman M. (2012)	High-level techno-economic assessment of negative emissions technologies. *Process Safety Environ. Protection*, 90, 501-510.	*Economics*
290	McLaren D.P. (2012)	Procedural justice in carbon capture and storage. *Energy Environ*. 23, 345-366; doi: 10.1260/0958-305X.23.2-3.345	*Policy & governance*
291	Michaelson J. (2013)	Geoengineering and climate management: from marginality to inevitability. In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed W.G. Burns & A.L. Strauss), Chapter 4, p 81-114. CUP, Cambridge UK	*Multi-topic*
292	Ming T., de Richter R., Liu W., & Caillol S. (2014).	Fighting global warming by climate engineering: Is the Earth radiation management and the solar radiation management any option for fighting climate change? *Renewable & Sustainable Energy Reviews*, 31, 792-834. doi: 10.1016/j.rser.2013.12.032	*Multi-topic*
(103)	Moreno-Cruz J.B. & Keith D.W. (2013)	Climate policy under uncertainty: a case for solar geoengineering. *Clim. Change* 121, 431-444	*Policy & governance*
293	Morrow D. R. (2014)	Why geoengineering is a public good, even if it is bad. *Clim. Change*, 123, 95-100; doi: 10.1007/s10584-013-0967-1	*Ethics & values*
294	Morrow D.R., Kopp R.E. & Oppenheimer M. (2013)	Political legitimacy in decisions about experiments in solar radiation management. In: *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks*. (Ed W.G. Burns & A.L. Strauss), Chapter 6, p 146-167. CUP, Cambridge UK	*Policy & governance*
295	Nerlich B. & Jaspal R. (2012)	Metaphors we die by? Geoengineering, metaphors, and the argument from catastrophe. *Metaphor & Symbol*, 27, 131-147	*Ethics and values*
296	Olson R. L. (2012)	Soft geoengineering: A gentler approach to addressing climate change. *Environment: Science & Policy for Sustainable Development*, 54, 29-39.	*Multi-topic*
297	Ott K. (2012)	Might solar radiation management constitute a dilemma? In: *Engineering the Climate: The Ethics of Solar Radiation Management* (Ed C.J. Preston), Chapter 2, p 33-42. Lexington Books/Rowman & Littlefield, Lanham MD	*Ethics & values*
298	Parkhill K. A., Pidgeon N. F., Corner A. & Vaughan N. (2013)	Deliberation and responsible innovation: a geoengineering case study. In: *Responsible Innovation* (ed: R. Owen, J. Bessant & M. Heintz), p. 219-239, Wiley, London.	*Ethics & values*
299	Parson E. A. & Ernst L.N. (2013)	International governance of climate engineering. *Theoretical Inquiries in Law*, 2013; UCLA School of Law Research Paper No 12-23; http://ssrn.com/abstract=2157754	*Policy & governance*
300	Parson E. A. & Keith D.W. (2013)	End the deadlock on governance of geoengineering research. *Science* 339, 1278-1279.	*Policy & governance*
301	Pidgeon N., Corner A., Parkhill K., Spence A. *et al.* (2012)	Exploring early public responses to geoengineering. *Phil. Trans. Roy. Soc. A*, 370, 4176-4196	*Ethics & values*
302	Pidgeon N., Parkhill K., Corner A. & Vaughan N. (2013)	Deliberating stratospheric aerosols for climate geoengineering and the SPICE project. *Nature Climate Change* 3, 451-457; doi: 10.1038/nclimate1807	*Ethics & values*
303	Porter K. E. & M. Hulme (2013)	The emergence of the geoengineering debate in the UK print media: a frame analysis. *Geographical J.*, 179, 342-355; doi: 10.1111/geoj.12003	*Discourse analysis*
304	Preston, C. J. (2012)	Re-thinking the unthinkable: Environmental ethics and the presumptive argument against geoengineering. *Environ. Values*, 20, 457-479.	*Ethics & values*
305	Preston C.J. (2012)	Solar radiation management and vulnerable populations: the moral deficit. In: *Engineering the Climate: The Ethics of Solar Radiation Management* (Ed C.J. Preston), Chapter 5, p 77-94. Lexington Books/Rowman & Littlefield, Lanham MD	*Ethics & values*

306	Preston C.J. (2013)	Ethics and geoengineering: reviewing the moral issues raised by solar radiation management and carbon dioxide removal. *WIREs Clim. Change*, 4, 23-37; doi: 10.1002/wcc.198	*Ethics & values*
307	Rayner S, Heyward C, Kruger T, Pidgeon N. *et al* (2013)	The Oxford Principles. *Climatic Change*, 121, 499-512	*Policy & governance*
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Annex II

EXCERPTS FROM THE SUMMARIES FOR POLICYMAKERS OF THE REPORTS OF WORKING GROUPS I AND III OF THE IPCC'S FIFTH ASSESSMENT REPORT THAT DIRECTLY ADDRESS CLIMATE-RELATED GEOENGINEERING

Working Group I

"Methods that aim to deliberately alter the climate system to counter climate change, termed geoengineering, have been proposed. Limited evidence precludes a comprehensive quantitative assessment of both Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR) and their impact on the climate system. CDR methods have biogeochemical and technological limitations to their potential on a global scale. There is insufficient knowledge to quantify how much CO2 emissions could be partially offset by CDR on a century timescale. Modelling indicates that SRM methods, if realizable, have the potential to substantially offset a global temperature rise, but they would also modify the global water cycle, and would not reduce ocean acidification. If SRM were terminated for any reason, there is high confidence that global surface temperatures would rise very rapidly to values consistent with the greenhouse gas forcing. CDR and SRM methods carry side effects and long-term consequences on a global scale."

(IPCC 2013, WG I, Summary for Policymakers, Section E.8,)

Working Group III

"**Scenarios reaching atmospheric concentration levels of about 450 ppm CO2eq by 2100 (consistent with a likely chance to keep temperature change below 2°C relative to pre-industrial levels) include substantial cuts in anthropogenic GHG emissions by mid-century through large-scale changes in energy systems and potentially land use** (high confidence). Scenarios reaching these concentrations by 2100 are characterized by lower global GHG emissions in 2050 than in 2010, 40% to 70% lower globally, and emissions levels near zero GtCO2eq or below in 2100. In scenarios reaching 500 ppm CO2eq by 2100, 2050 emissions levels are 25% to 55% lower than in 2010 globally. In scenarios reaching 550 ppm CO2eq, emissions in 2050 are from 5% above 2010 levels to 45% below 2010 levels globally (Table SPM.1). At the global level, scenarios reaching 450 ppm CO2eq are also characterized by more rapid improvements of energy efficiency, a tripling to nearly a quadrupling of the share of zero- and low-carbon energy supply from renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS), or bioenergy with CCS (BECCS) by the year 2050 (Figure SPM.4, lower panel). These scenarios describe a wide range of changes in land use, reflecting different assumptions about the scale of bioenergy production, afforestation, and reduced deforestation. All of these emissions, energy, and land-use changes vary across regions. Scenarios reaching higher concentrations include similar changes, but on a slower timescale. On the other hand, scenarios reaching lower concentrations require these changes on a faster timescale."
(IPCC 2013, WG III, Summary for Policymakers, Section SPM.4)

"Mitigation scenarios reaching about 450 ppm CO2eq in 2100 typically involve temporary overshoot of atmospheric concentrations, as do many scenarios reaching about 500 ppm to 550 ppm CO2eq in 2100. Depending on the level of the overshoot, overshoot scenarios typically rely on the availability and widespread deployment of BECCS and afforestation in the second half of the century. The availability and scale of these and other Carbon Dioxide Removal (CDR) technologies and methods are uncertain and CDR technologies and methods are, to varying degrees, associated with challenges and risks (see Section SPM 4.2) (*high confidence*)**.** CDR is also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive. There is only limited evidence on the potential for large-scale deployment of BECCS, large-scale afforestation, and other CDR technologies and methods."
(IPCC 2013, WG III, Summary for Policymakers, Section SPM.4)

"Carbon dioxide capture and storage (CCS) technologies could reduce the lifecycle GHG emissions of fossil fuel power plants (*medium evidence, medium agreement*)**.** While all components of integrated CCS systems exist and are in use today by the fossil fuel extraction and refining industry, CCS has not yet been applied at scale to a large, operational commercial fossil fuel power plant. CCS power plants could be seen in the market if this is incentivized by regulation and/or if they become competitive with their unabated counterparts, if the additional investment and operational costs, caused in part by efficiency reductions, are compensated by sufficiently high carbon prices (or direct financial support). For the large-scale future deployment of CCS, well-defined regulations concerning short- and long-term responsibilities for storage are needed as well as economic incentives. Barriers to large-scale deployment of CCS technologies include concerns about the operational safety and long-term integrity of CO2 storage as well as transport risks. There is, however, a growing body of literature on how to ensure the integrity of CO2 wells, on the potential consequences of a pressure build-up within a geologic formation caused

by CO2 storage (such as induced seismicity), and on the potential human health and environmental impacts from CO2 that migrates out of the primary injection zone (*limited evidence, medium agreement*).”
(IPCC 2013, WG III, Section SPM.4.2.2)

“**Combining bioenergy with CCS (BECCS) offers the prospect of energy supply with large-scale net negative emissions which plays an important role in many low-stabilization scenarios, while it entails challenges and risks** (*limited evidence, medium agreement*)**.** These challenges and risks include those associated with the upstream large-scale provision of the biomass that is used in the CCS facility as well as those associated with the CCS technology itself.”
(IPCC 2013, WG III, Section SPM.4.2.2)

“Policies governing agricultural practices and forest conservation and management are more effective when involving both mitigation and adaptation. Some mitigation options in the AFOLU sector (such as soil and forest carbon stocks) may be vulnerable to climate change (*medium evidence, high agreement*). When implemented sustainably, activities to reduce emissions from deforestation and forest degradation (REDD+ is an example designed to be sustainable) are cost-effective policy options for mitigating climate change, with potential economic, social and other environmental and adaptation co-benefits (e.g., conservation of biodiversity and water resources, and reducing soil erosion) (*limited evidence, medium agreement*).”
(IPCC 2013, WG III, Section SPM.4.2.4)

“**Bioenergy can play a critical role for mitigation, but there are issues to consider, such as the sustainability of practices and the efficiency of bioenergy systems** (*robust evidence, medium agreement*)**.** Barriers to large-scale deployment of bioenergy include concerns about GHG emissions from land, food security, water resources, biodiversity conservation and livelihoods. The scientific debate about the overall climate impact related to land-use competition effects of specific bioenergy pathways remains unresolved (*robust evidence, high agreement*). Bioenergy technologies are diverse and span a wide range of options and technology pathways. Evidence suggests that options with low lifecycle emissions (e.g., sugar cane, Miscanthus, fast growing tree species, and sustainable use of biomass residues), some already available, can reduce GHG emissions; outcomes are site-specific and rely on efficient integrated ‘biomass-to-bioenergy systems’, and sustainable land-use management and governance. In some regions, specific bioenergy options, such as improved cookstoves, and small-scale biogas and biopower production, could reduce GHG emissions and improve livelihoods and health in the context of sustainable development (*medium evidence, medium agreement*).”
(IPCC 2013, WG III, Section SPM.4.2.4)
